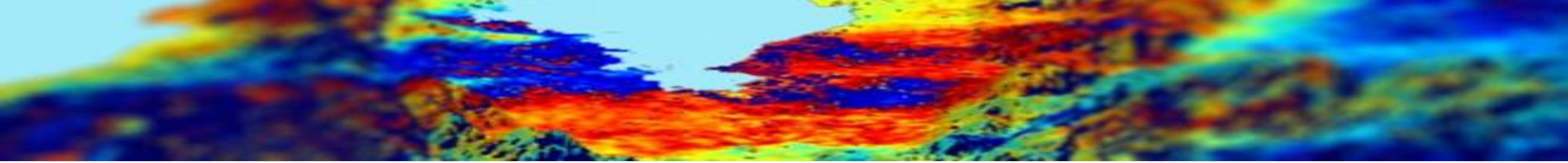

SPACE-BORNE SAR INTERFEROMETRY AND APPLICATIONS
THREE DECADES OF INNOVATION AND PROBLEM SOLVING

MANOOCHEHR SHIRZAEI

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MOSTAFA KHOSHMANESH

GRACE CARLSON

SONAM SHERPA

EMMA BLACKWELL

25 YEARS AGO…

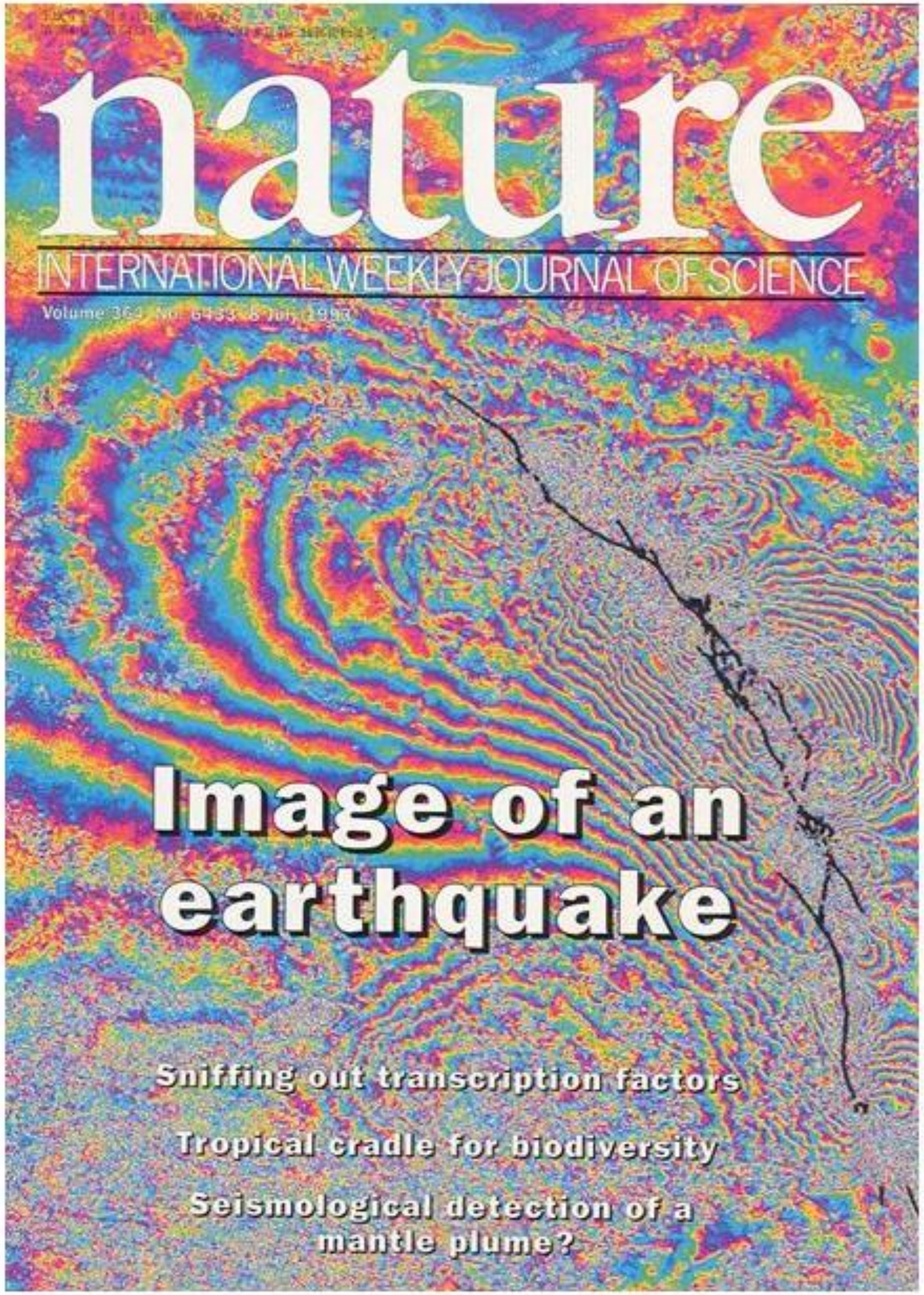
Letter

The displacement field of the Landers earthquake mapped by radar interferometry

Didier Massonnet, Marc Rossi, César Carmona, Frédéric Adragna, Gilles Peltzer, Kurt Feigl & Thierry Rabaute

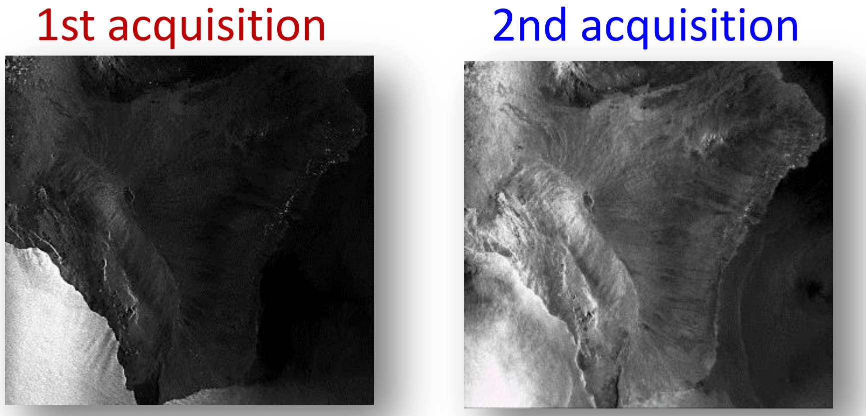
Nature **364**, 138–142 (08 July 1993)
doi:10.1038/364138a0
Download Citation

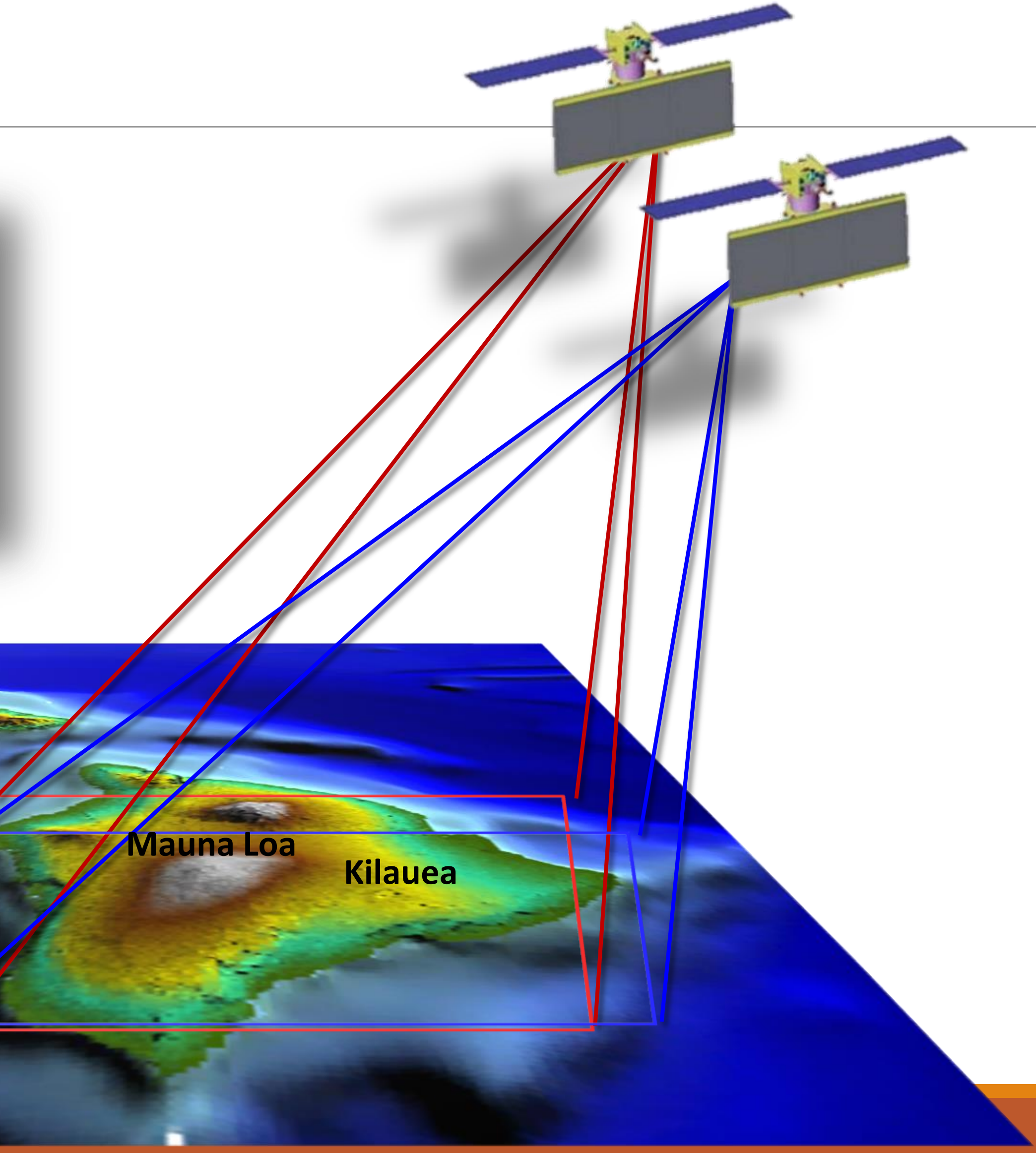
Received: 21 April 1993
Accepted: 02 June 1993
Published: 08 July 1993



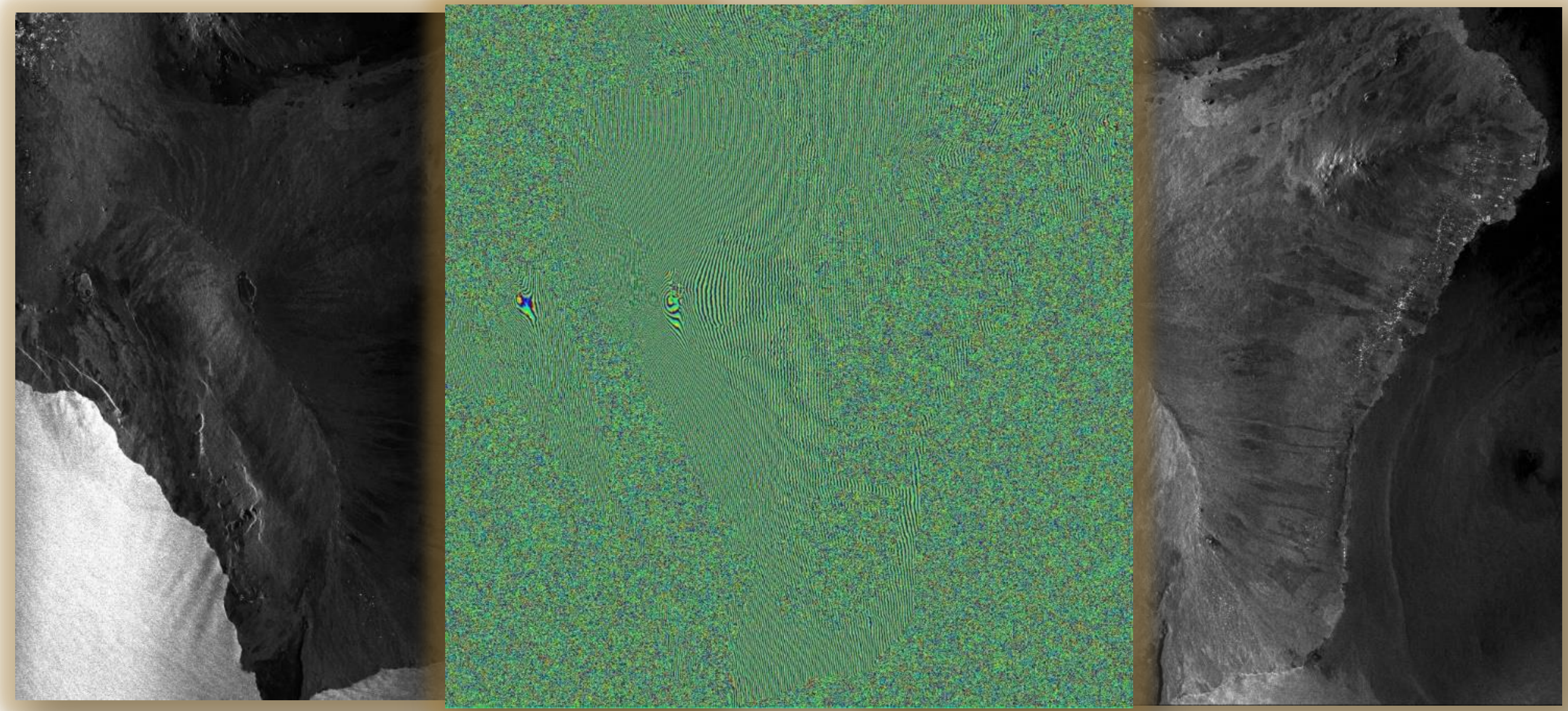
Massonnet et al., 1993 Nature

HOW INSAR WORKS…



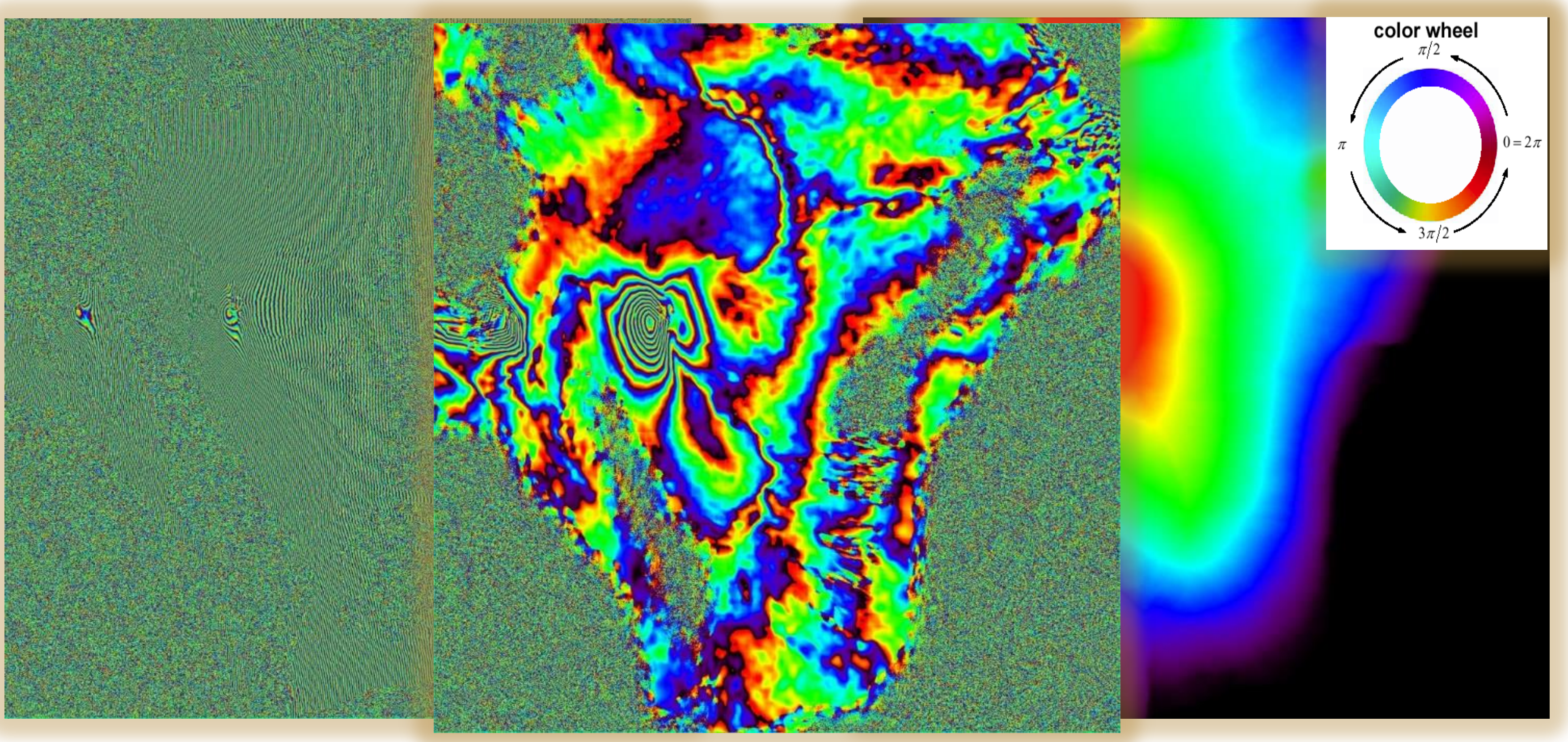


INTERFEROGRAM GENERATION



1st image **Multiply (X)** **2nd image**

DIFFERENTIAL INTERFEROGRAM GENERATION



Int.

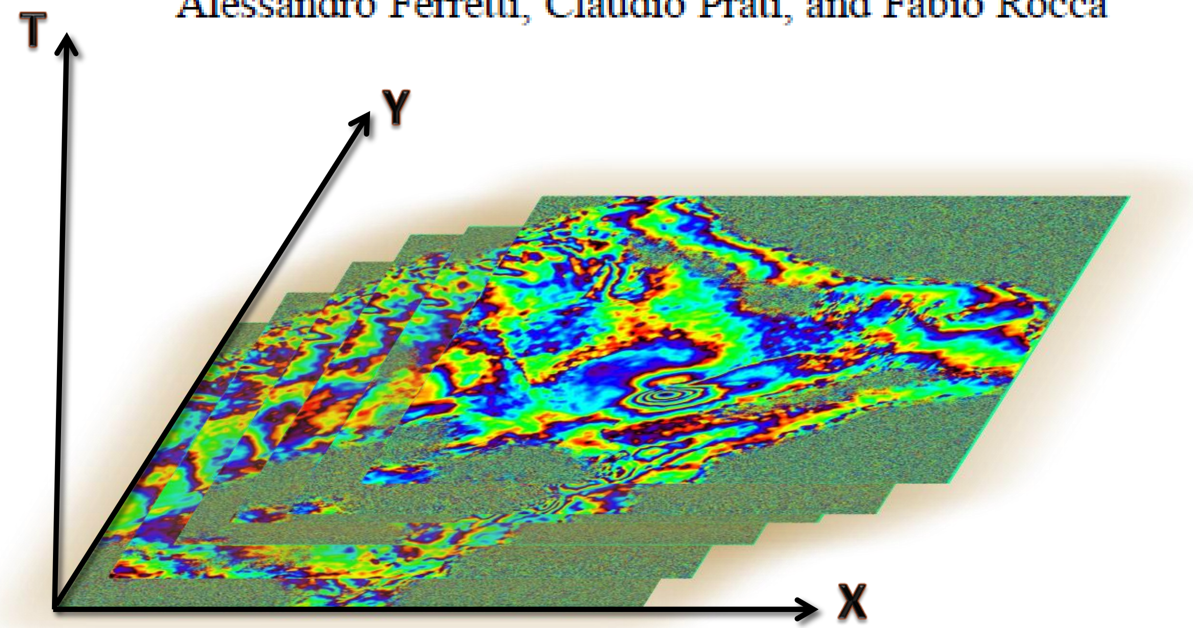
DEM

NEXT BIG THING…

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 39, NO. 1, JANUARY 2001

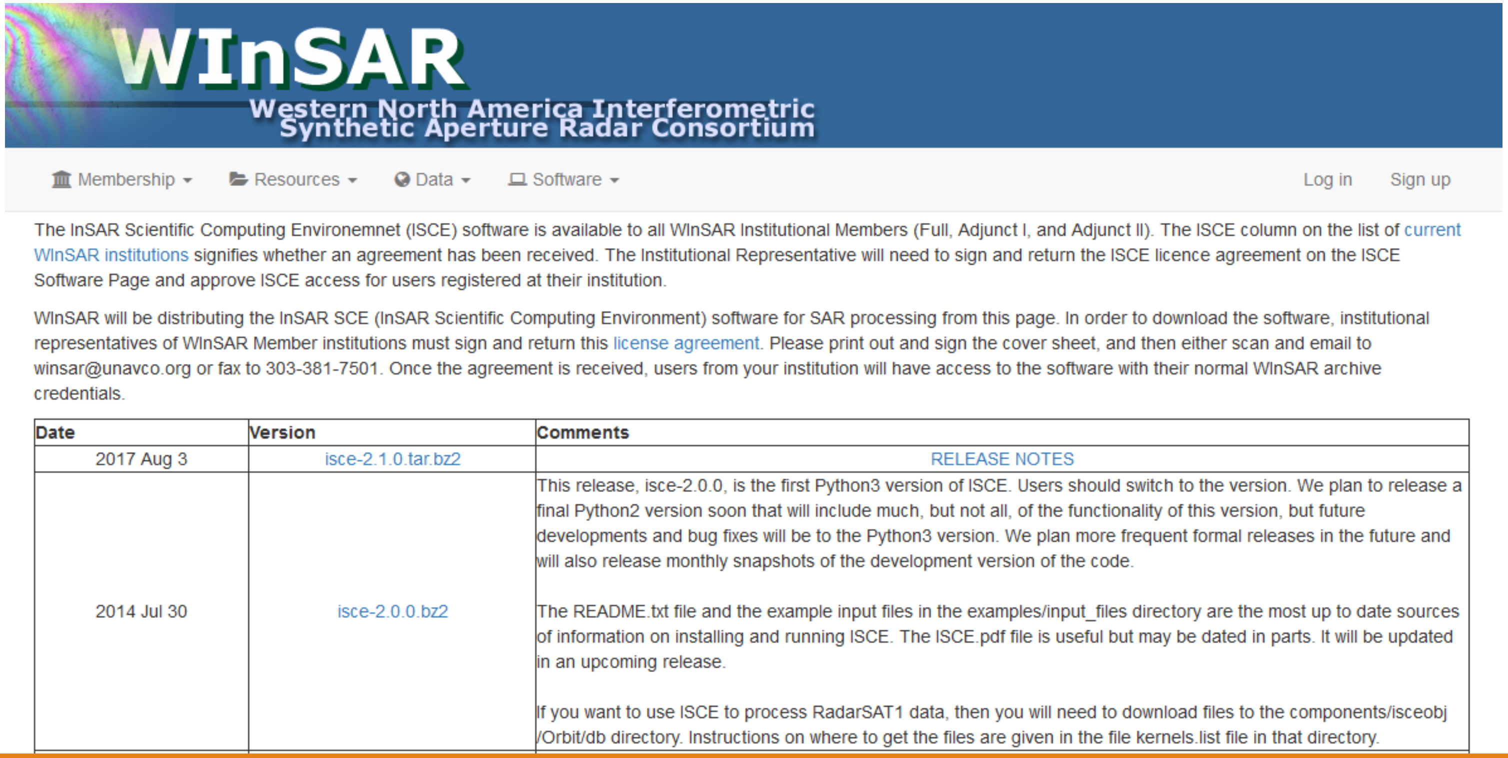
Permanent Scatterers in SAR Interferometry

Alessandro Ferretti, Claudio Prati, and Fabio Rocca



SOFTWARE FOR ACADEMIC USE

- **ISCE (aka, Roi-Pac)**
  - JPL/Caltech/Stanford InSAR Scientific Computing Environment

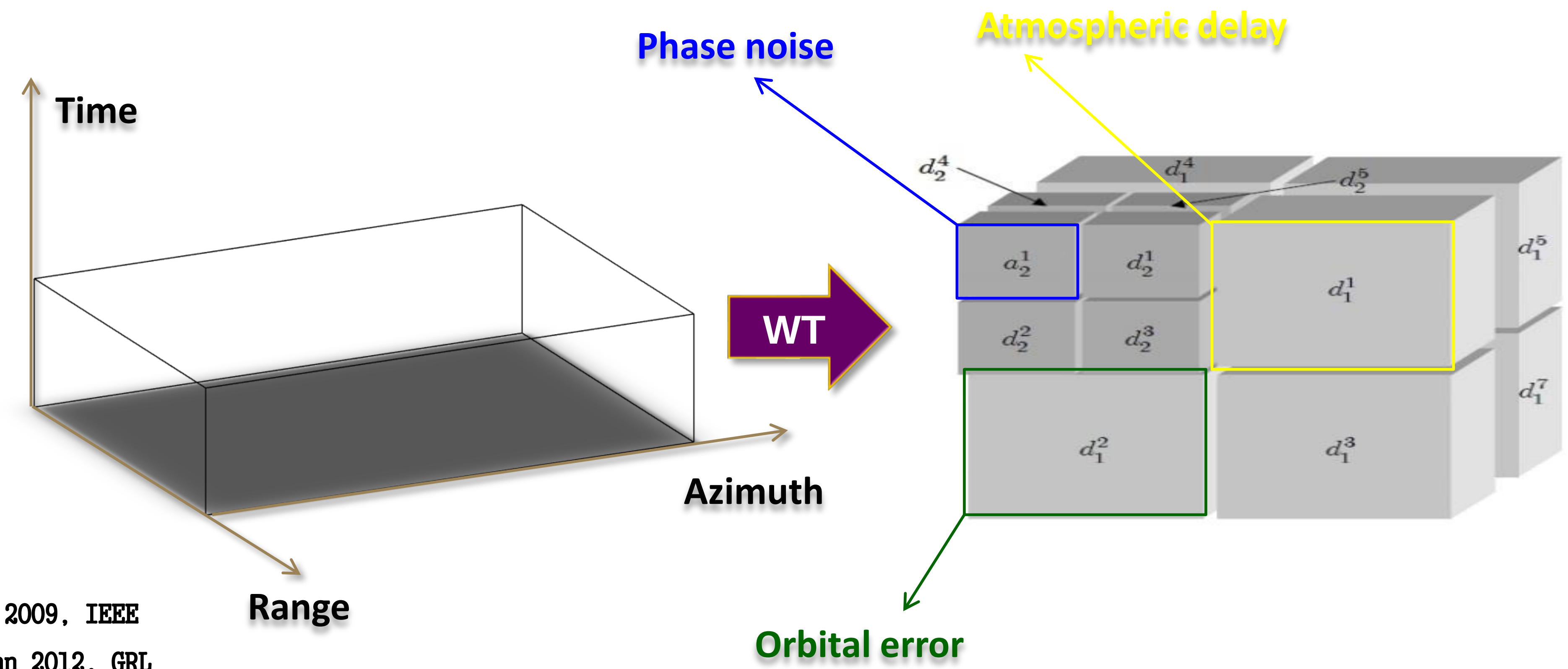


The InSAR Scientific Computing Environemnet (ISCE) software is available to all WInSAR Institutional Members (Full, Adjunct I, and Adjunct II). The ISCE column on the list of current WInSAR institutions signifies whether an agreement has been received. The Institutional Representative will need to sign and return the ISCE licence agreement on the ISCE Software Page and approve ISCE access for users registered at their institution.

WInSAR will be distributing the InSAR SCE (InSAR Scientific Computing Environment) software for SAR processing from this page. In order to download the software, institutional representatives of WInSAR Member institutions must sign and return this license agreement. Please print out and sign the cover sheet, and then either scan and email to winsar@unavco.org or fax to 303-381-7501. Once the agreement is received, users from your institution will have access to the software with their normal WInSAR archive credentials.

Date	Version	Comments
2017 Aug 3	isce-2.1.0.tar.bz2	RELEASE NOTES
2014 Jul 30	isce-2.0.0.bz2	This release, isce-2.0.0, is the first Python3 version of ISCE. Users should switch to the version. We plan to release a final Python2 version soon that will include much, but not all, of the functionality of this version, but future developments and bug fixes will be to the Python3 version. We plan more frequent formal releases in the future and will also release monthly snapshots of the development version of the code. The README.txt file and the example input files in the examples/input_files directory are the most up to date sources of information on installing and running ISCE. The ISCE.pdf file is useful but may be dated in parts. It will be updated in an upcoming release. If you want to use ISCE to process RadarSAT1 data, then you will need to download files to the components/isceobj/Orbit/db directory. Instructions on where to get the files are given in the file kernels.list file in that directory.

WAVELET BASED MULTI-TEMPORAL INSAR (WABINSAR)



Stack of interferograms

Wavelet decomposition

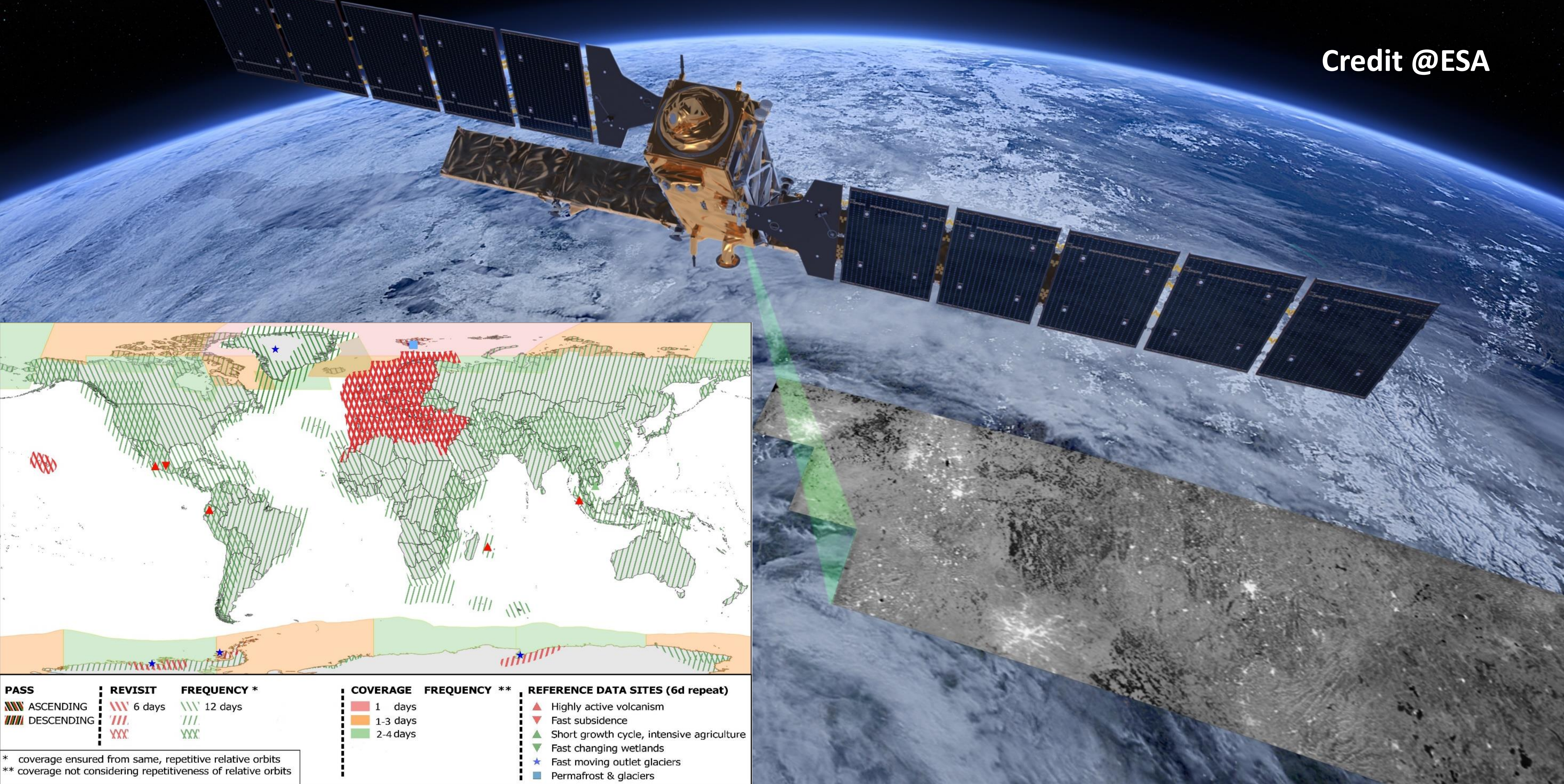
Shirzaei & Walter 2009, IEEE

Shirzaei & Bürgmann 2012, GRL

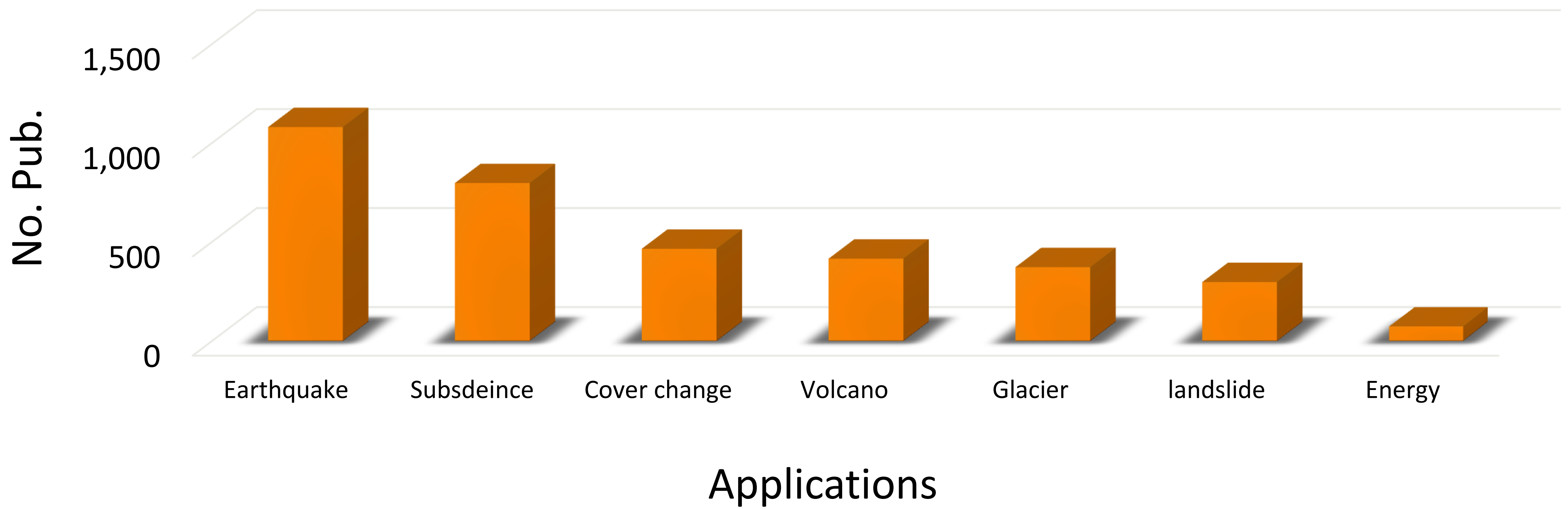
Shirzaei 2013, IEEE

Shirzaei 2015, G3

SENTINEL ERA…



INSAR APPLICATIONS IN PUBLICATIONS



REMOTE SENSING OF WATER MASS BUDGET VARIATIONS IN CALIFORNIA

Prof. Susanna Werth
swerth@asu.edu

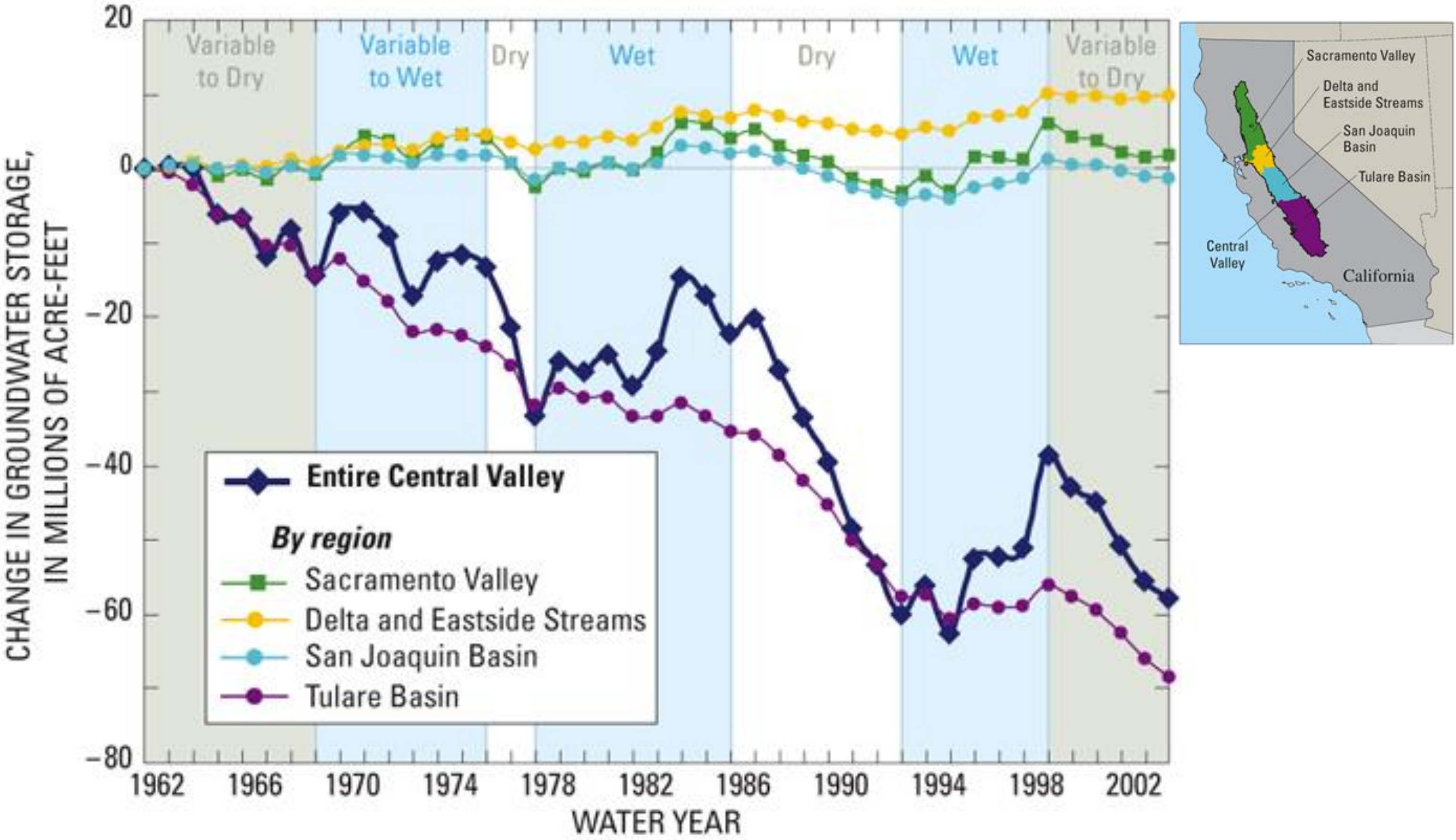
**IF YOU CAN'T MEASURE IT,
YOU CAN'T MANAGE IT!**

Dr. Chandra Ojha

Grace Carlson

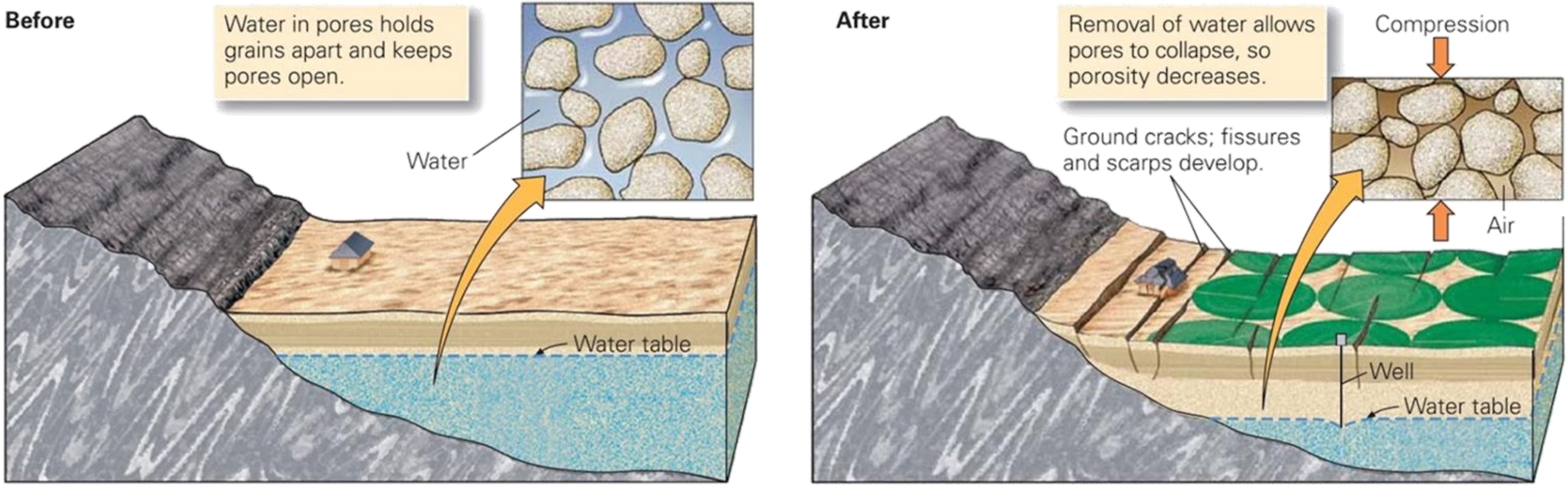
CENTRAL VALLEY GROUNDWATER

- More than 250 different crops are grown in the Central Valley, with an estimated value of $17 billion/yr.
- Approximately one-sixth of the Nation's irrigated land is in the Central Valley.
- About one-fifth of the Nation's groundwater pumpage is from the Central Valley aquifer system.



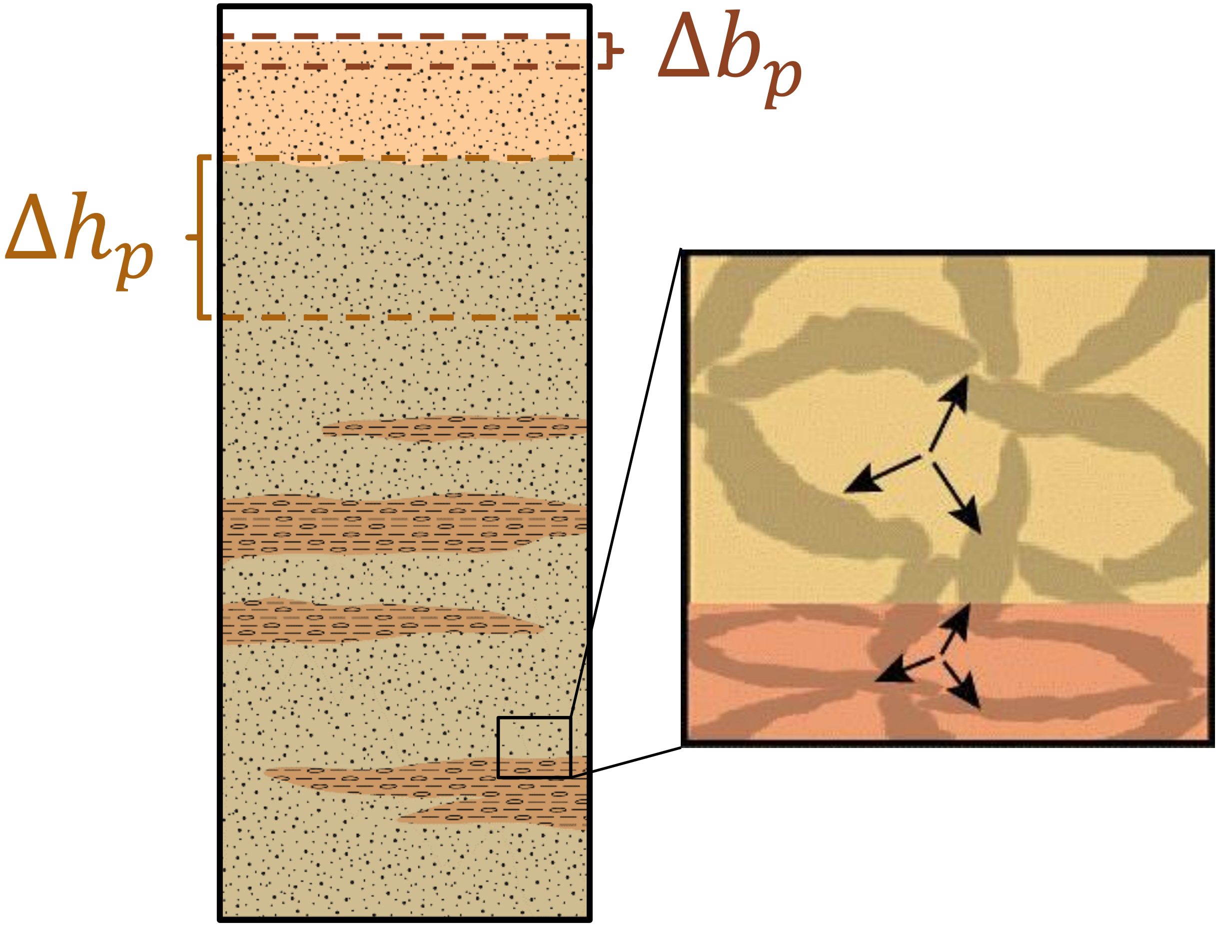
Source: USGS

GROUNDWATER EXPLOITATION



Courtesy: S. Marshak

ELASTIC DEFORMATION



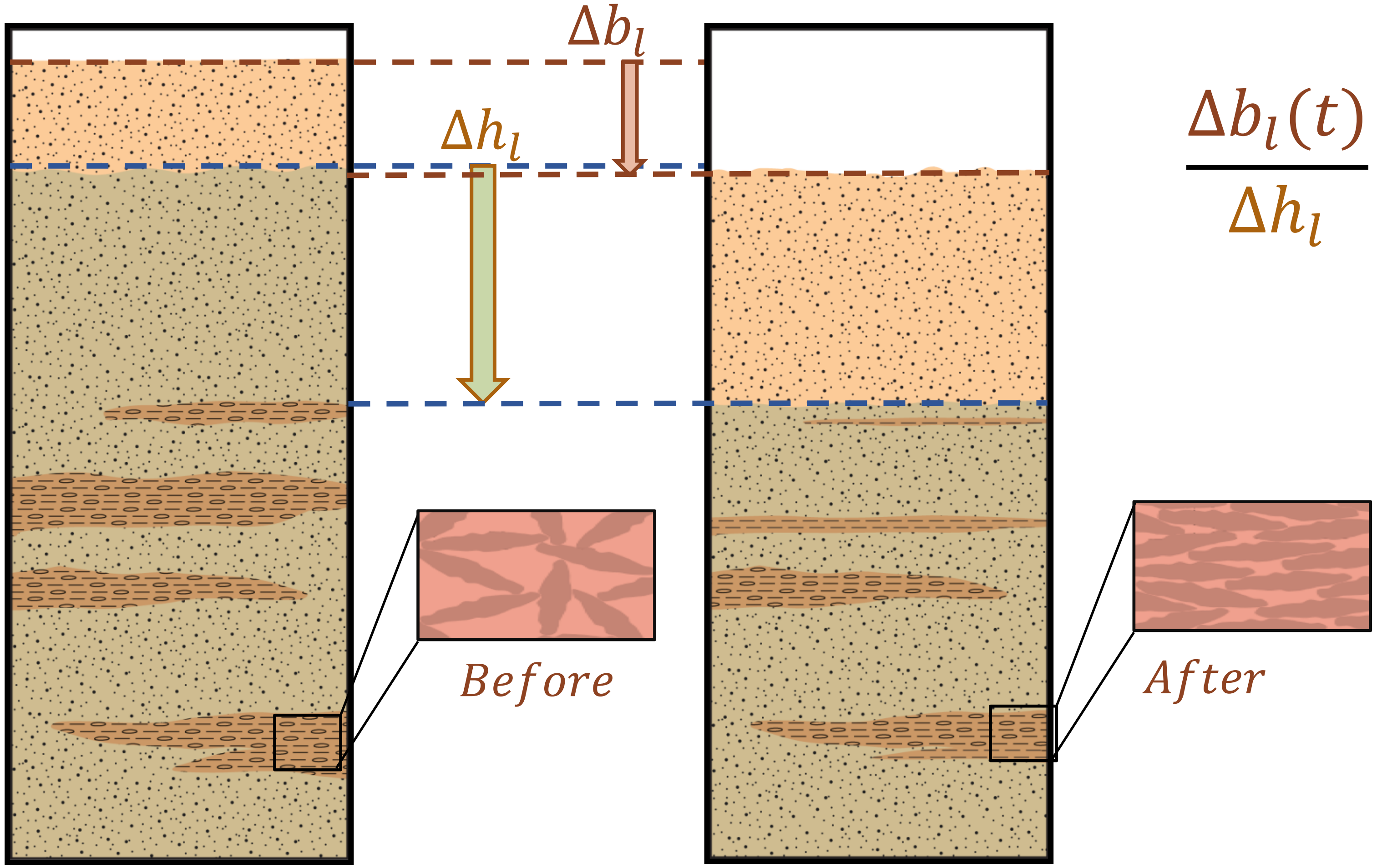
$$\frac{\Delta b_p}{\Delta h_p} = S_{ke}$$

Δb_p - seasonal displacement
Δh_p - seasonal well levels
S_{ke} - elastic storage coefficient

S_{ke} is the volume of water released or absorbed per Δh_p of an aquifer system area, coupled with elastic deformation Δb_p.

Courtesy: M. Miller

INELASTIC DEFORMATION



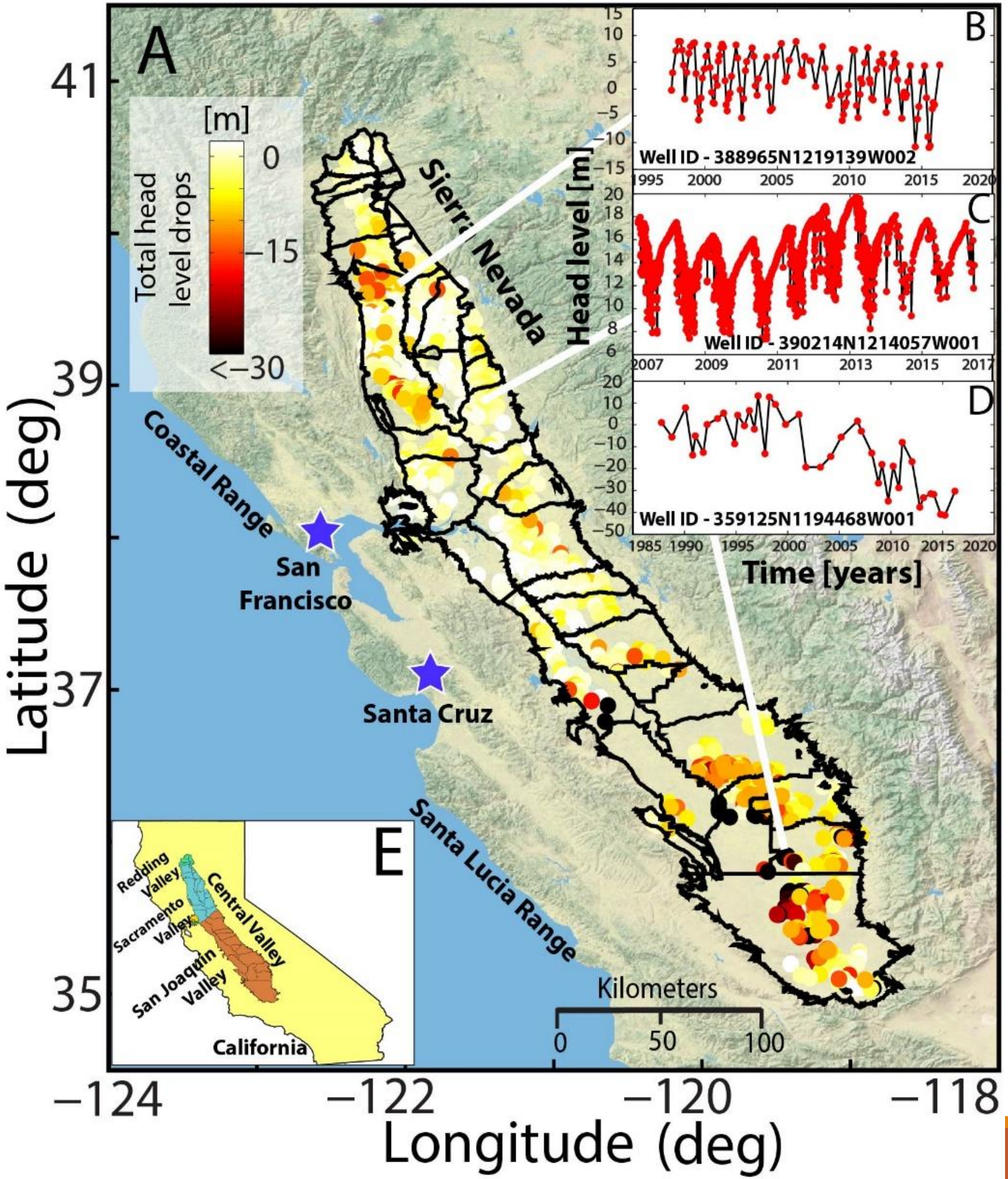
$$\frac{\Delta b_l(t)}{\Delta h_l} = S_{kv}\left(1 - \frac{8}{\pi^2} e^{\frac{-\pi^2 t}{4\tau}}\right)$$

Δh_l - step change in well level
Δb_l - subsidence
τ - compaction time constant
S_{kv} - inelastic storage coefficient

S_{kv} is the volume of water released per Δh_l of aquitards, from compaction Δb_l delayed by τ.

GROUNDWATER LEVEL (2007 - 2010)

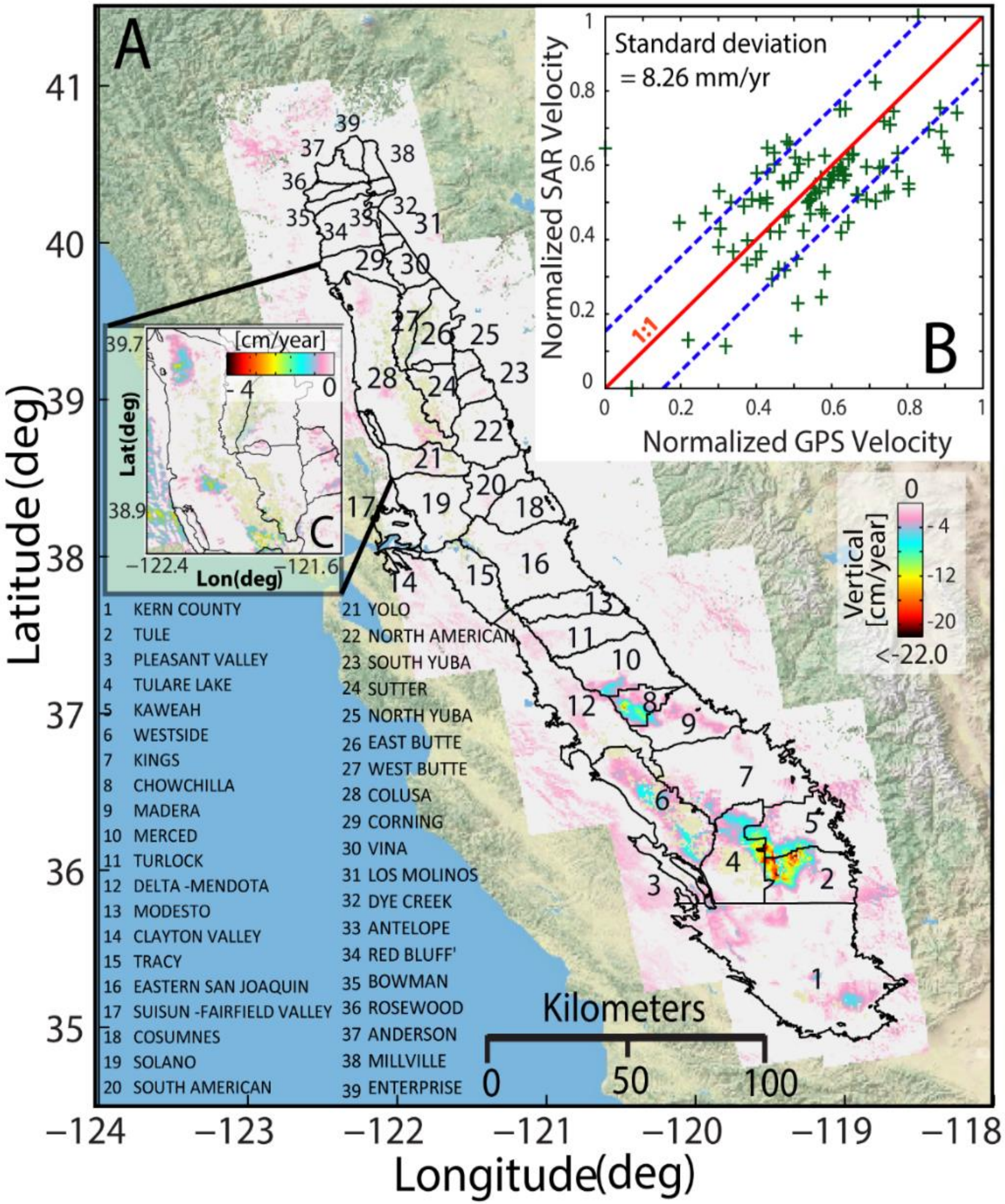
- Panel A: Groundwater level change during Dec 24, 2006 and Jan 1, 2010.
- Panels B-D: Groundwater level change over decadal time scale at selected wells in the Central Valley.



Ojha et al., 2018

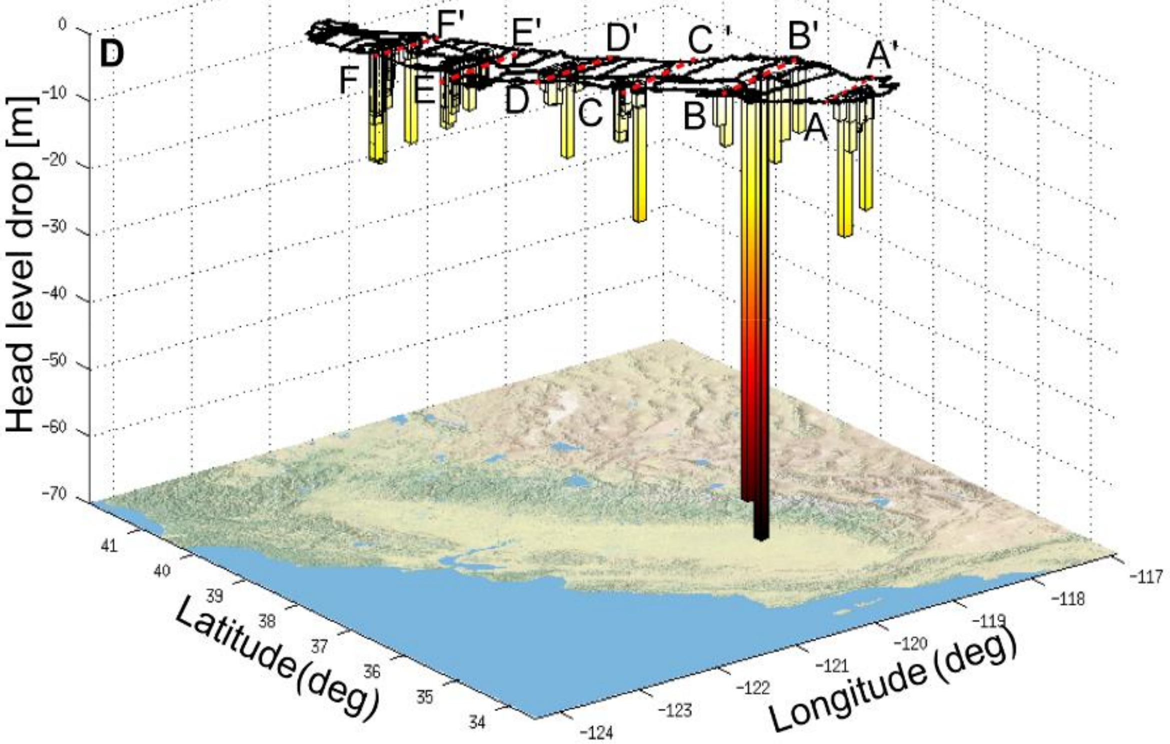
LAND SUBSIDENCE (2007 - 2010)

- Panel A: Subsidence during Dec 24, 2006 and Jan 1, 2010
  - 420 ALOS SAR images
  - 1604 Interferograms
  - 23 Millions pixels
- Panels B: InSAR vs GPS comparison

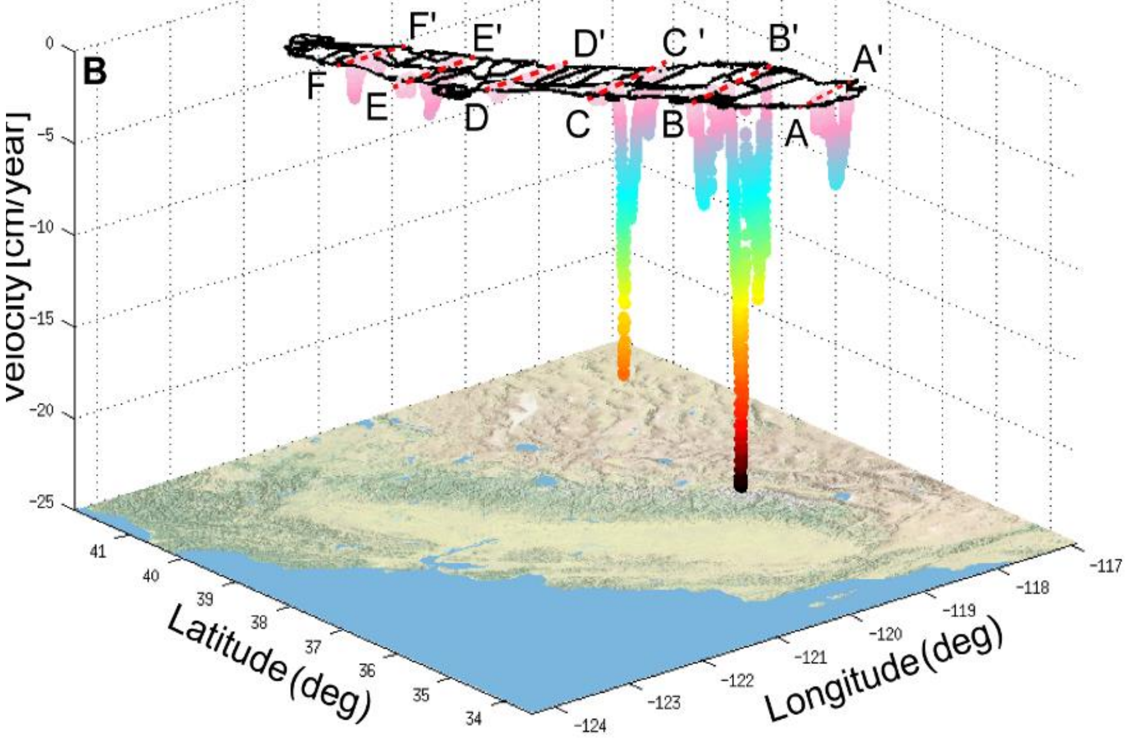


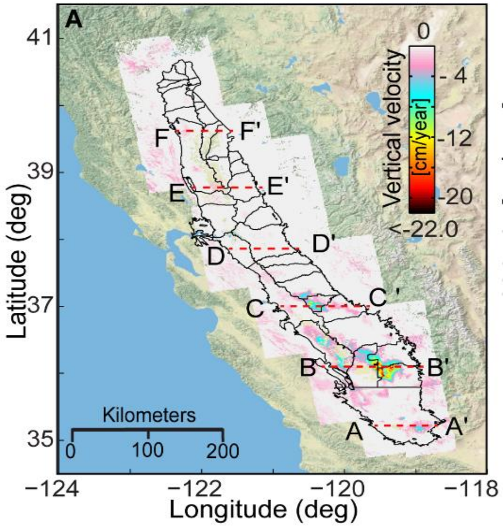
GROUNDWATER LEVEL VS LAND SUBSIDENCE

Groundwater



Subsidence





Ojha et al., 2018

TERZAGHI'S THEORY OF 1D CONSOLIDATION

TERZAGHI'S THEORY OF 1D CONSOLIDATION

$$d\epsilon_v = \frac{dV}{V} = -\frac{d\sigma'}{K}$$

$$dv_w = A.dh = -A\frac{d\sigma'}{\alpha_\beta.\rho.g} = \frac{A.db.K}{\alpha_\beta.\rho.g.b}$$

K: Bulk modulus
α_β: Biot-Willis coefficient $(0 < \alpha_\beta < 1)$
b = aquifer thickness
ρ: water density
g: gravitational acceleration
σ : Total stress
A: InSAR pixel area
db = Subsidence

$\sigma' = \sigma - \alpha_\beta P$: effective stress
P= ρg dh : pressure
dh: groundwater level change

Ojha et al., 2018

TERZAGHI'S THEORY OF 1D CONSOLIDATION

$$d\epsilon_v = \frac{dV}{V} = -\frac{d\sigma'}{K}$$

From InSAR From seismicity

$$dv_w = A.dh = -A\frac{d\sigma'}{\alpha_\beta.\rho.g} = \frac{A.db.K}{\alpha_\beta.\rho.g.b}$$

Output

From Lab

From Geology

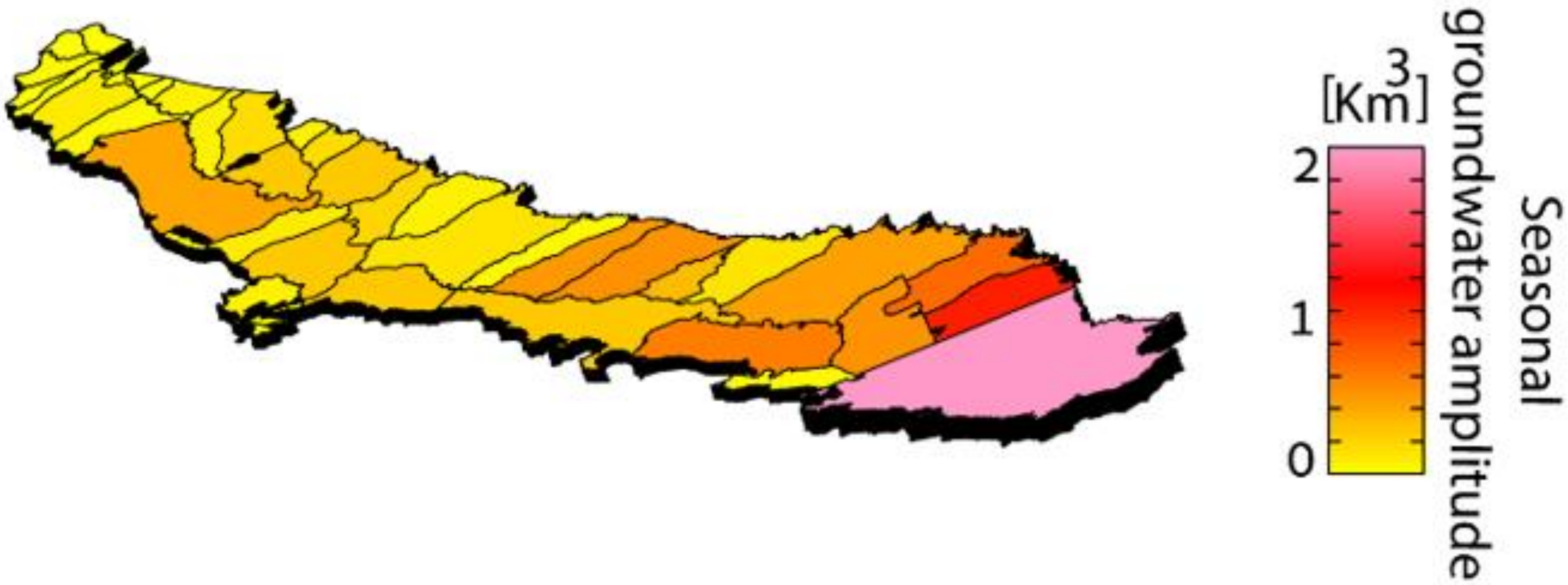
K: Bulk modulus
α_β: Biot-Willis coefficient ($0 < \alpha_\beta < 1$)
b = aquifer thickness
ρ: water density
g: gravitational acceleration
σ : Total stress
A: InSAR pixel area
db = Subsidence

$\sigma' = \sigma - \alpha_\beta P$: effective stress
$P = \rho g\, dh$: pressure
dh: groundwater level change

Ojha et al., 2018

GROUNDWATER SEASONAL CHANGE (2007 - 2010)

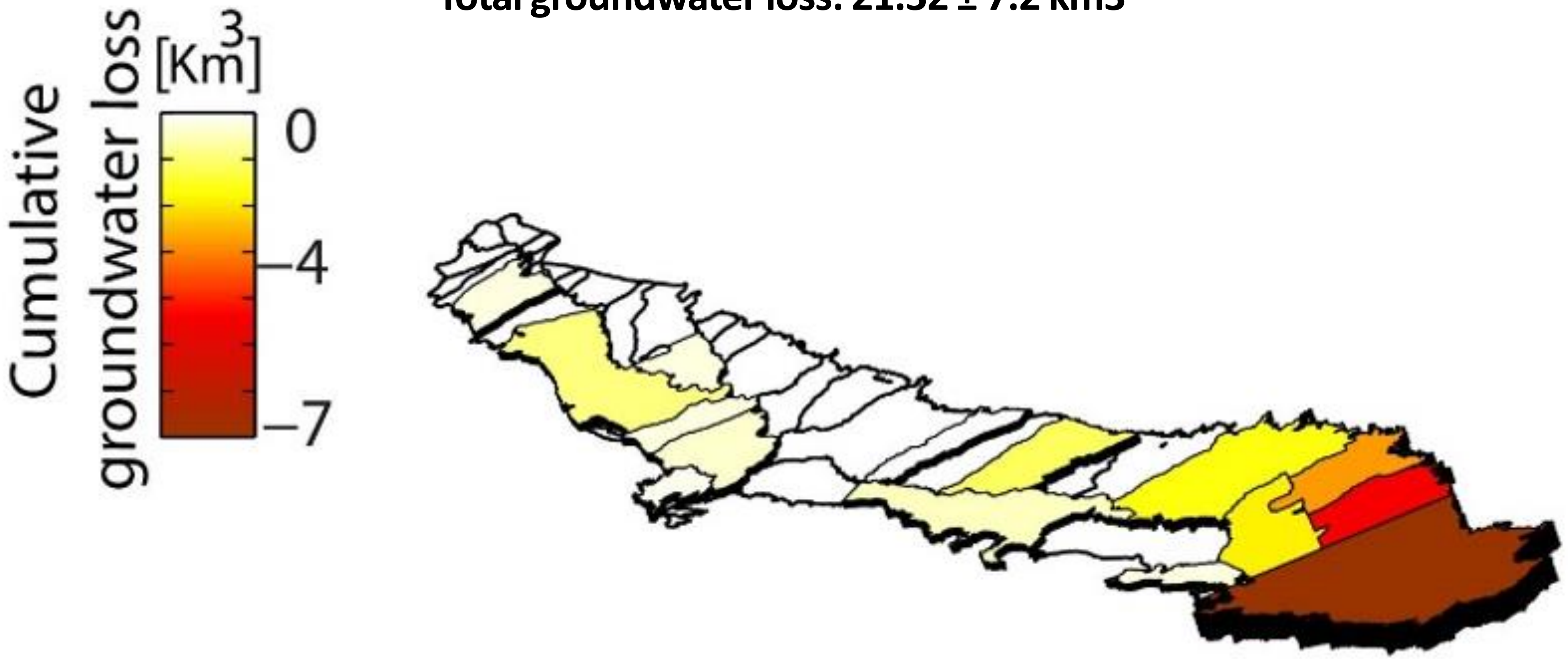
Seasonal groundwater oscillation: 10.11 ± 2.5 km3



Ojha et al., 2018

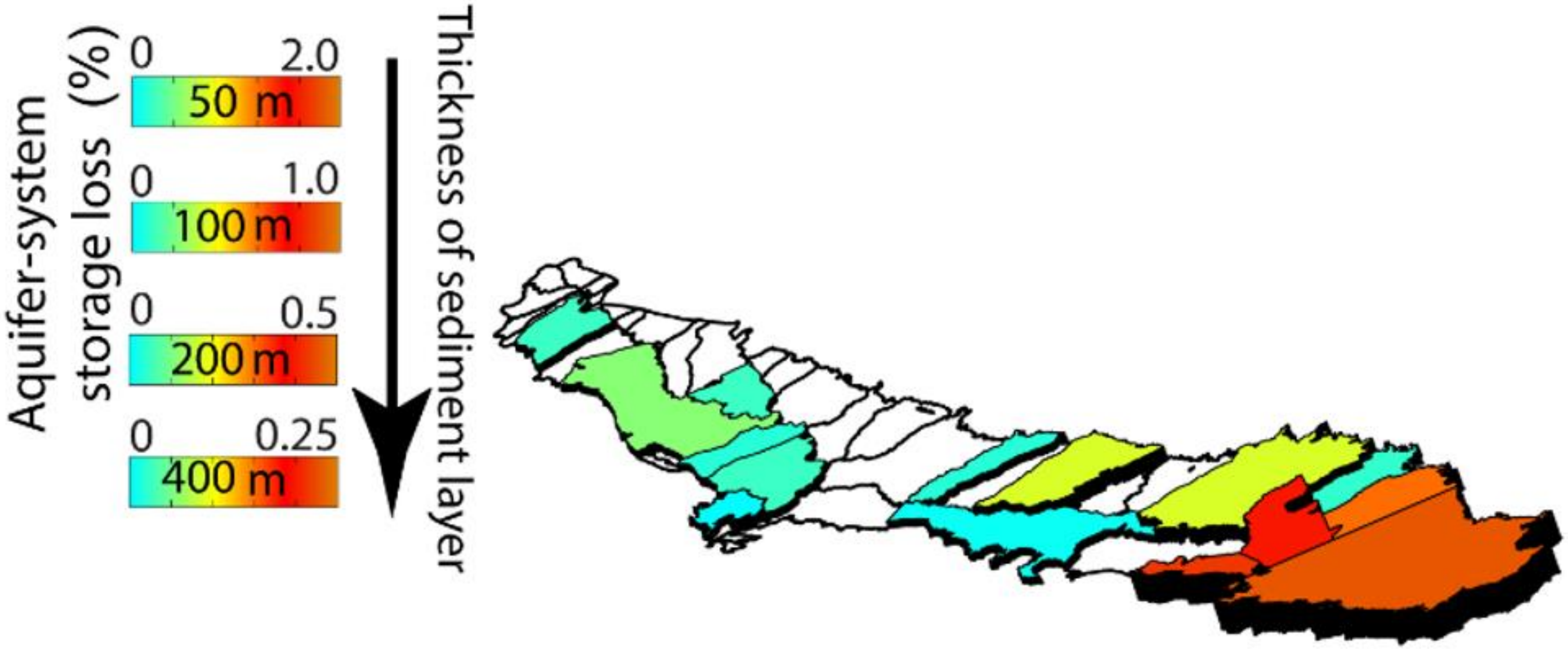
GROUNDWATER TOTAL LOSS (2007 - 2010)

Total groundwater loss: 21.32 ± 7.2 km3



Ojha et al., 2018

AQUIFER STORAGE LOSS (2007 - 2010)



Ojha et al., 2018

SUMMARY

- For the first time, InSAR derived maps of vertical land motion are used to estimate groundwater oscillation and change at regional scale.

- During drought period of 2007 - 2010 up to 2% of the central valley aquifer storage capacity is lost.

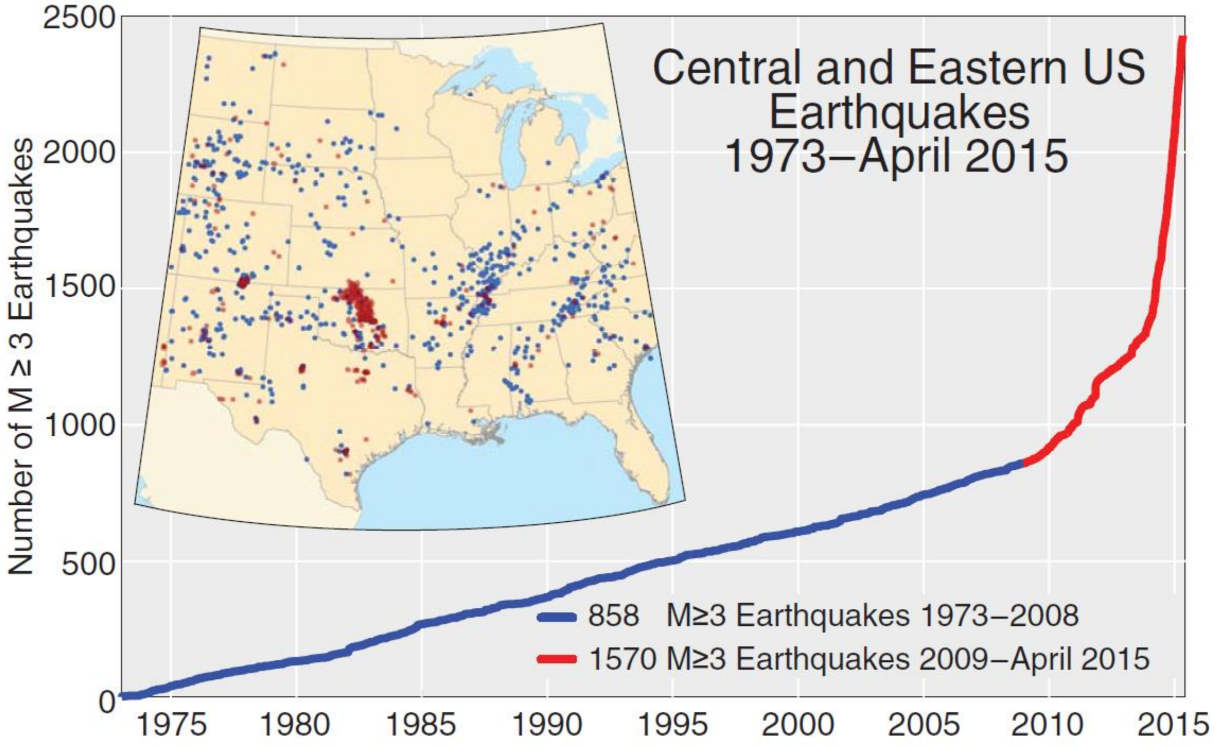
PHYSICS-BASED OPERATIONAL INDUCED EARTHQUAKE FORECASTING

ENERGY PRODUCTION MUST GO ON,
LET'S MAKE IT SAFER!

Dr. Guang Zhai

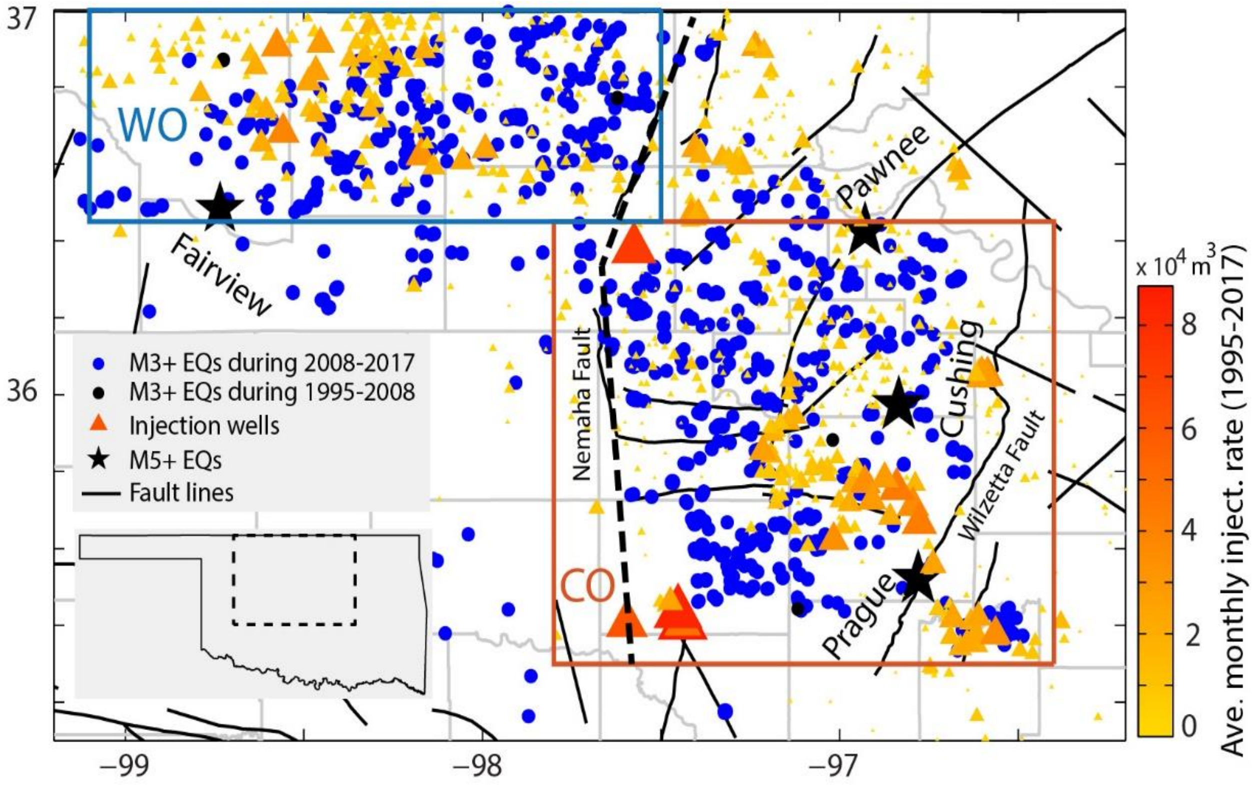
U.S. DEPARTMENT OF ENERGY

RECENT INCREASE IN SEISMICITY

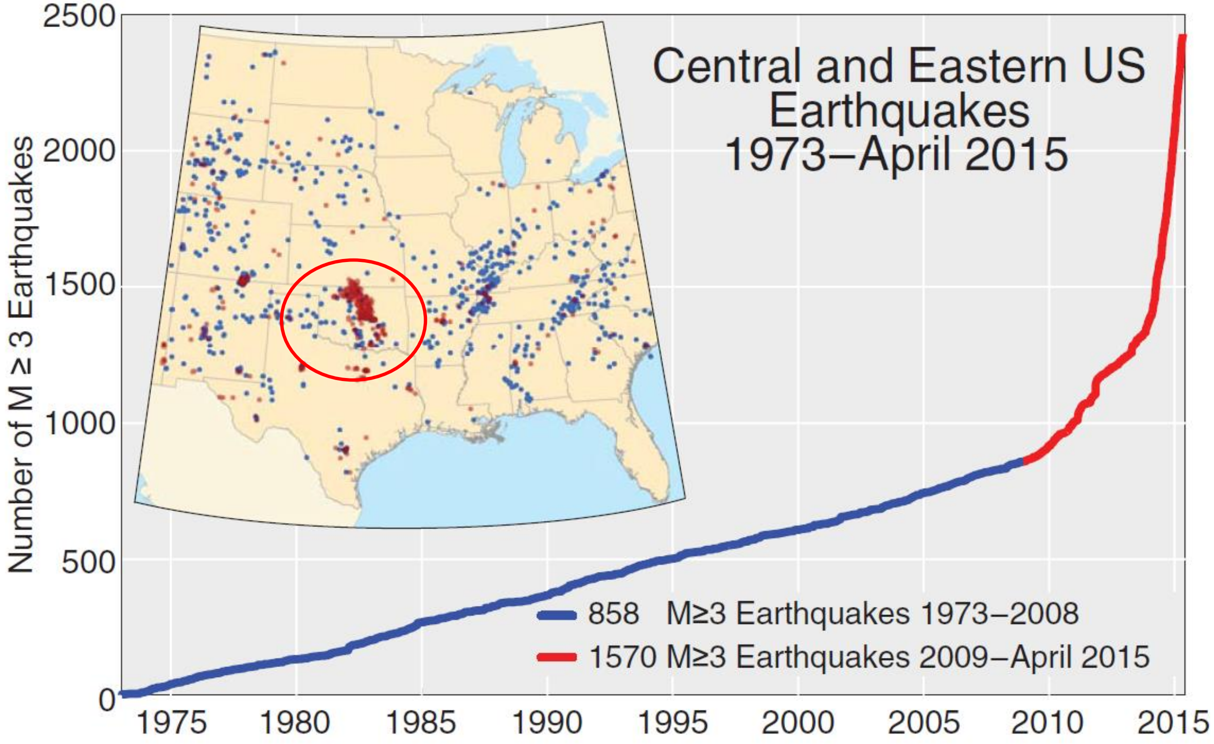


Rubinstein and Mahani, 2015

RECENT INCREASE IN SEISMICITY

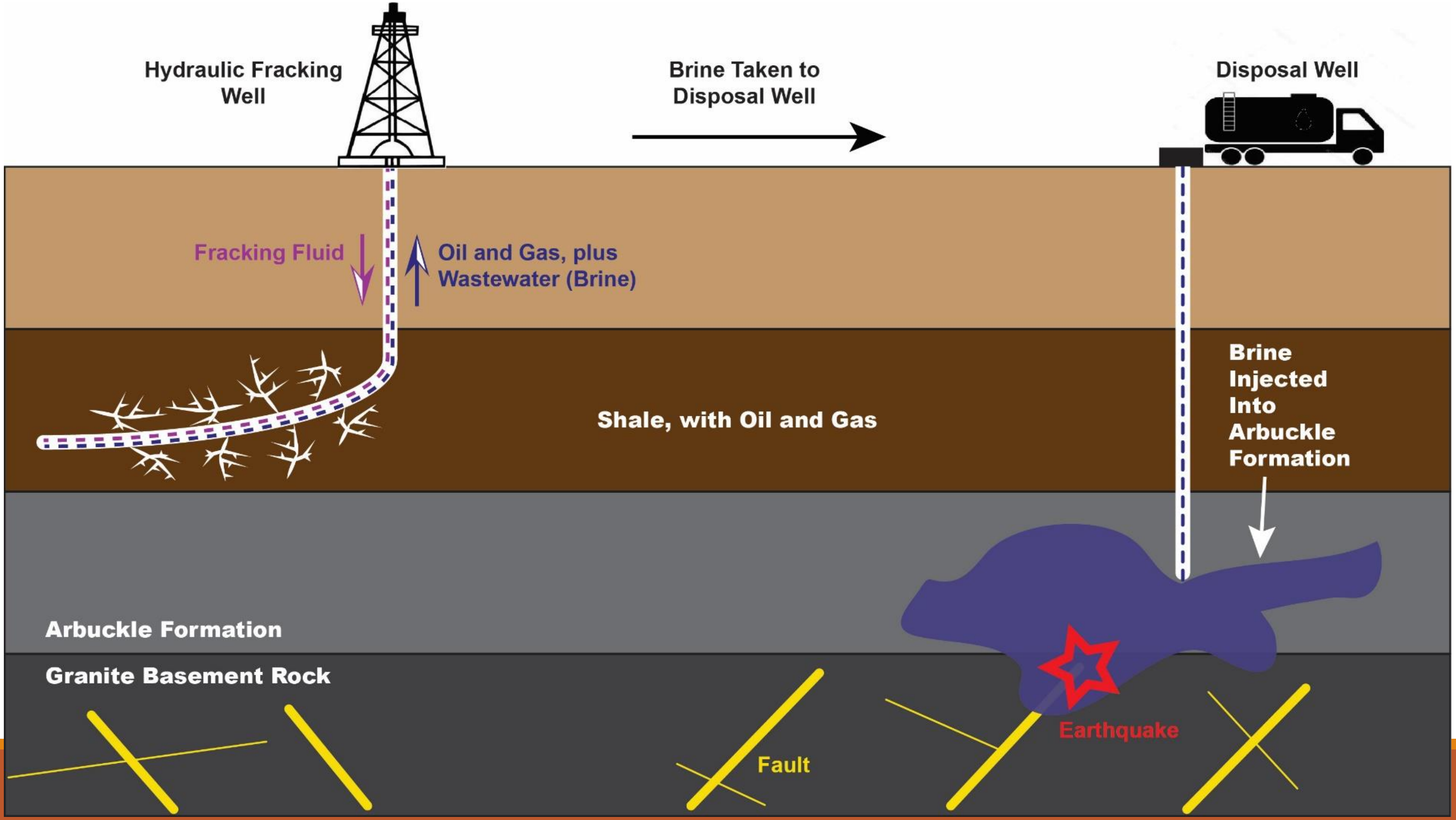


Zhai & Shirzaei 2018, in review



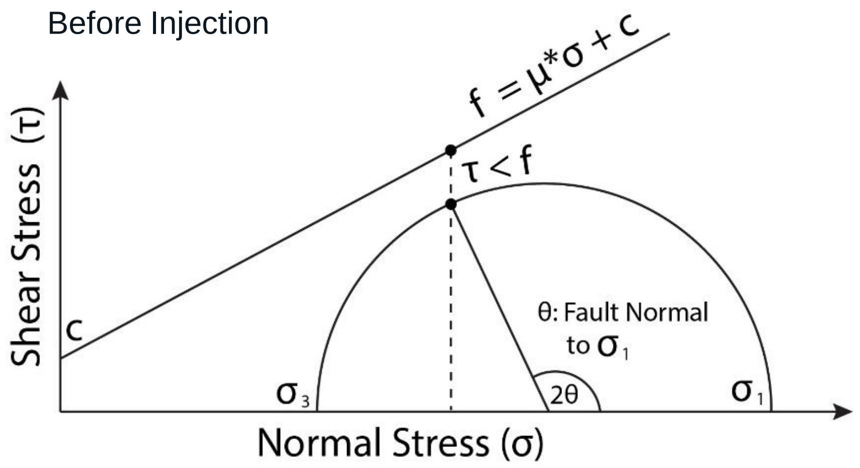
Rubinstein and Mahani, 2015

FRACKING VS WASTEWATER INJECTION



MOHR CIRCLE

Before Injection

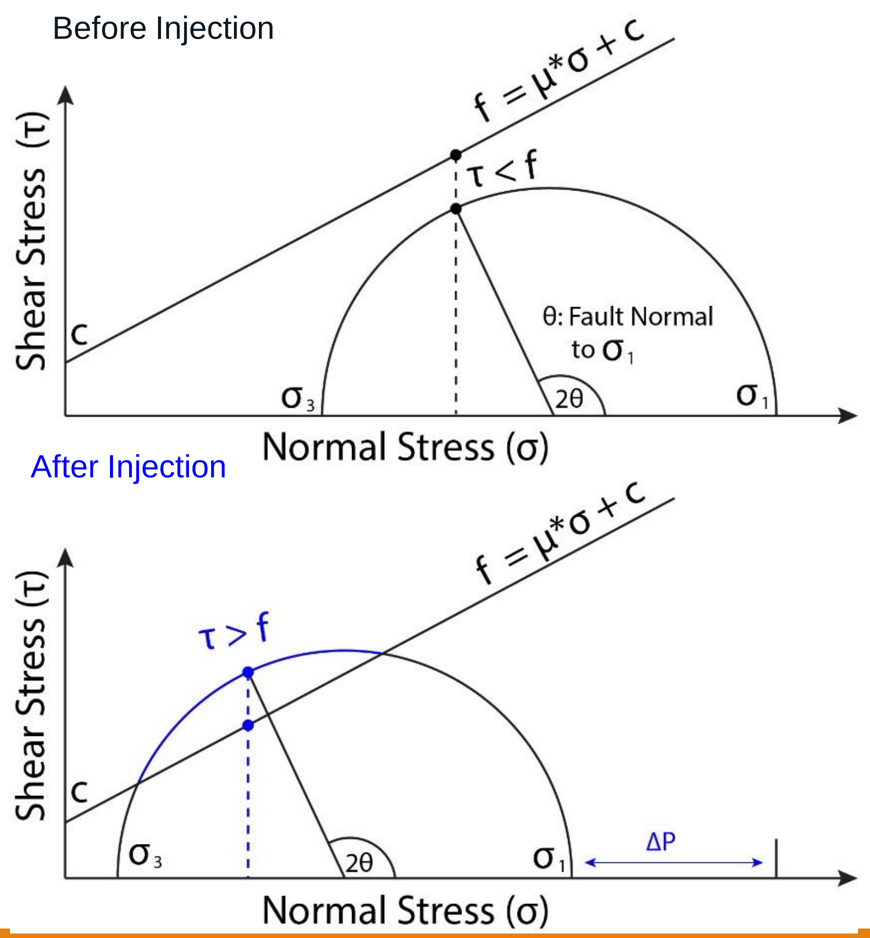


f: Shear Strength

μ: Material internal Friction

c: Material Cohesive Strength

MOHR CIRCLE

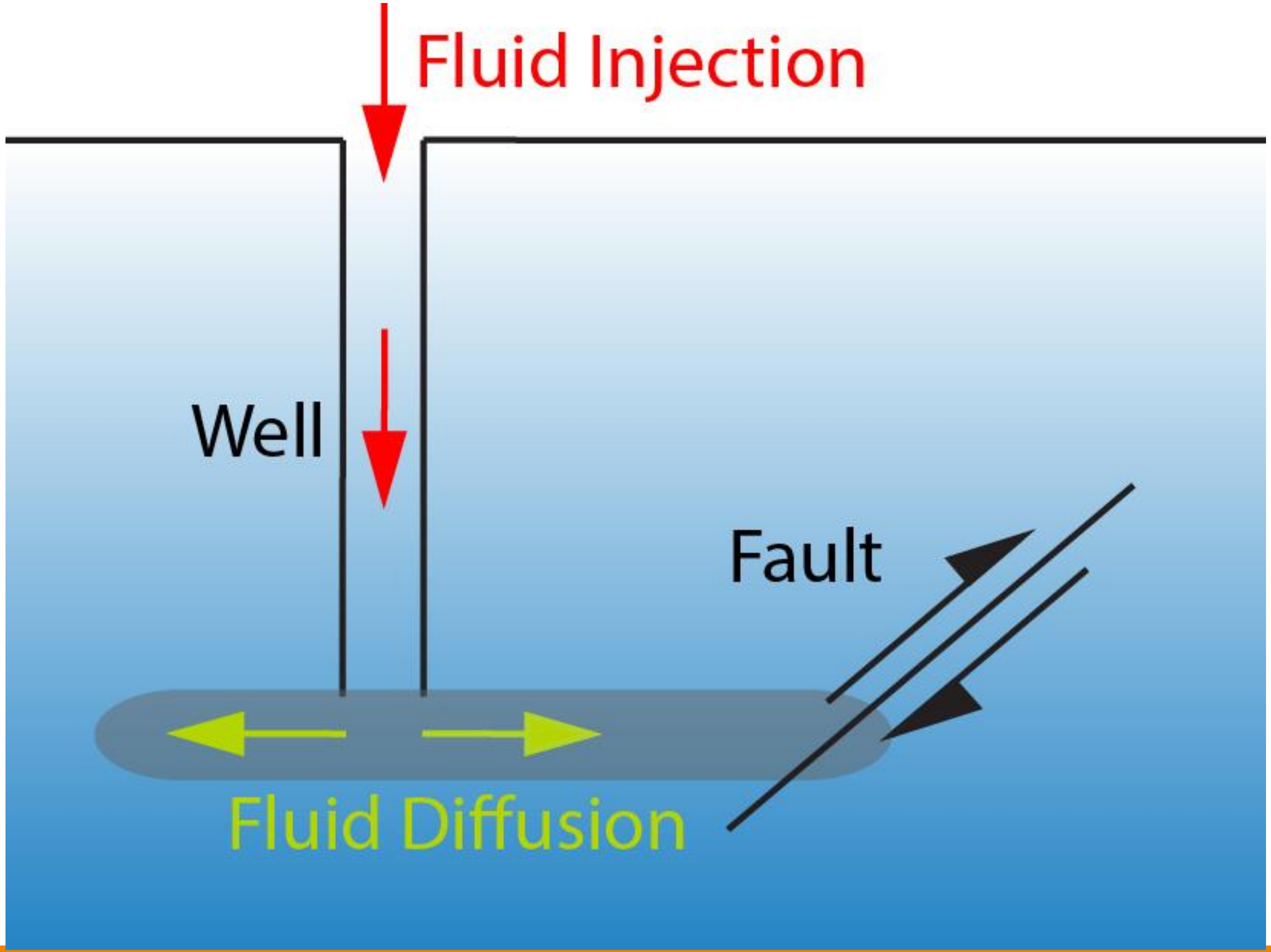


f: Shear Strength

μ: Material internal Friction

c: Material Cohesive Strength

PHYSICS-BASED INDUCED EARTHQUAKE FORECASTING



Fluid Diffusion

↓

Stress Change Model

↓

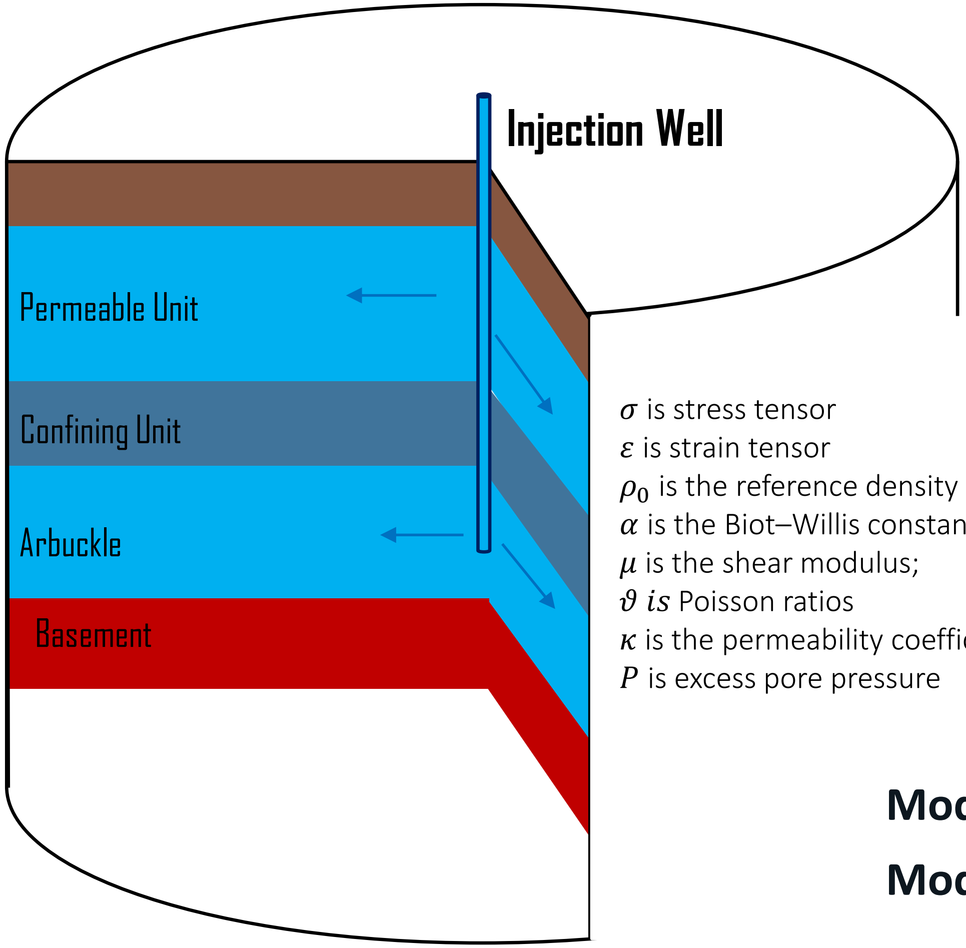
Seismicity Rate Change Model

↓

Earthquake Probability Model

Zhai & Shirzaei (2018, GRL)

STEP1: COUPLED FLOW AND POROELASTIC MODEL



Rice and Cleary (1976)

$$\sigma_{ij} = 2\mu\varepsilon_{ij} + 2\mu\varepsilon_{kk}\frac{\vartheta}{1-2\vartheta}\delta_{ij} - \alpha P\delta_{ij}$$

$$q_i = -\rho_0\kappa\frac{\partial}{\partial X_i}P$$

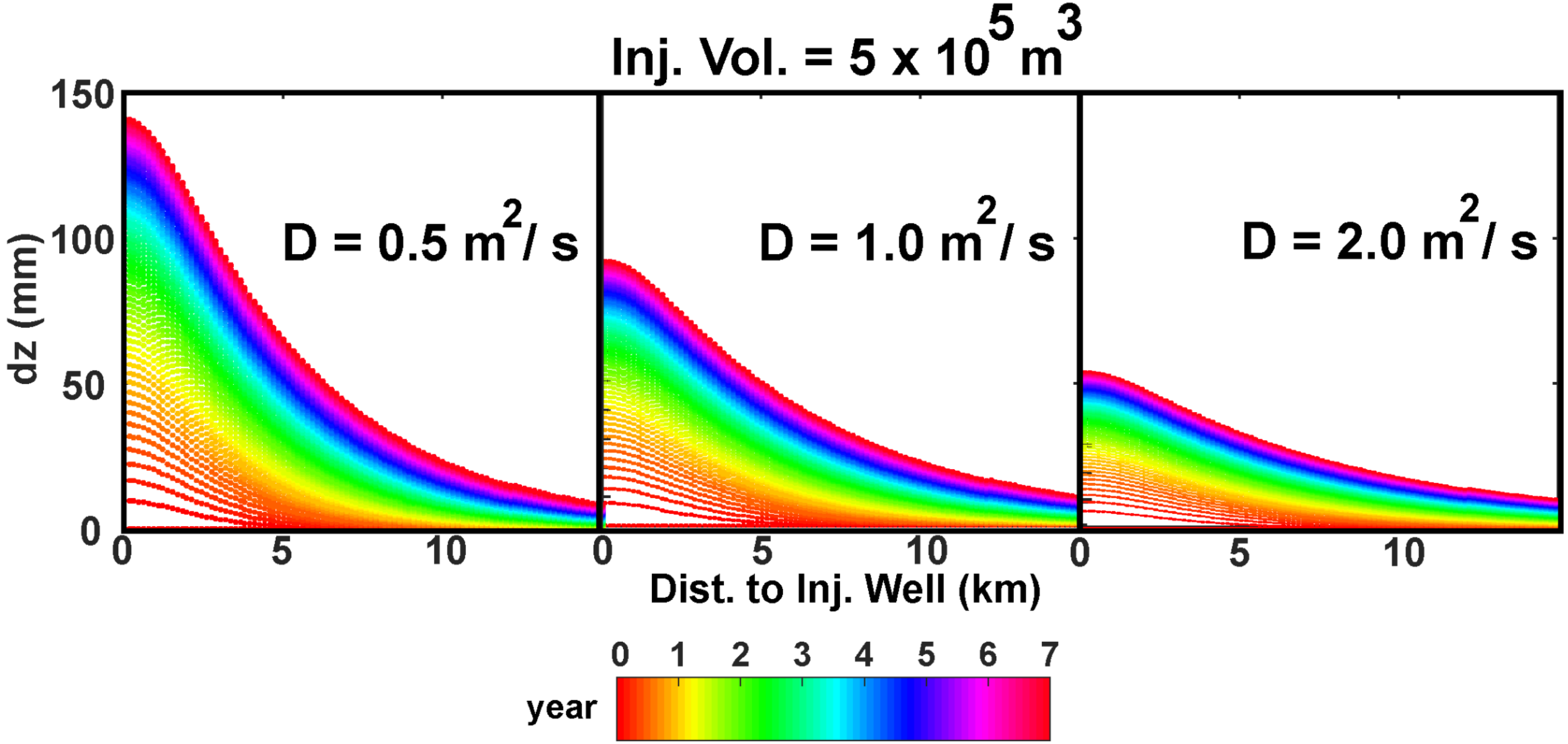
$$\frac{\partial}{\partial t}m = -\frac{\partial}{\partial X_i}q_i$$

σ is stress tensor
ε is strain tensor
ρ_0 is the reference density
α is the Biot–Willis constant
μ is the shear modulus;
ϑ *is* Poisson ratios
κ is the permeability coefficient
P is excess pore pressure

Model Input: Time series of volumetric injection rates

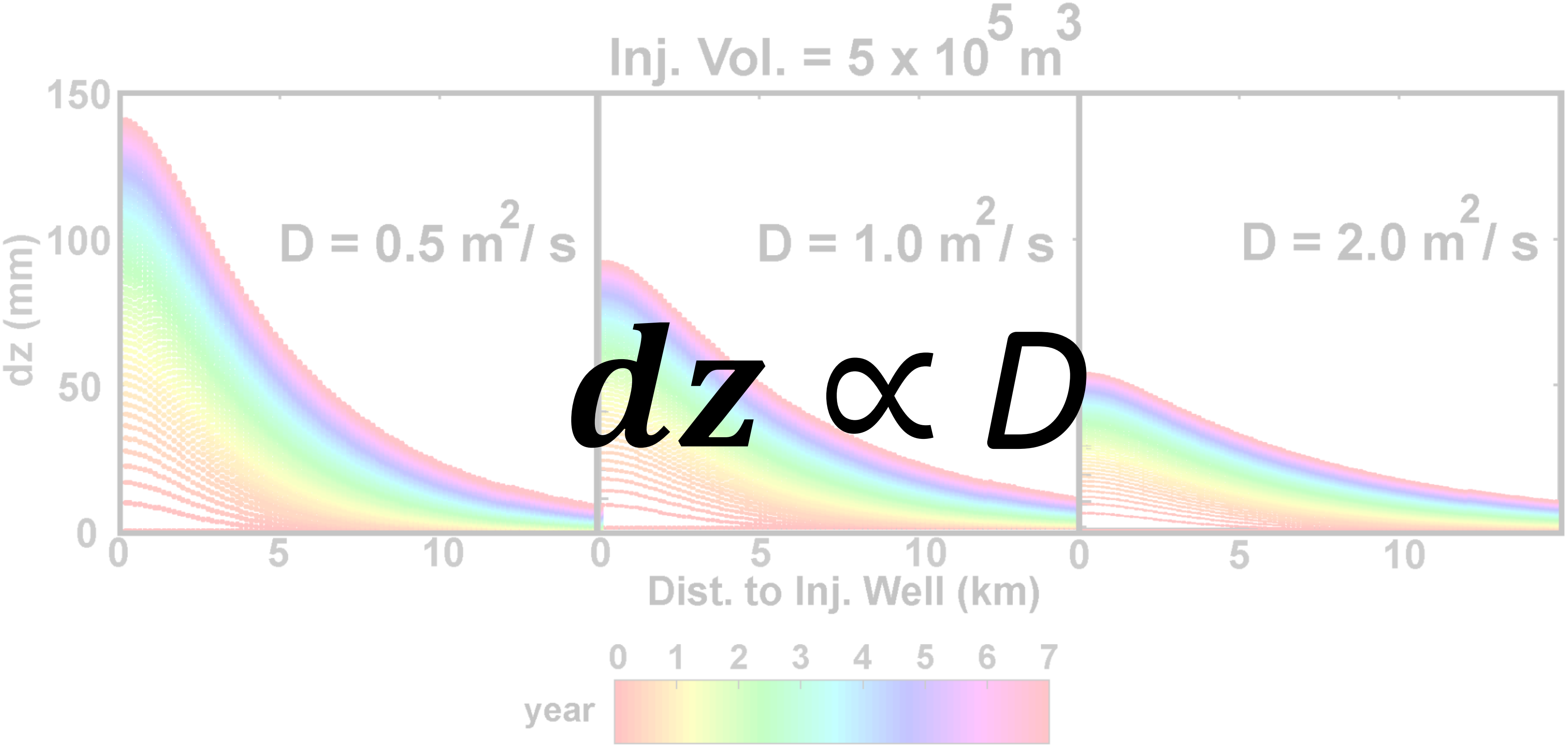
Model Output: Pore pressure and Poroelastic stresses

CONSTRAINING HYDROLOGICAL PROPERTIES



Shirzaei & Manga (2018, in review)

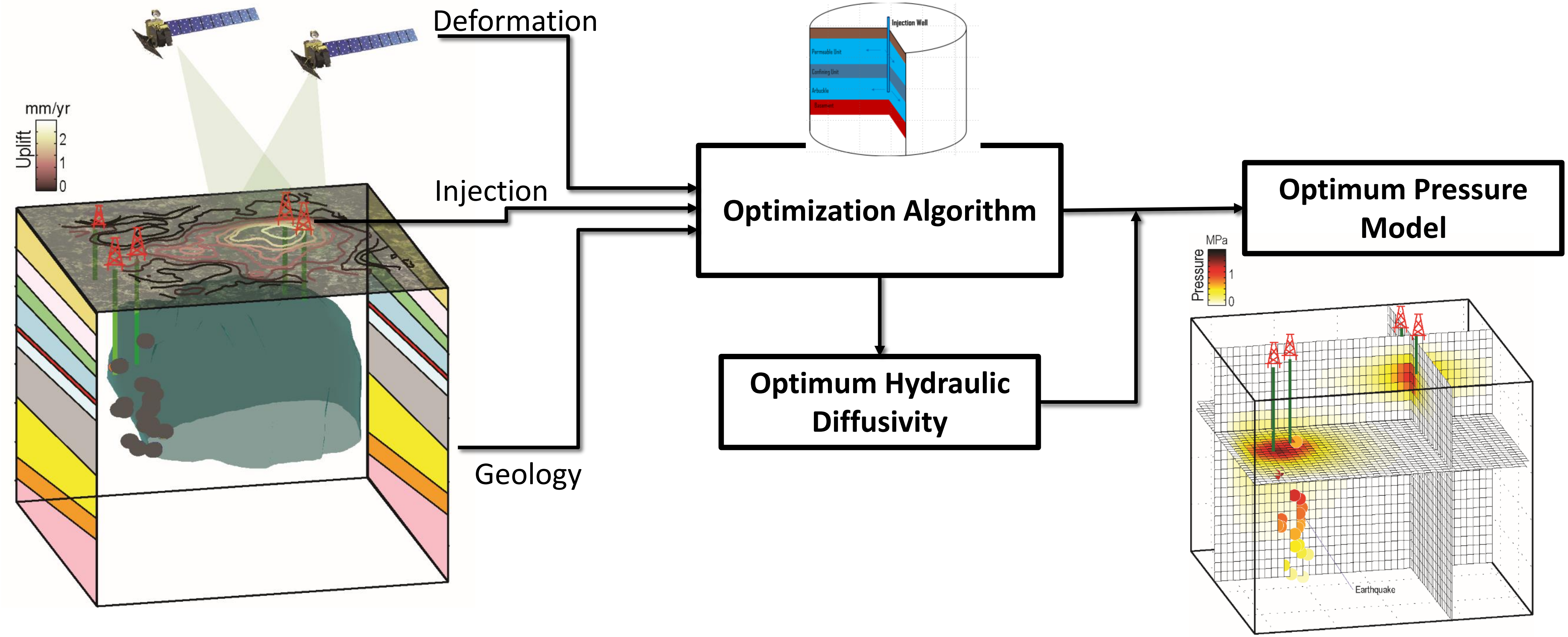
CONSTRAINING HYDROLOGICAL PROPERTIES



$$dz \propto D$$

Shirzaei & Manga (2018, in review)

CONSTRAINING HYDROLOGICAL PROPERTIES



Shirzaei & Manga (2018, in review)

STEP2: SEISMICITY RATE MODEL

$$\frac{dR}{dt} = \frac{R\dot{\tau}_0}{A\bar{\sigma}}\left(\frac{\dot{\tau}}{\dot{\tau}_0} - R\right)$$

Poroelastic Stress   Pore Pressure

$$\Delta\tau = (\Delta\tau_s + \mu\Delta\sigma) + \mu\Delta p$$

[After Dieterich 1994]

$\dot{\tau} = \Delta\tau/\Delta t$

μ: Coefficient of Friction

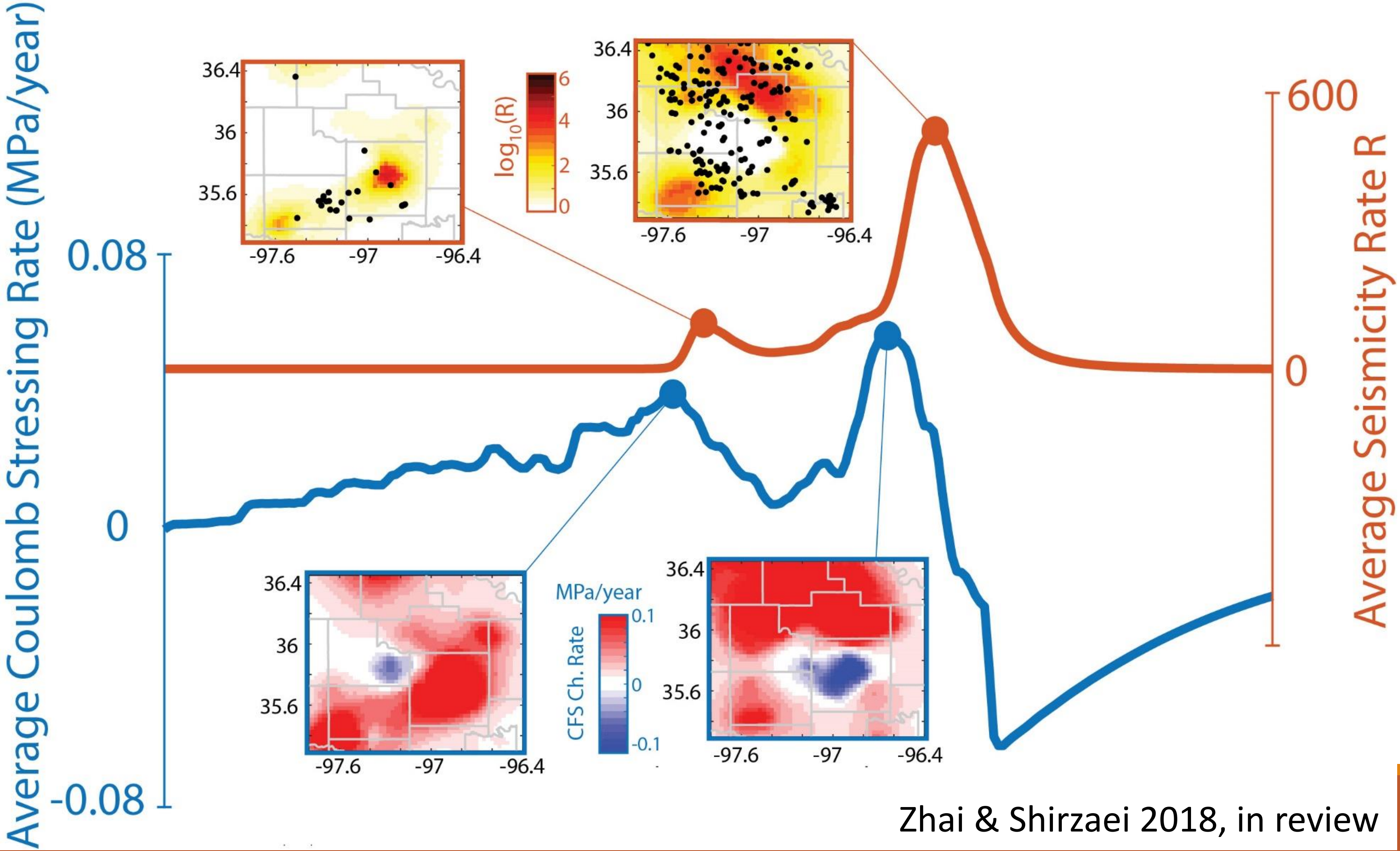
$\dot{\tau}_0$: Background Stressing Rate
$\bar{\sigma}$: Effective Normal Stress
A: Rate-State Parameter

Model Input: Pore pressure and Poroelastic stresses

Model Output (R): Seismicity Rate Relative to Background Rate

Zhai & Shirzaei (2018, GRL)

STRESS AND SEISMICITY RATE CHANGE FOR OKLAHOMA



Zhai & Shirzaei 2018, in review

STEP3: EARTHQUAKE MAGNITUDE EXCEEDANCE PROBABILITY

$$P_{\geq M}(t_1, t_2, S) = 1 - \exp[-N_{\geq M}(t_1, t_2, S)]$$

Inhomogeneous Poisson process

$$N_{\geq M}(t_1, t_2, S) = \int_{t_1}^{t_2} \int_{S} \frac{k10^{-bM}}{S_0} R(\boldsymbol{x}, t)\, d\boldsymbol{x} dt$$

S_0: Size of Study Area
b: Slope of GR Law
k : Annual Rate of M≥0 Earthquakes over S_0

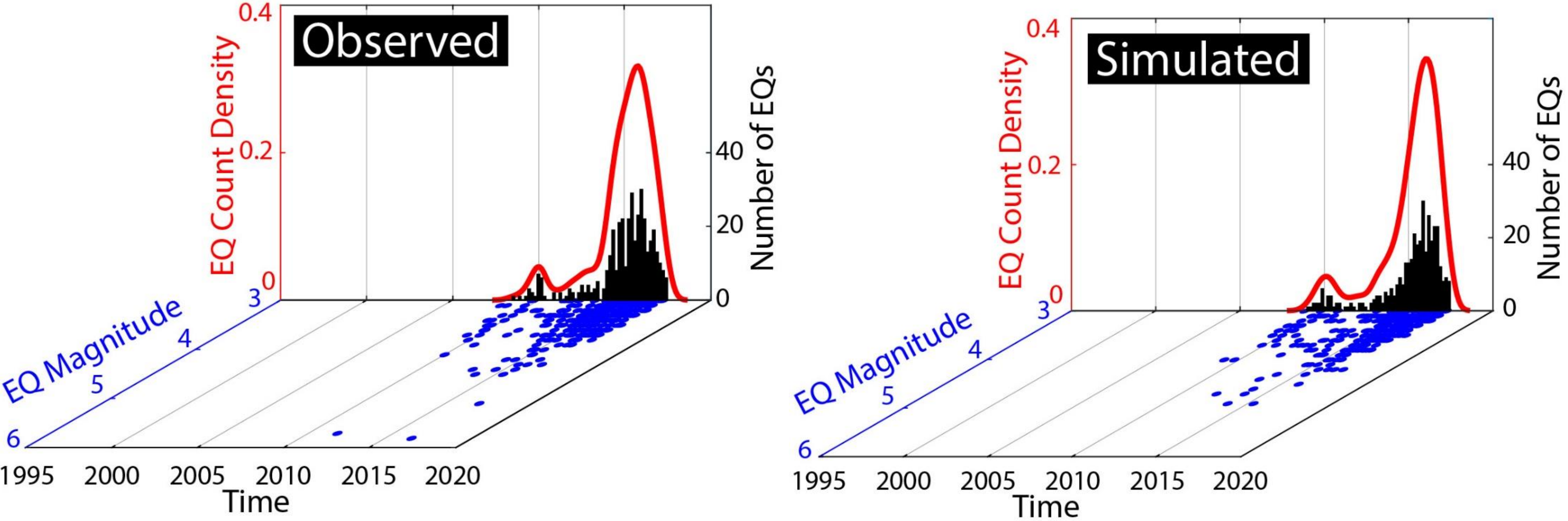
Prior to Injection

Model Input: Relative Seismicity Rate R

Model Output: Earthquake Magnitude Exceedance Probability

Zhai & Shirzaei (2018, GRL)

EARTHQUAKE MAGNITUDE/TIME DISTRIBUTION



Zhai & Shirzaei 2018, in review

FINAL REMARKS

- A golden era for InSAR has just began, thanks to Sentinel mission (and soon NISAR).

- The more people use InSAR the better is for the business.

- It is time to make available higher level products to public.