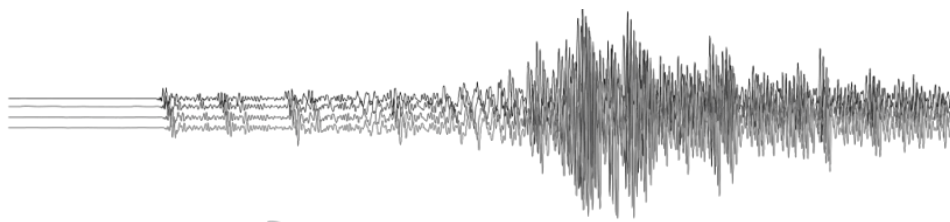
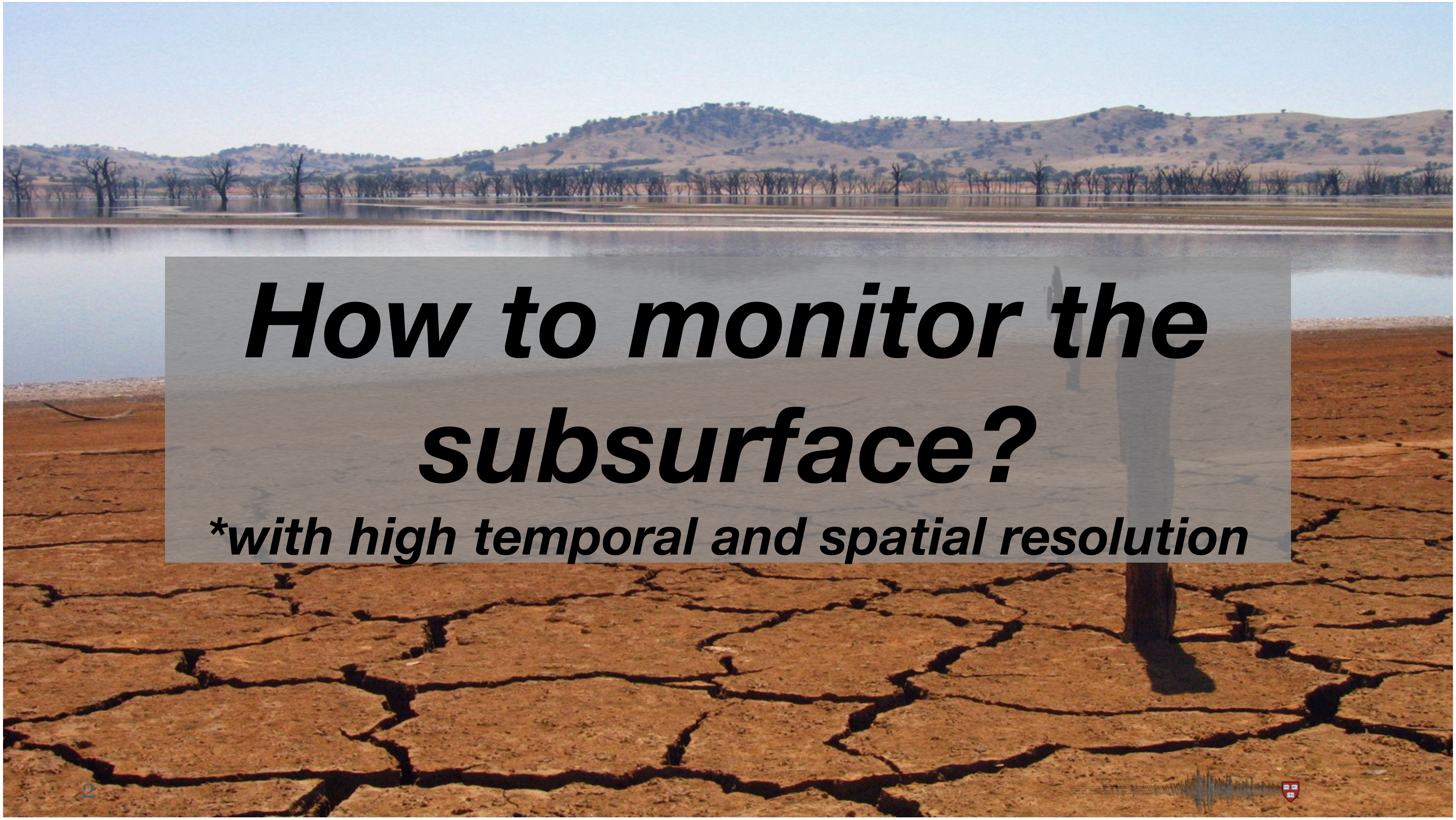
Ambient Noise Monitoring of the Near-Surface at Scales

Tim Clements[1] , Loic Viens[1,2] & Marine Denolle[1]

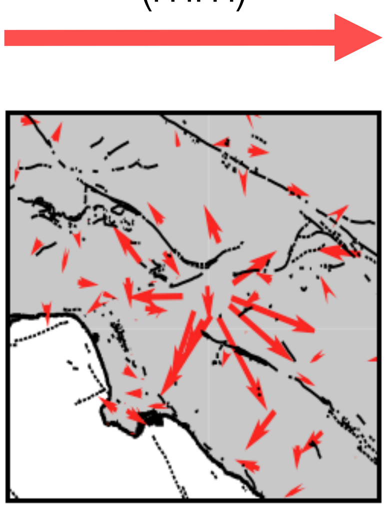
[1]Department of Earth and Planetary Sciences, Harvard University
[2]Disaster Prevention Research Institute, University of Kyoto




How to monitor the subsurface?
*with high temporal and spatial resolution

Geodetic Monitoring of the Subsurface

Horizontal Motion
(mm)



Loading H_2O (cm)

10 cm Subsidence
per color cycle

GPS

GRACE

InSAR

Surface Deformation

Gravity Change

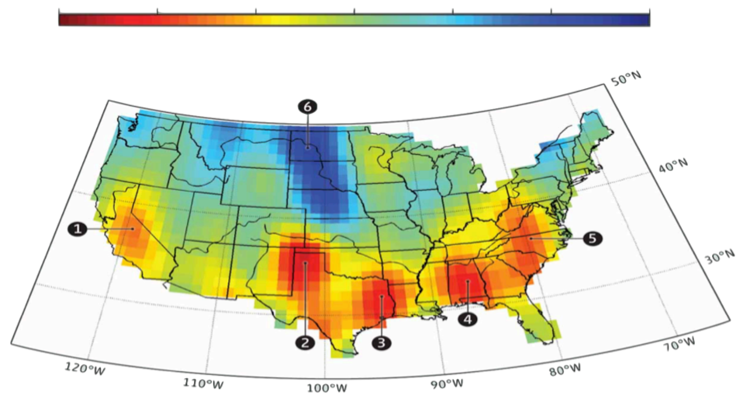
Phase Difference

King et al., 2007

Geodetic Monitoring of the Subsurface

Horizontal Motion (mm)

Loading H_2O (cm)



10 cm Subsidence per color cycle

GPS | **GRACE** | **InSAR**

Surface Deformation | ***Gravity Change*** | ***Phase Difference***

Famiglietti et al., 2011

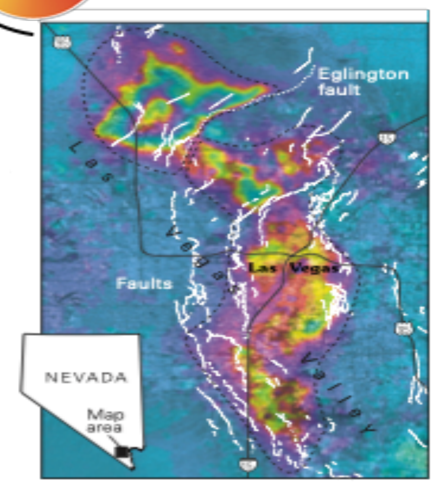
Geodetic Monitoring of the Subsurface

Horizontal Motion (mm)

Loading H_2O (cm)

-3 -2 -1 0 1 2 3

10 cm Subsidence per color cycle



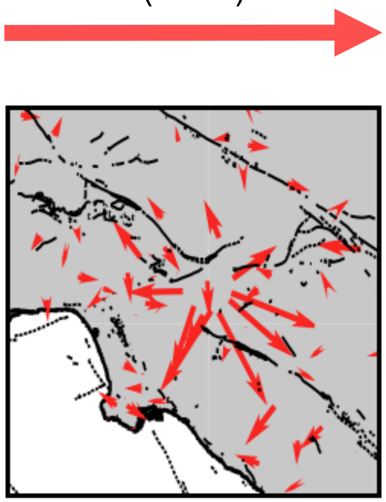
GPS | **GRACE** | **InSAR**

Surface Deformation | ***Gravity Change*** | ***Phase Difference***

Amelung et al., 1999

Geodetic Monitoring of the Subsurface

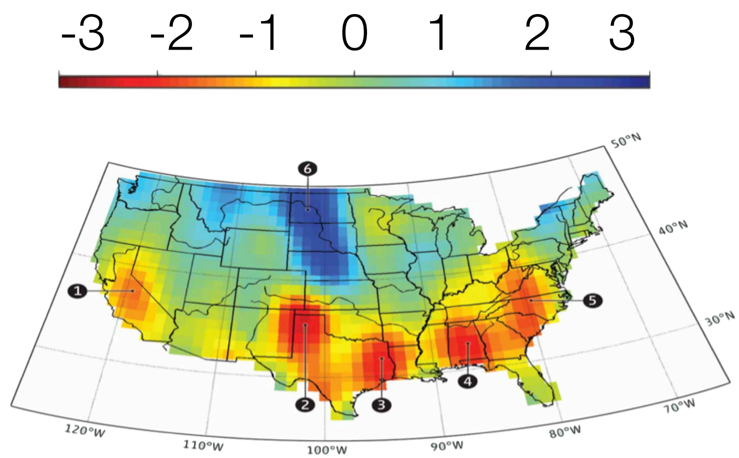
Horizontal Motion (mm)



GPS

Surface Deformation

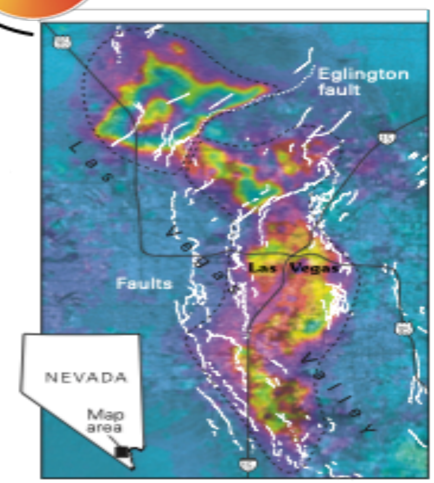
Loading H_2O (cm)



GRACE

Gravity Change

10 cm Subsidence per color cycle



InSAR

Phase Difference

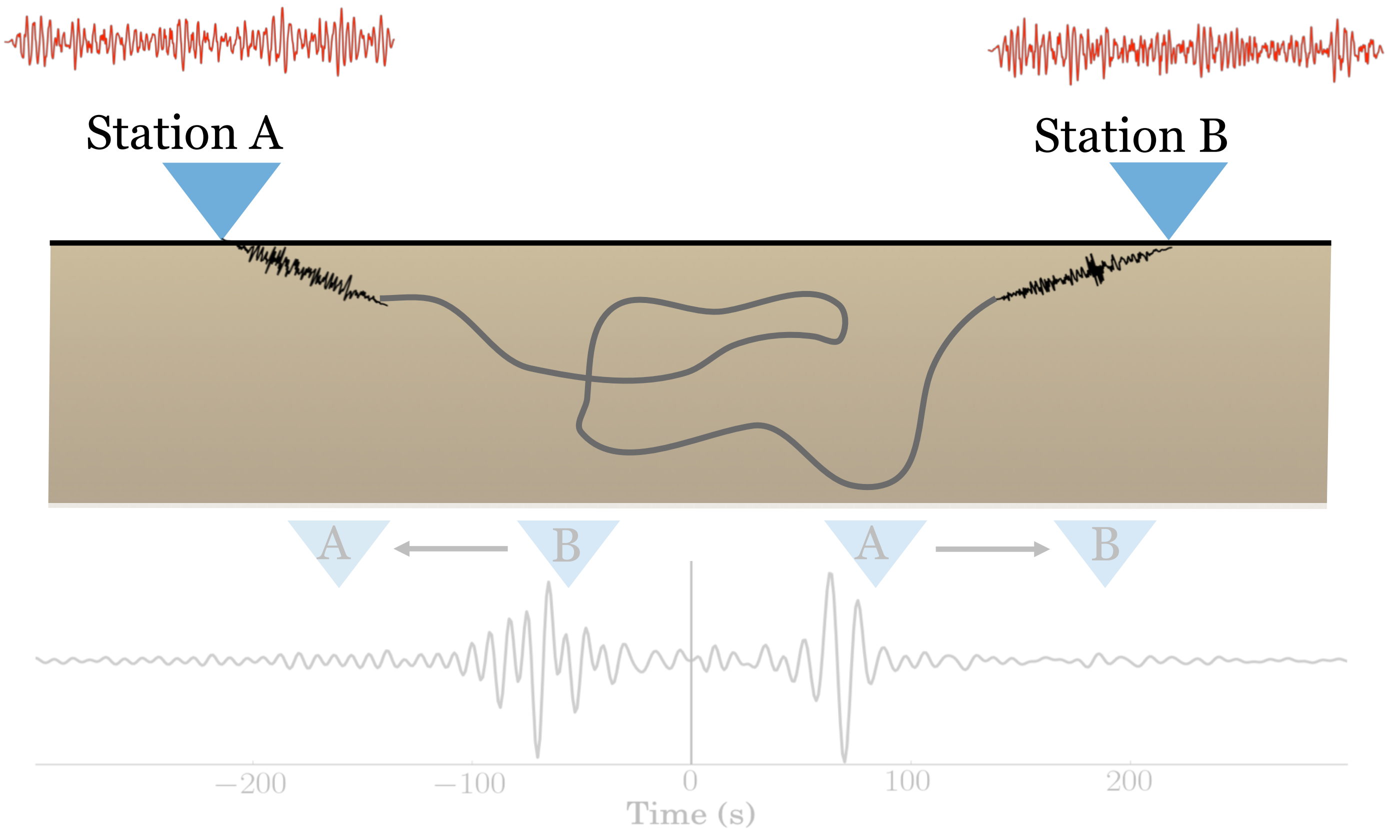
Subsurface monitoring with ambient noise cross-correlation

Subsurface monitoring with ambient data cross-correlation

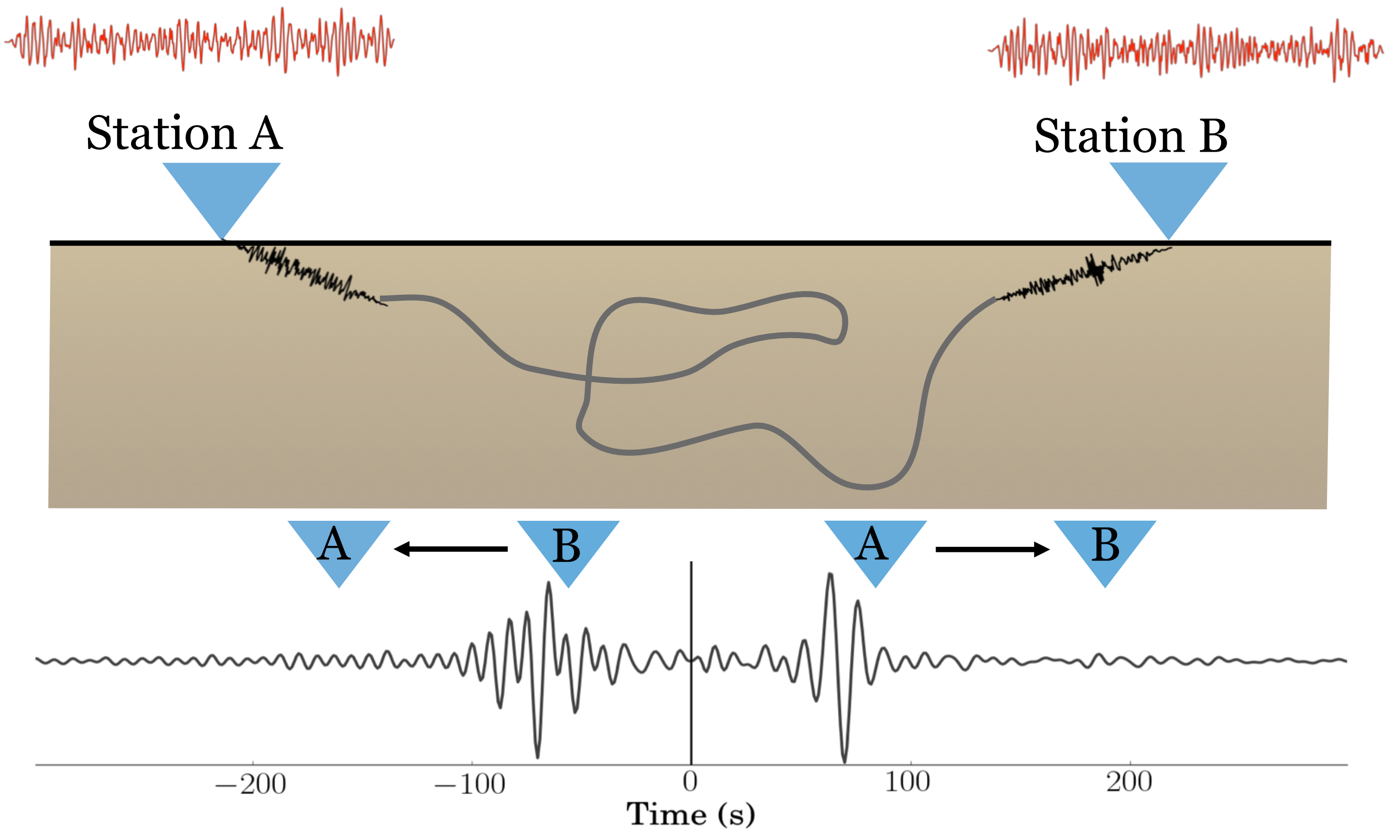
I frequently hear music in the heart of noise.

- *George Gershwin*

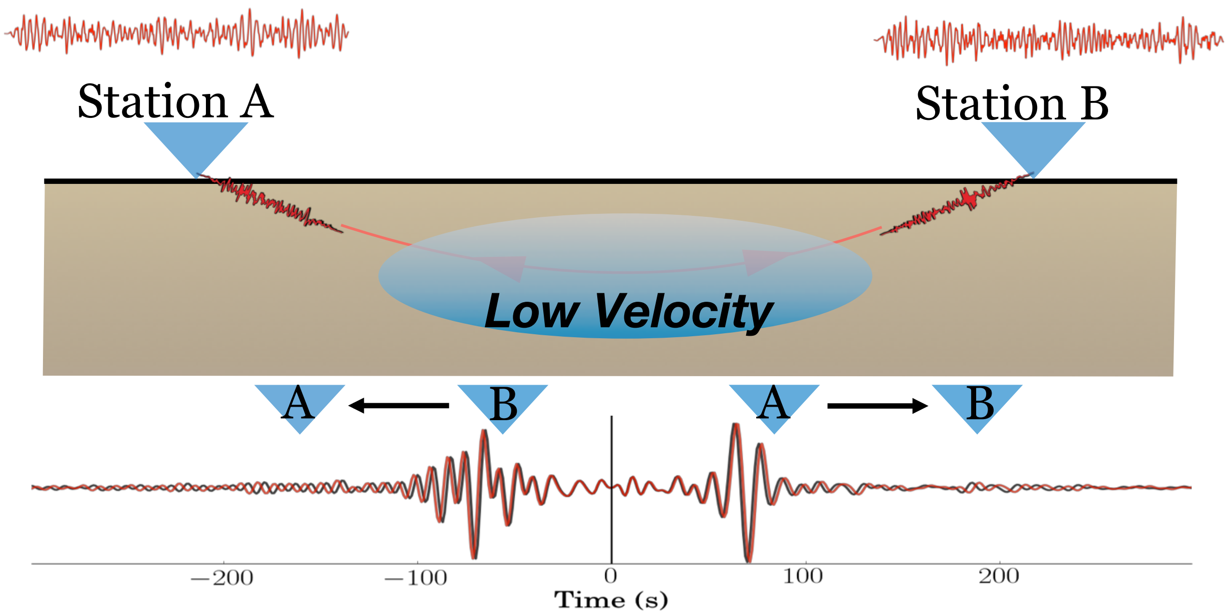
Ambient Noise Cross-Correlation



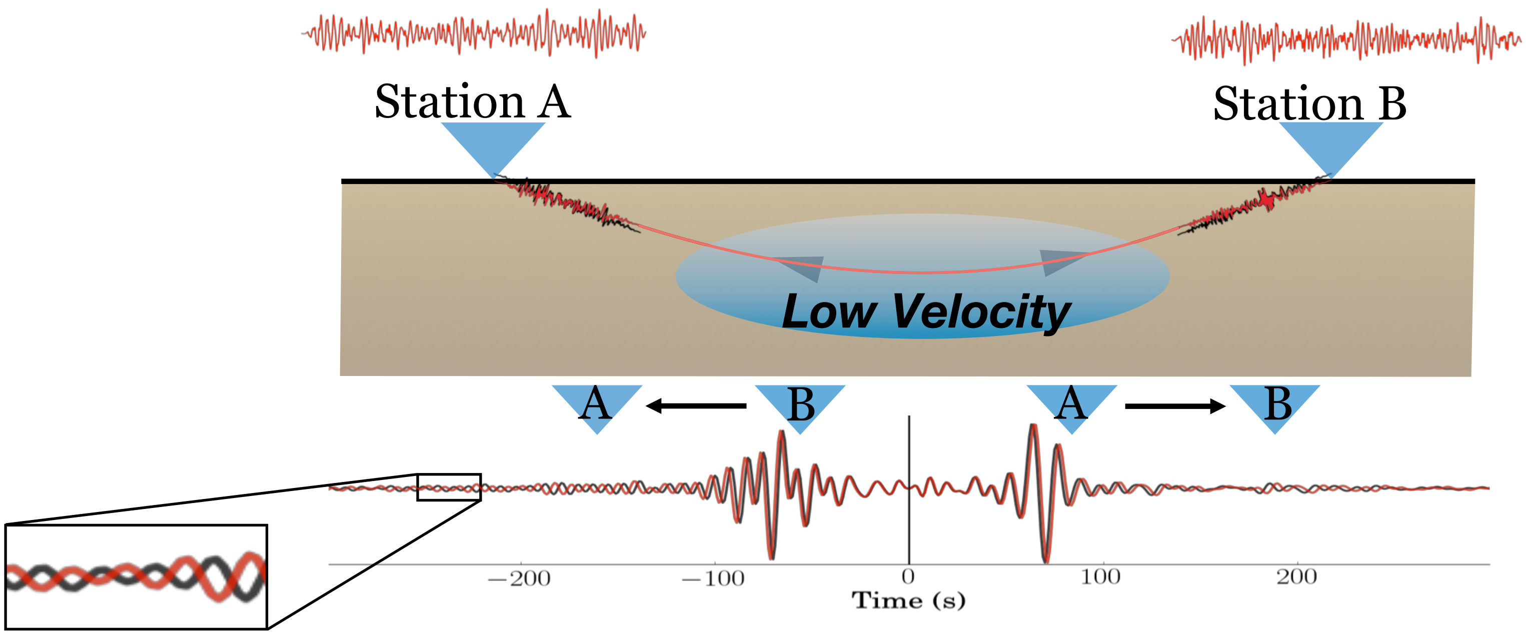
Ambient Noise Cross-Correlation



Seismic Velocity Change, *dv/v*

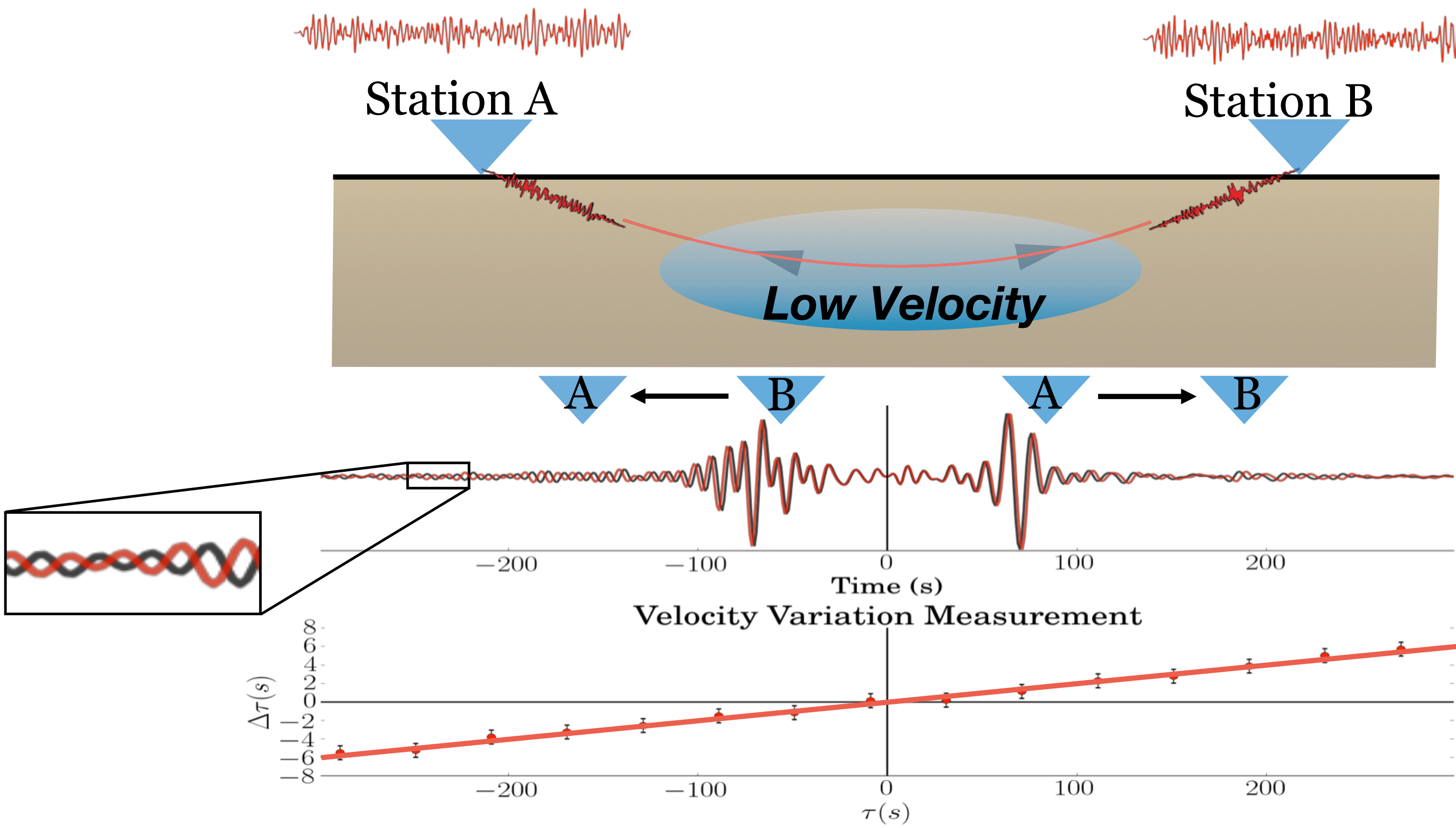


Seismic Velocity Change, *dv/v*



 Clarke et al., 2011

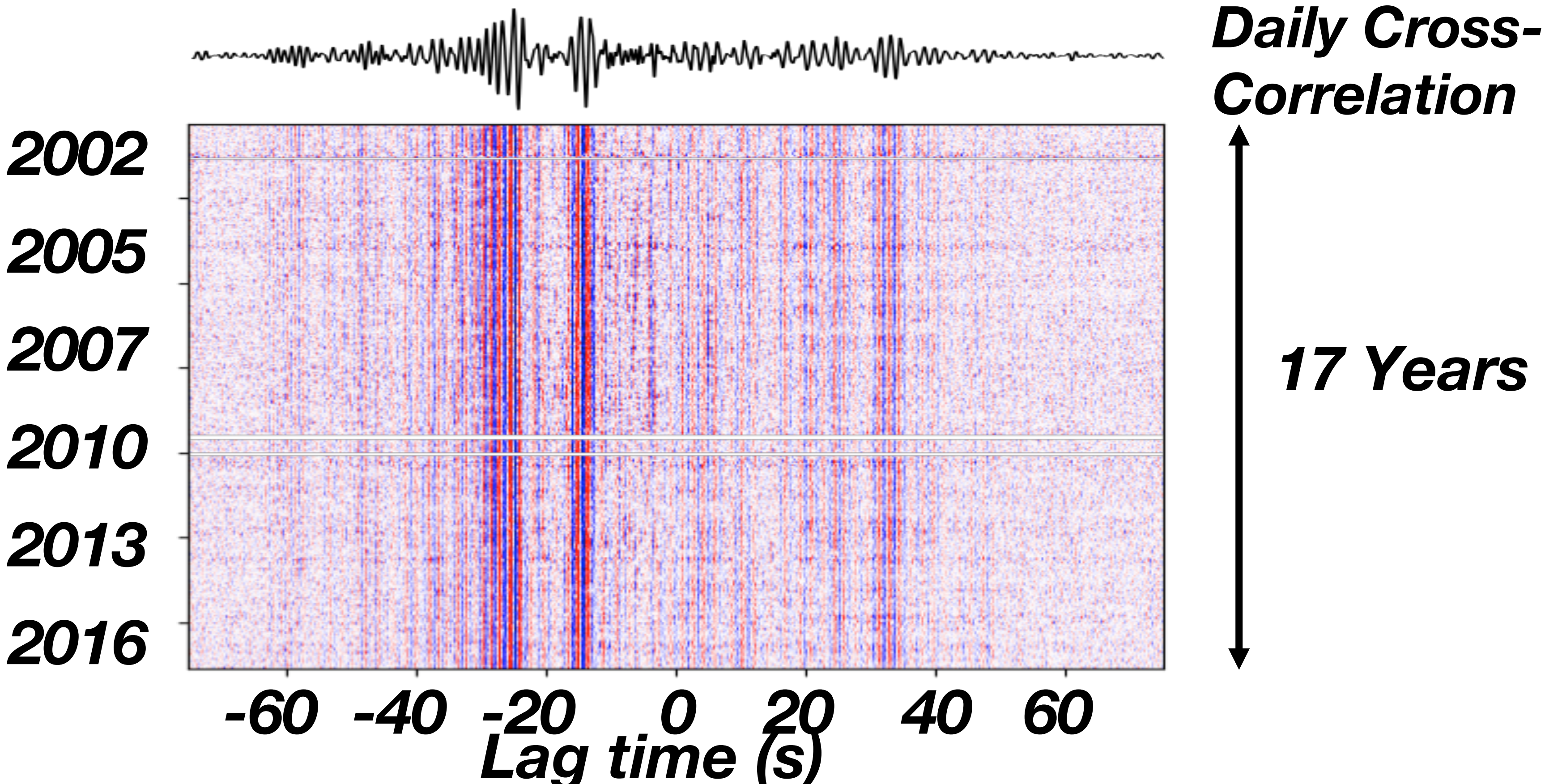
Seismic Velocity Change, *dv/v*



$$-d\tau/\tau = dv/v = -5\%$$

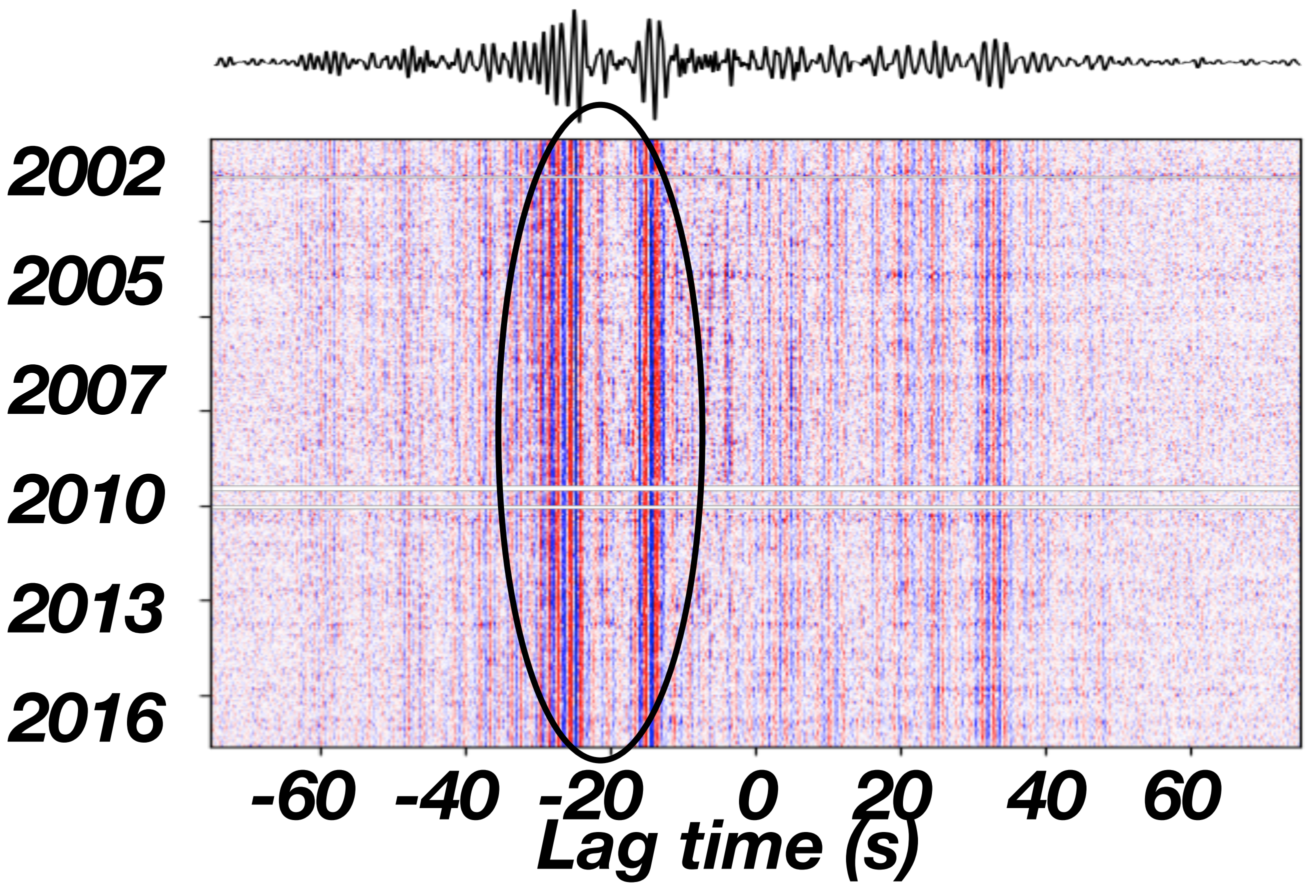
Clarke et al., 2011

Ambient Noise Cross-Correlation



Clements and Denolle, 2018

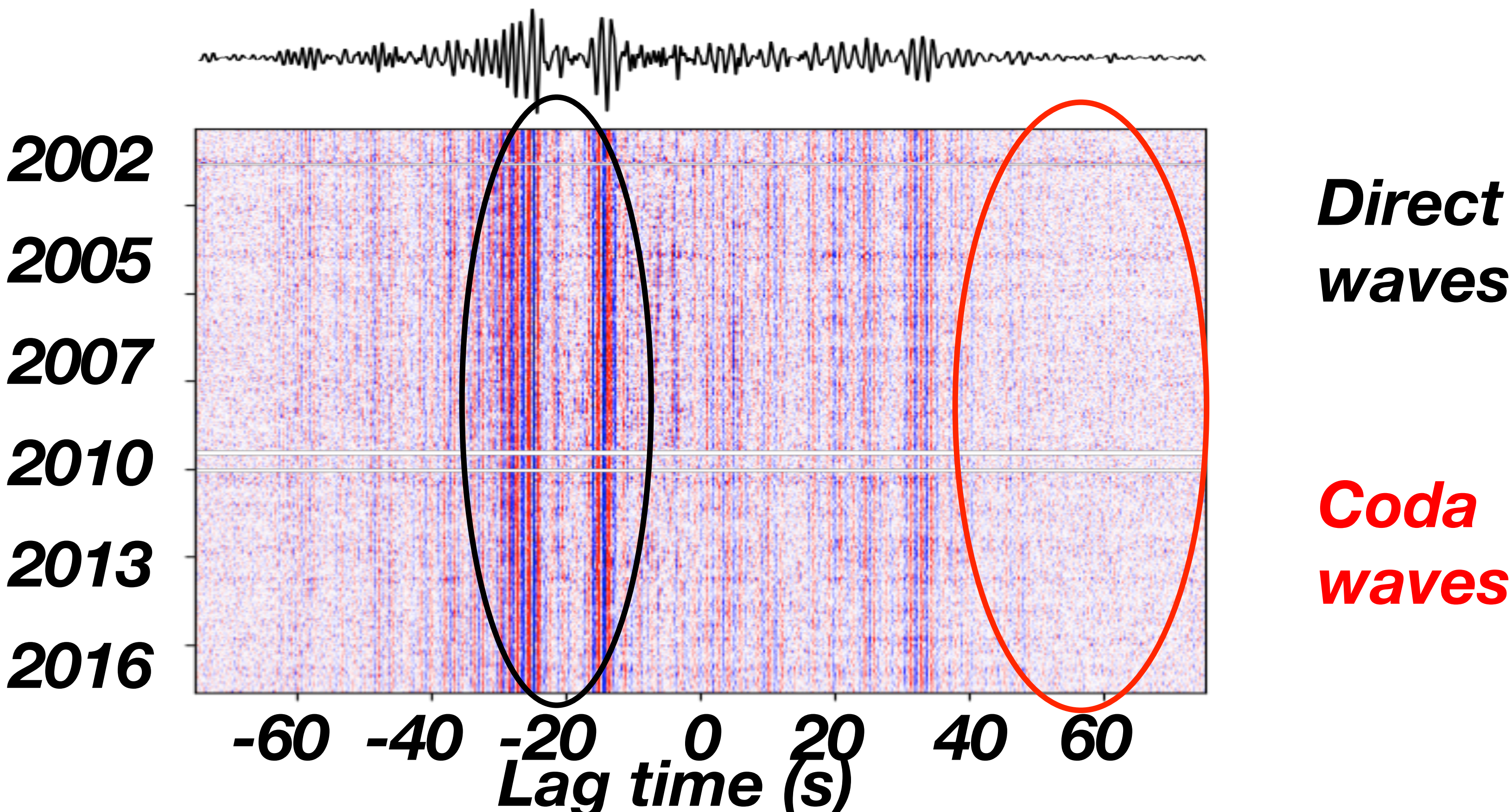
Ambient Noise Cross-Correlation



Direct waves

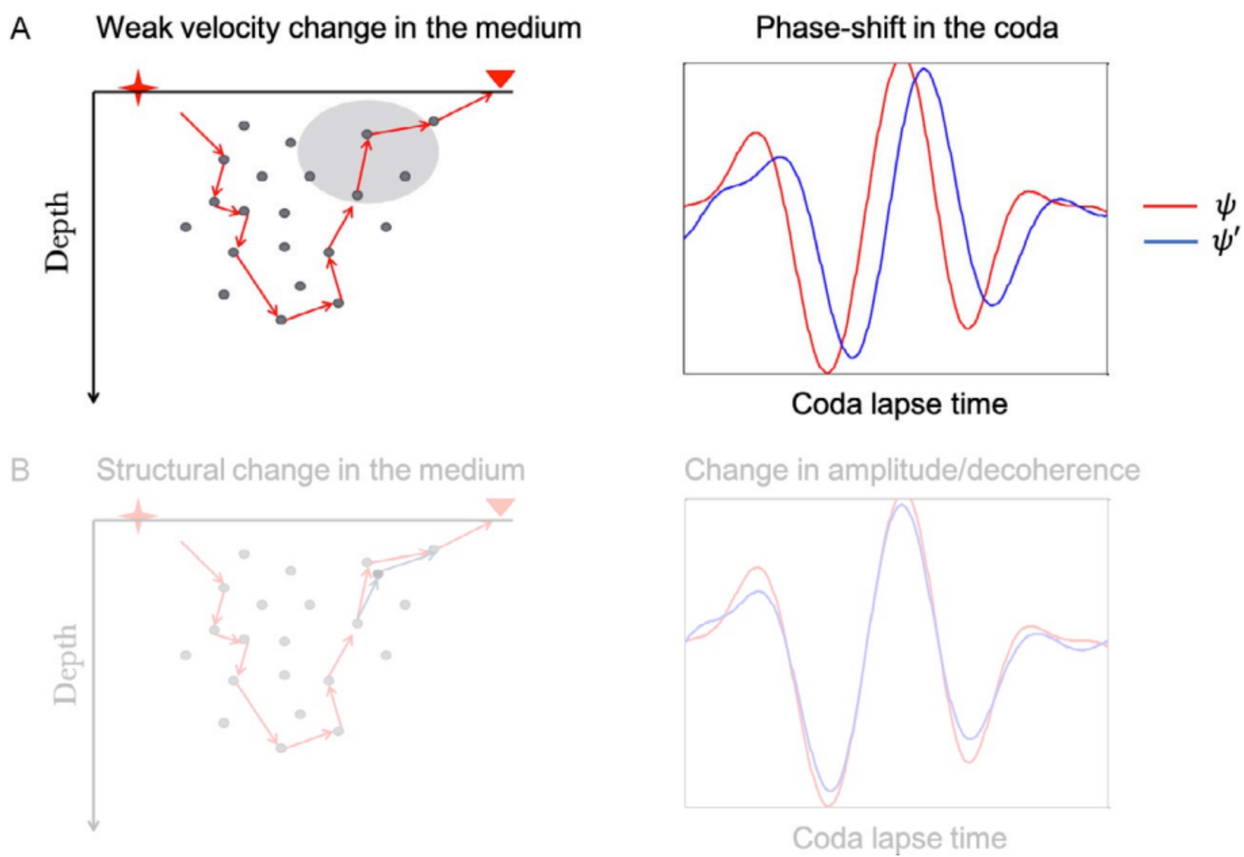
Clements and Denolle, 2018

Ambient Noise Cross-Correlation



Clements and Denolle, 2018

Coda Wave Interferometry

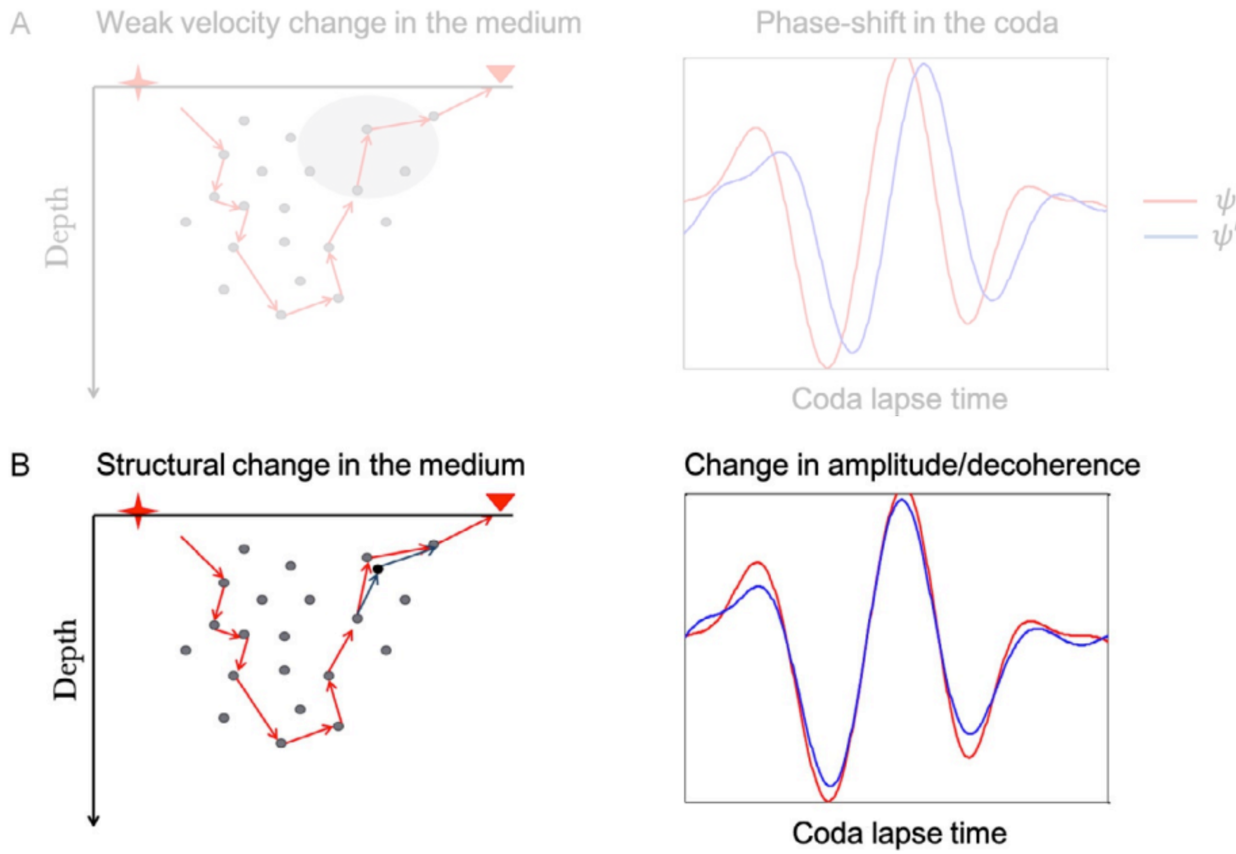


dv/v

dc/c

Obermann and Hillers, 2019

Coda Wave Interferometry



dv/v

dc/c

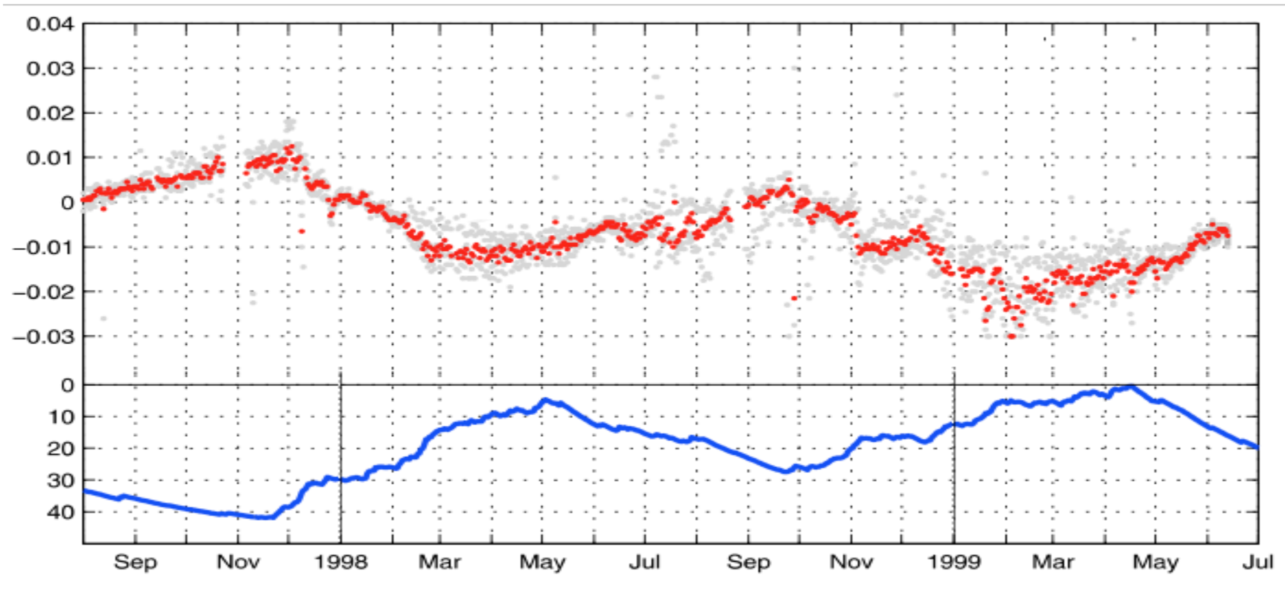
Obermann and Hillers, 2019

dv/v: Change in Seismic Velocity

Merapi Volcano, Indonesia

dv/v %

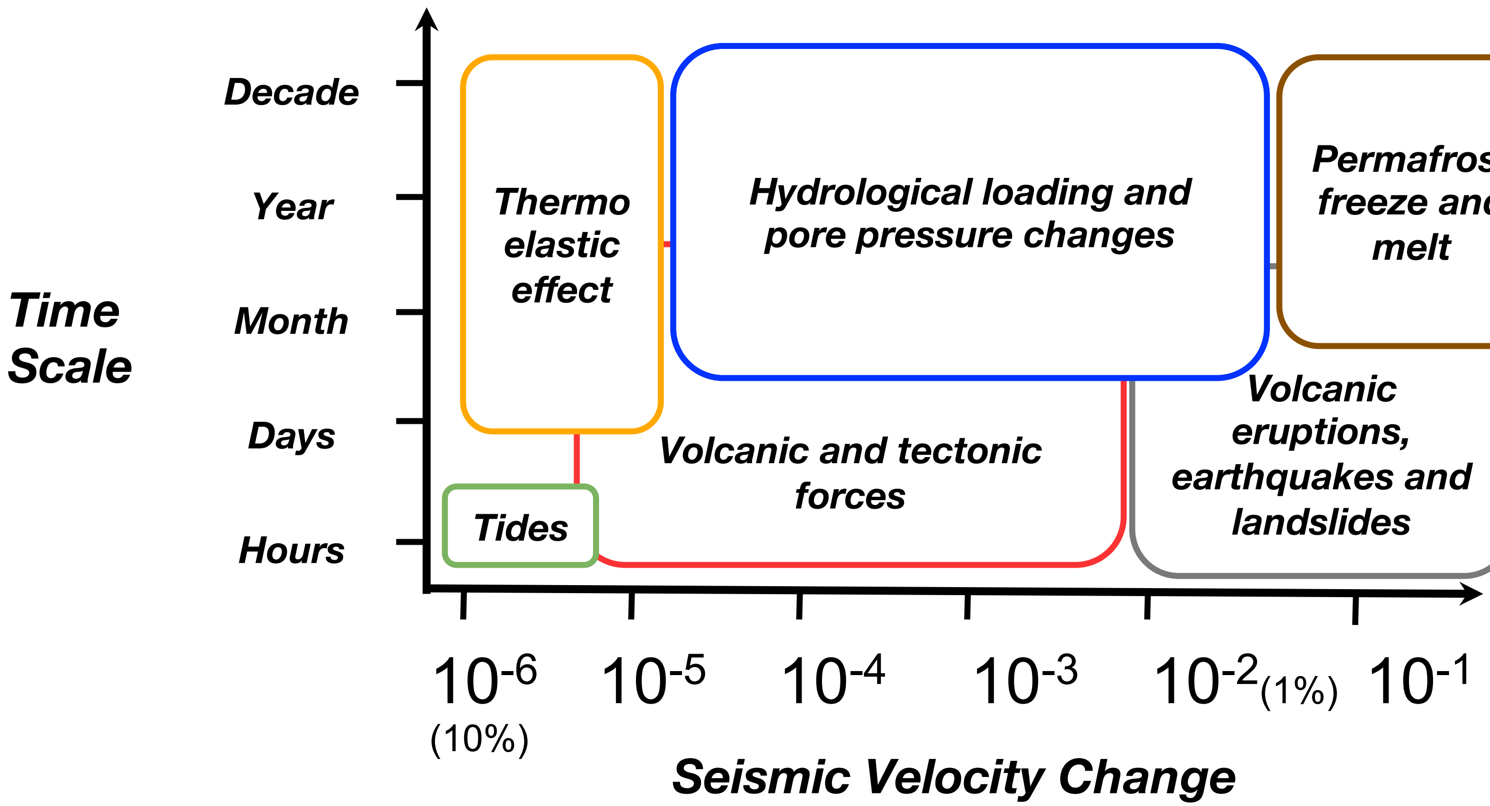
GWL (m)



Groundwater level ↑ ***dv/v*** ↓

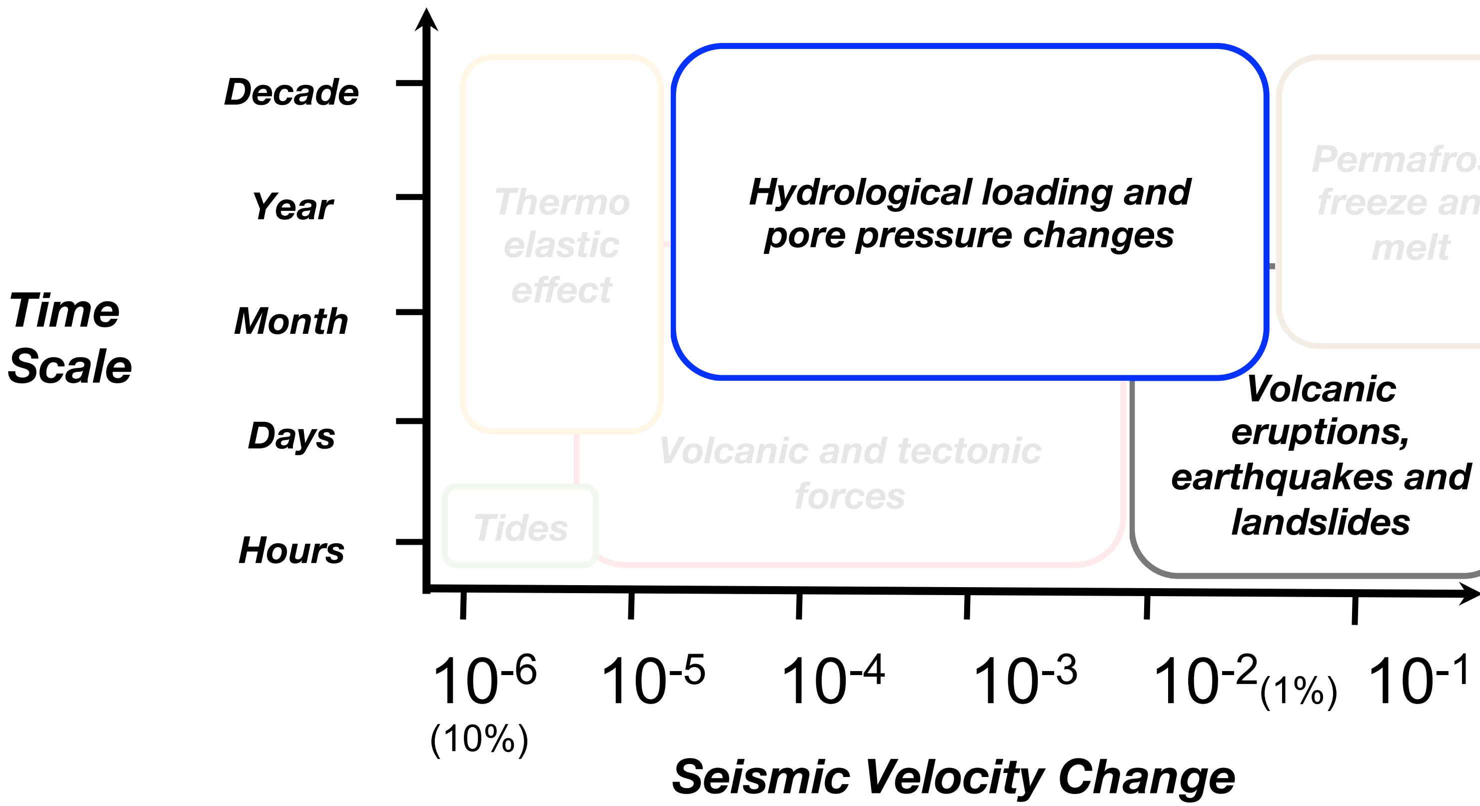
Sens-Schonfelder and Wegler, 2006

Seismic Velocity Change: dv/v



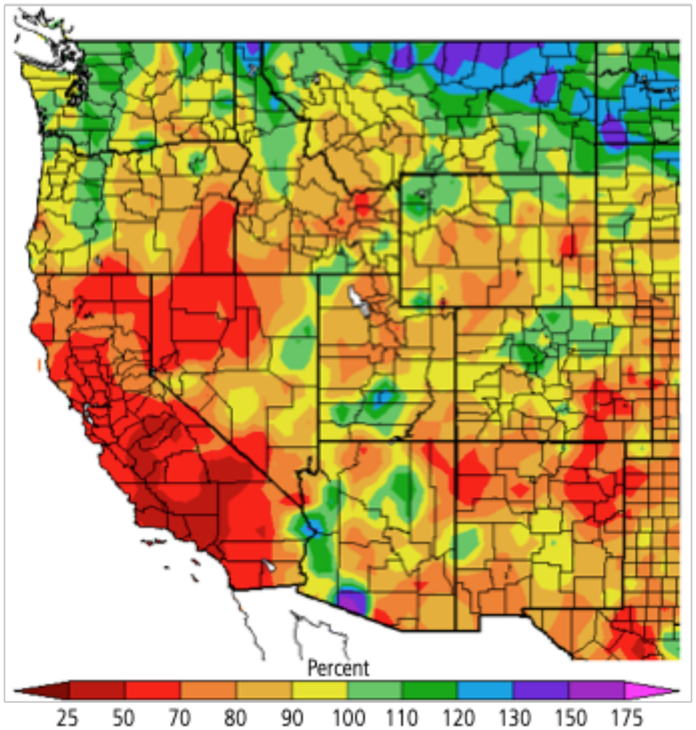
From Florent Brenguier

Seismic Velocity Change: dv/v

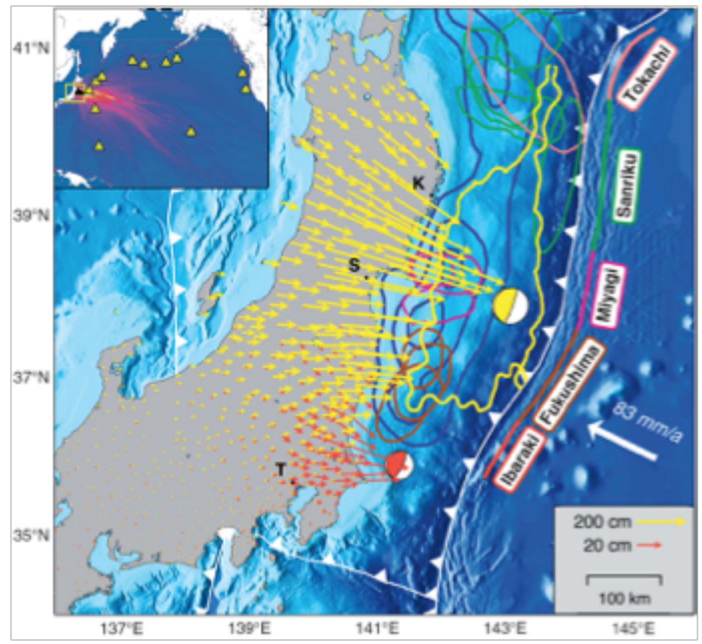


 From Florent Brenguier

Seismic Velocity Change: dv/v



Drought



Strong-Motion Response

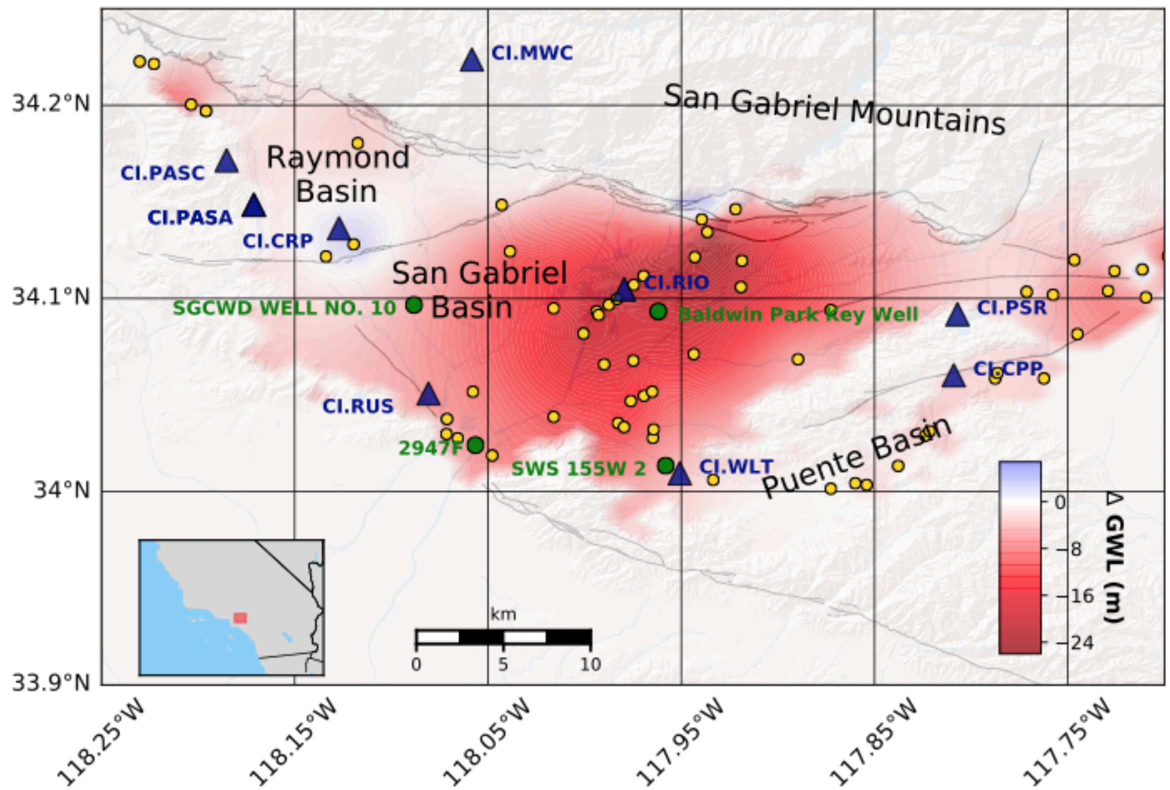
California DWR; Simons et al., 2011

Monitoring Drought: San Gabriel Valley, CA

Seismometers

Wells

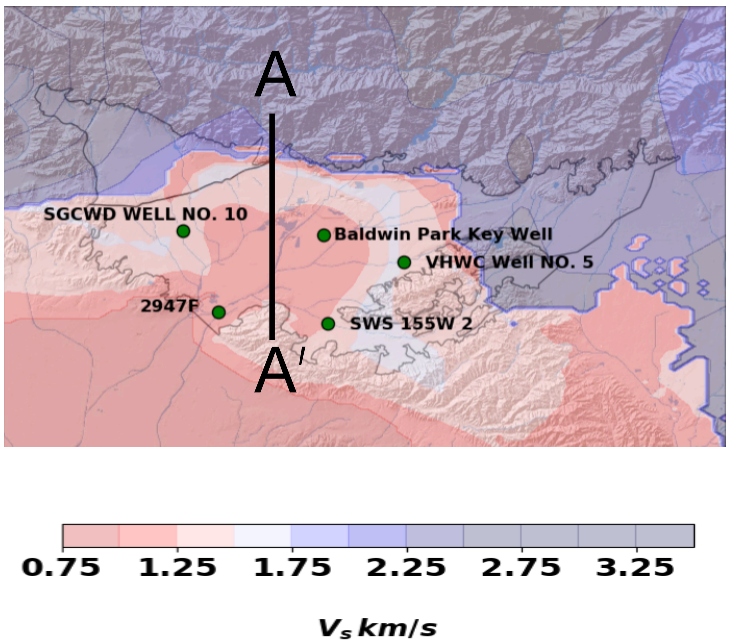
Water levels fall ~20m from 2011 - 2016

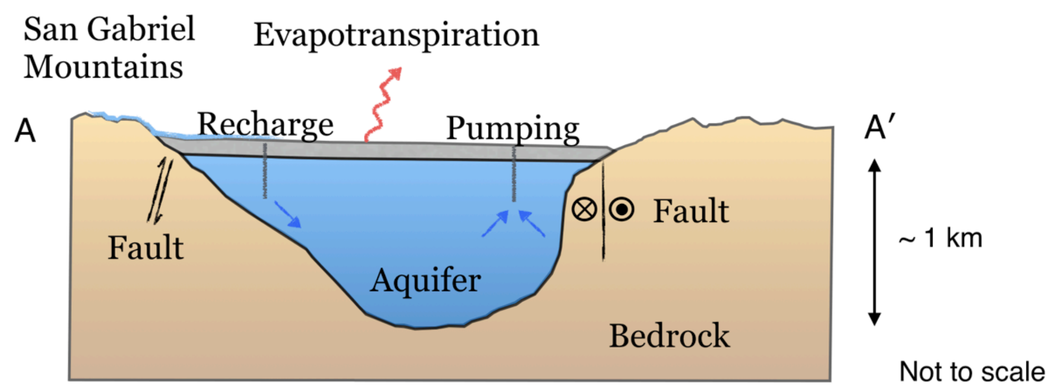


Clements and Denolle, 2018

Monitoring Drought: San Gabriel Valley, CA

Cross-section of the San Gabriel Basin

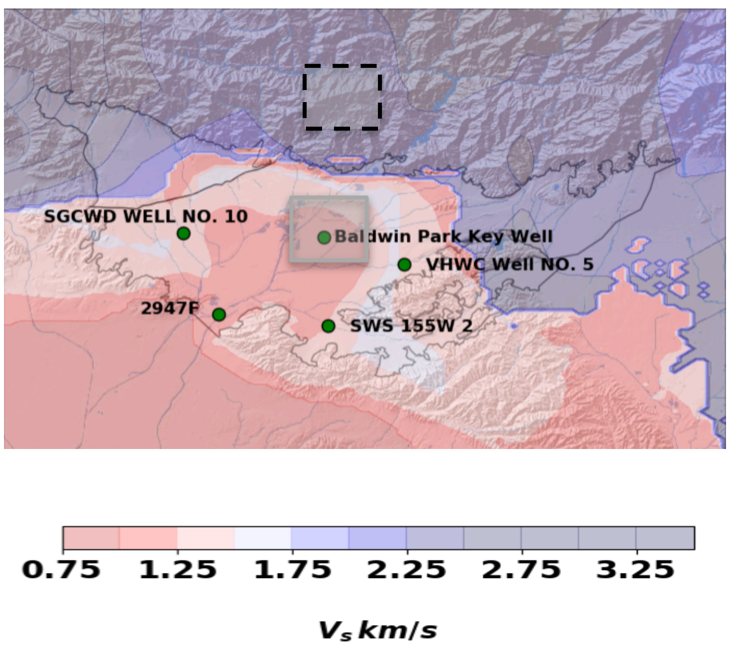


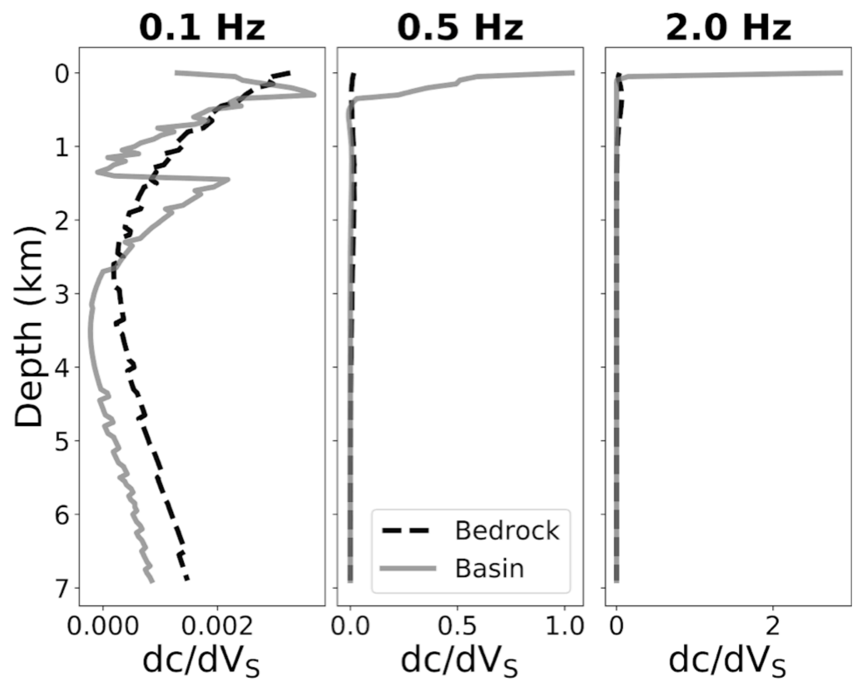


Clements and Denolle, 2018

Monitoring Drought: San Gabriel Basin, CA

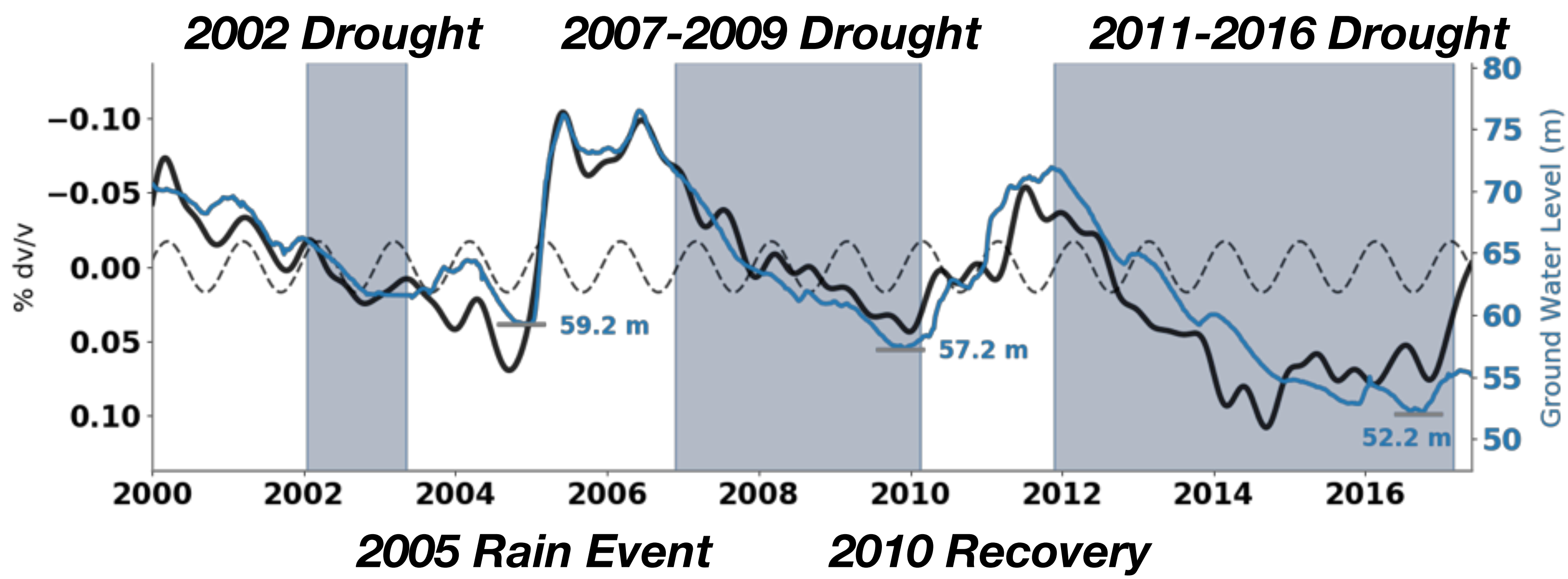
Surface wave frequency-depth sensitivity





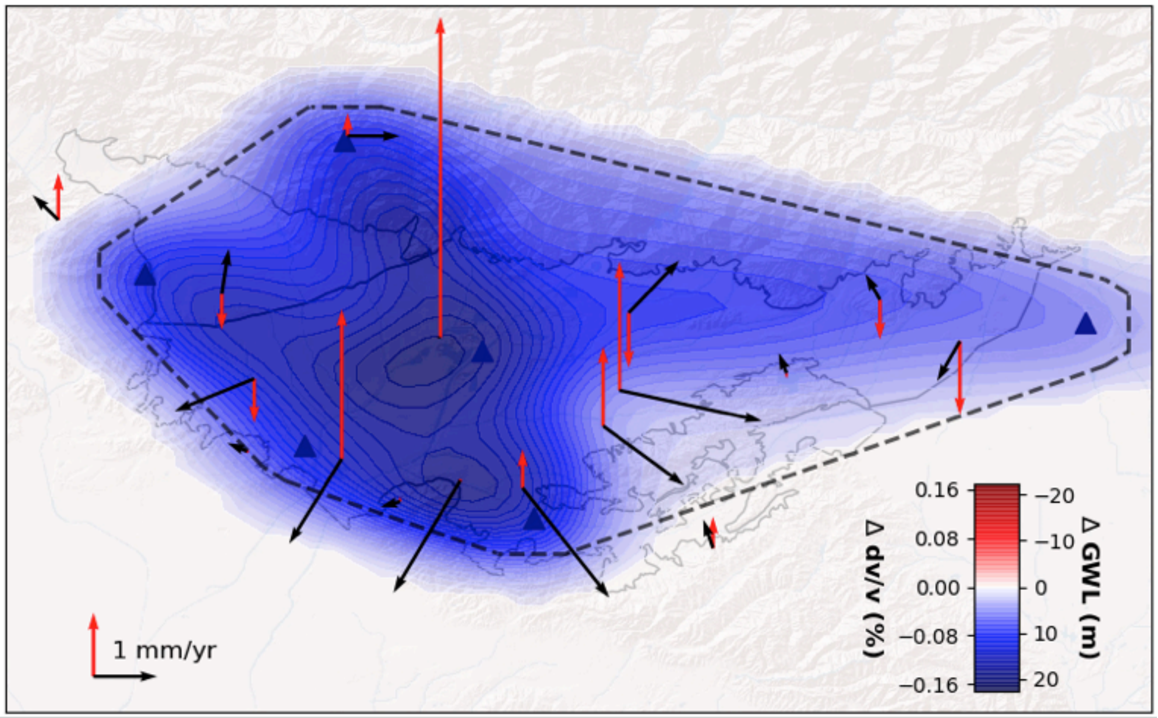
Clements and Denolle, 2018

dv/v: San Gabriel Basin, CA



 Clements and Denolle, 2018

dv/v: San Gabriel Basin Winter 2005

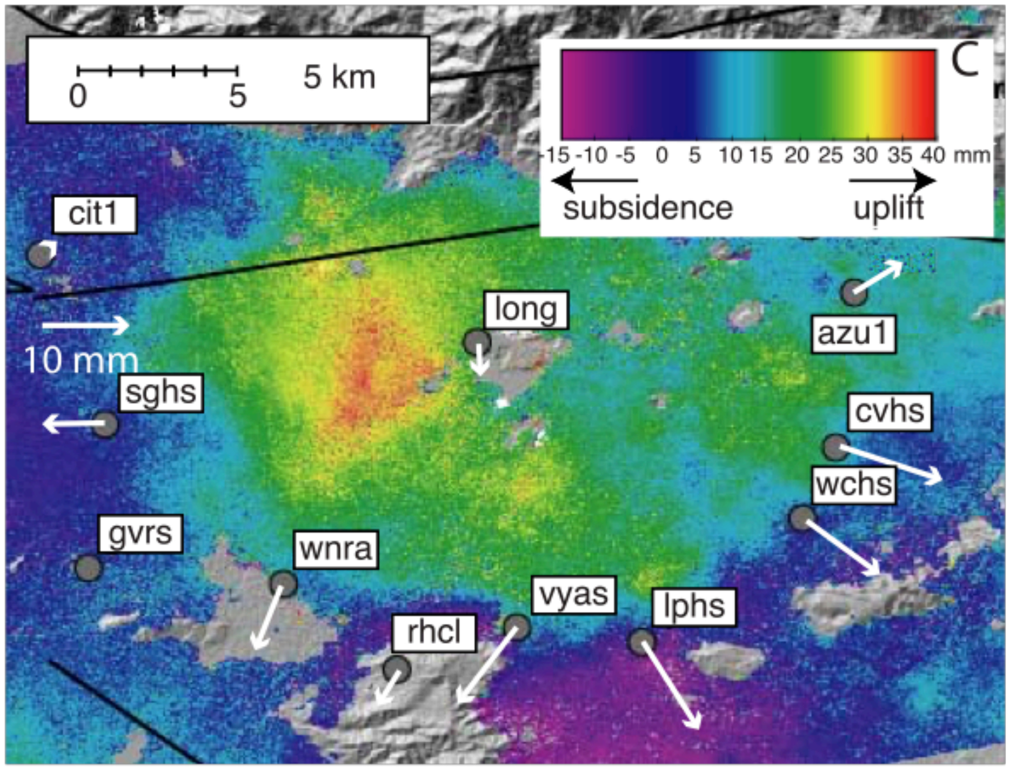


Groundwater levels increase 16 m in 5 months!

dv/v: San Gabriel Valley Basin 2005

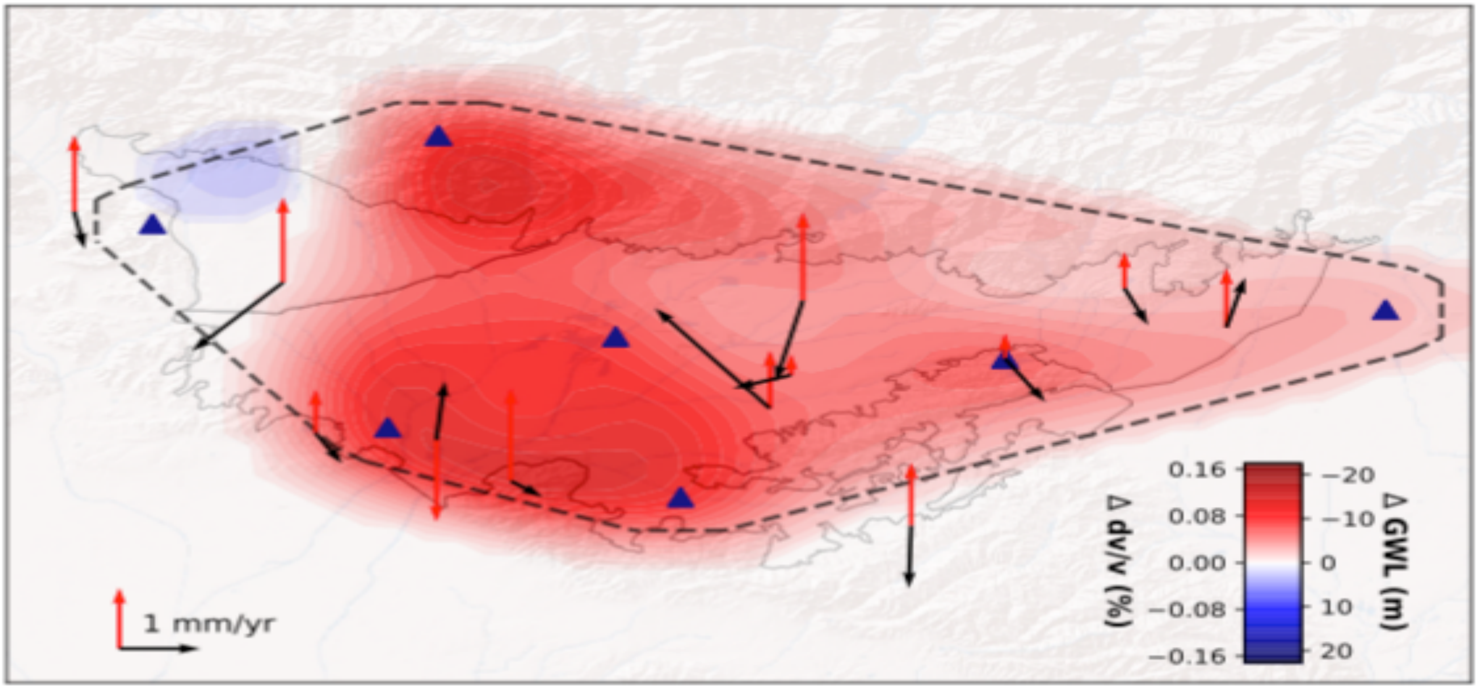
1 m of rainfall in Los Angeles

InSAR
+
GPS



King et al., 2007

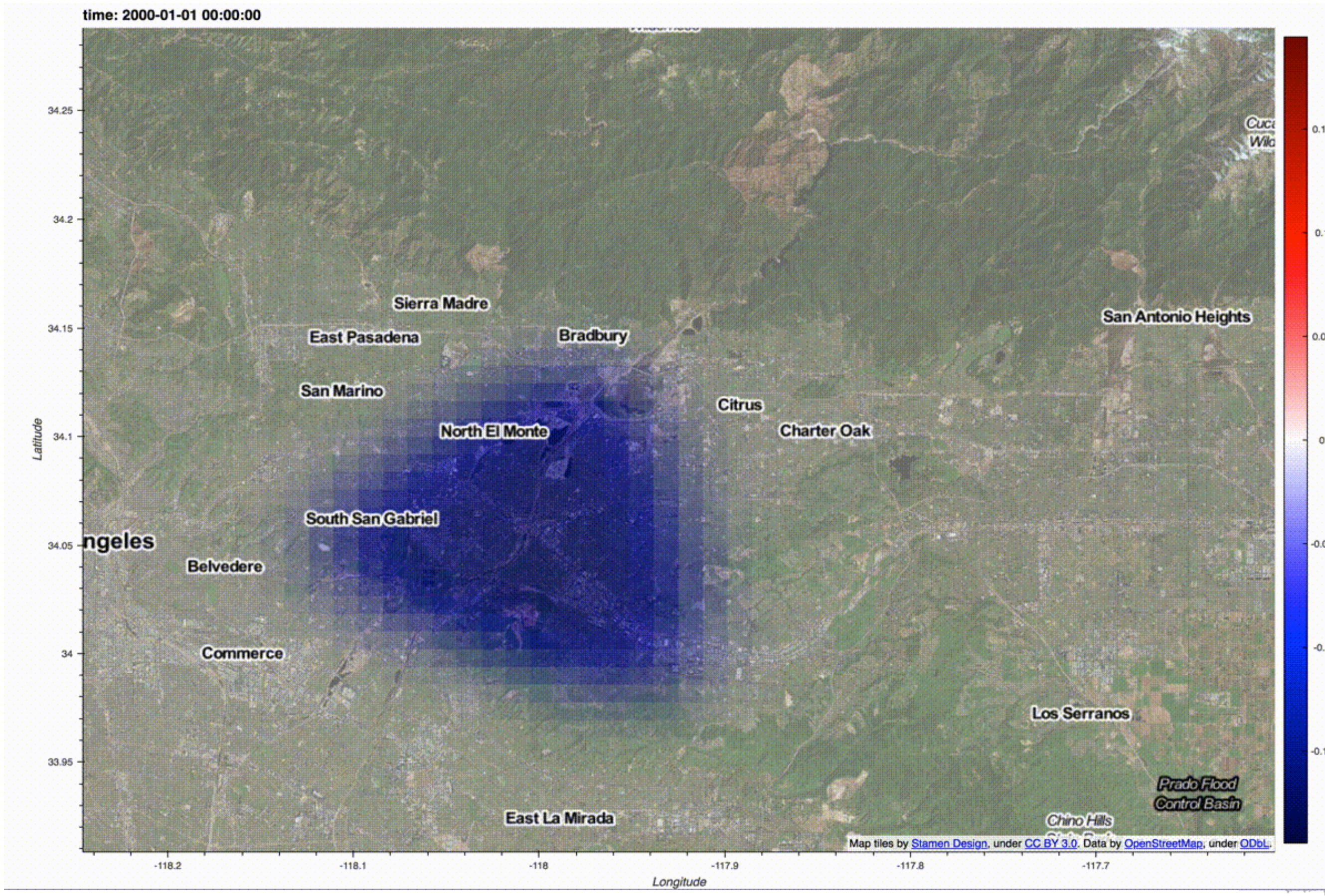
dv/v: San Gabriel Basin, CA



Groundwater levels fall 20 m in 5 years!

Clements and Denolle, 2018

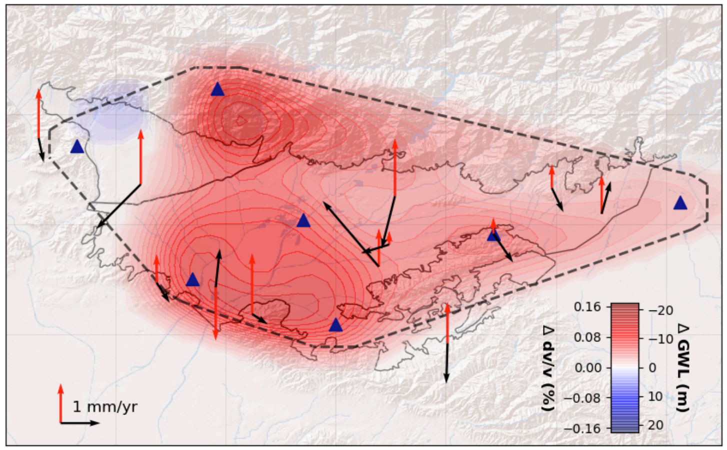
dv/v: San Gabriel Valley, CA



dv/v (%)

dv/v: San Gabriel Valley, CA

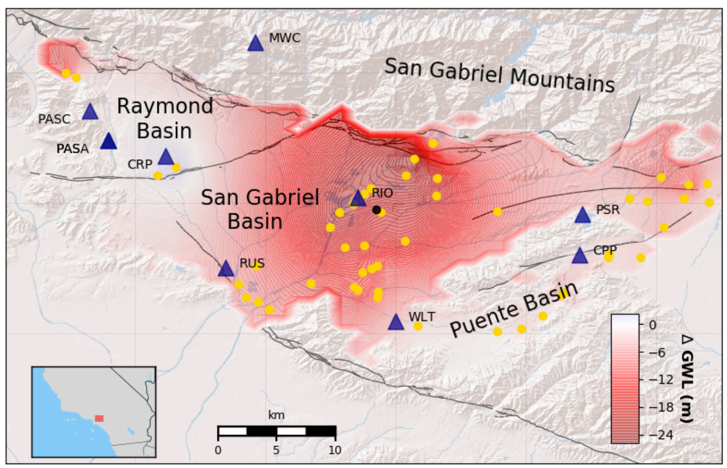
Predictions (dv/v)



Volume loss

$V_W = 0.48\ km^3$

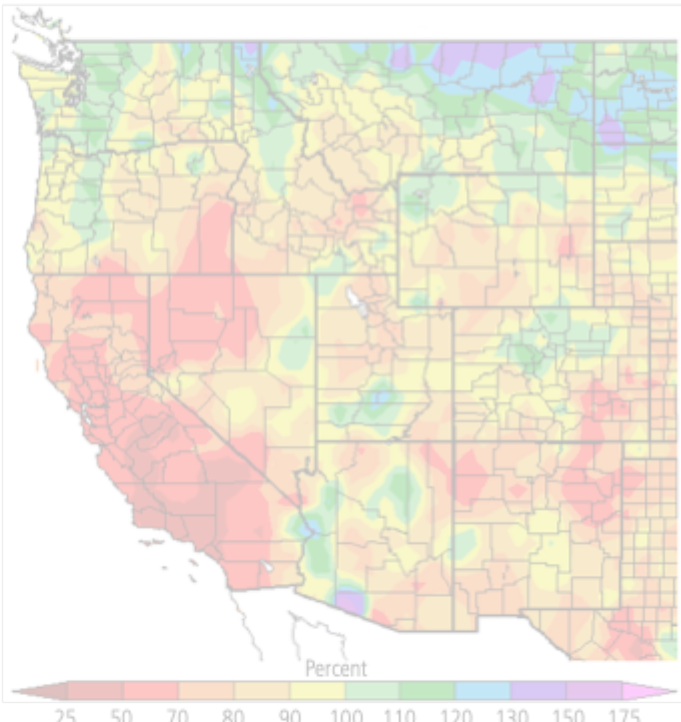
Observations (interpolated wells)



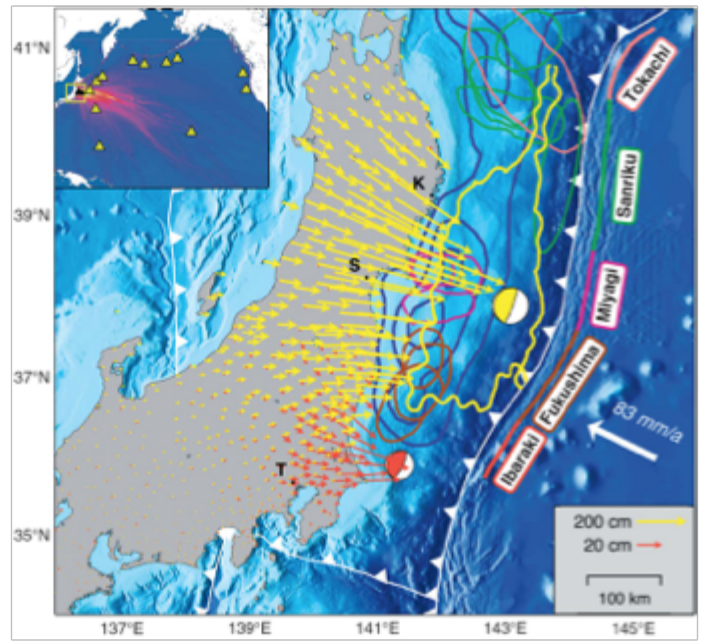
Volume pumped

$V_W = 0.45\text{-}0.5\ km^3$

Seismic Velocity Change: dv/v



Drought

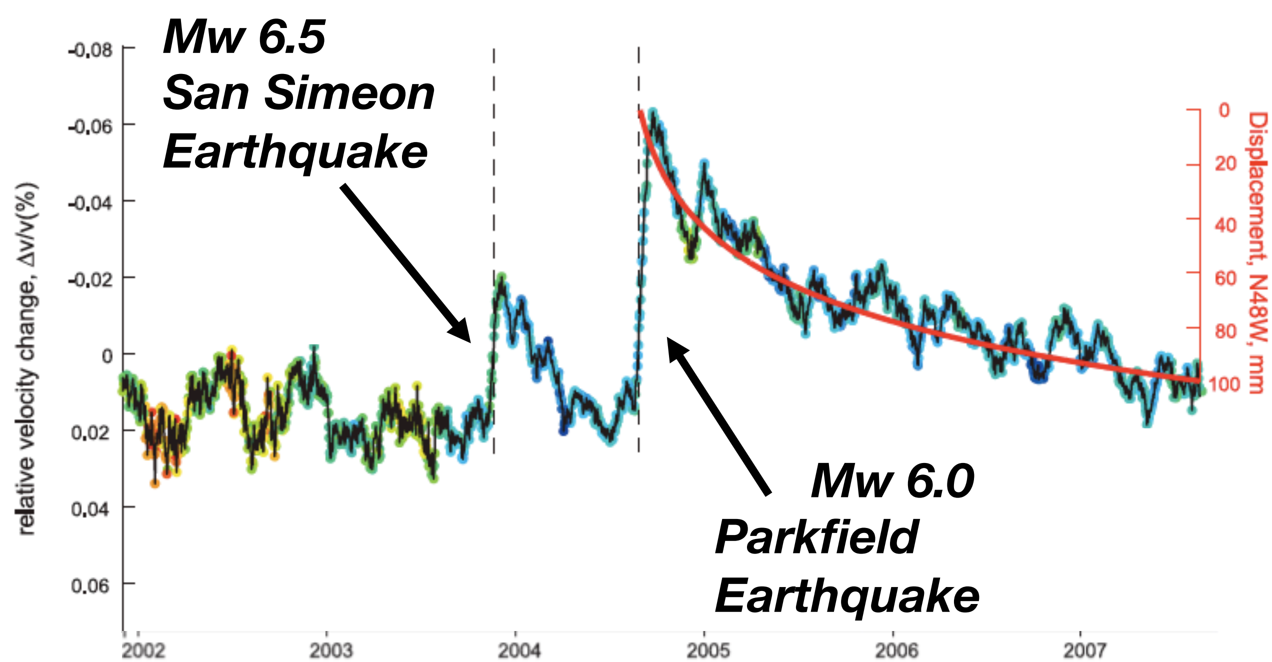


Strong-Motion Response

California DWR; Simons et al., 2011

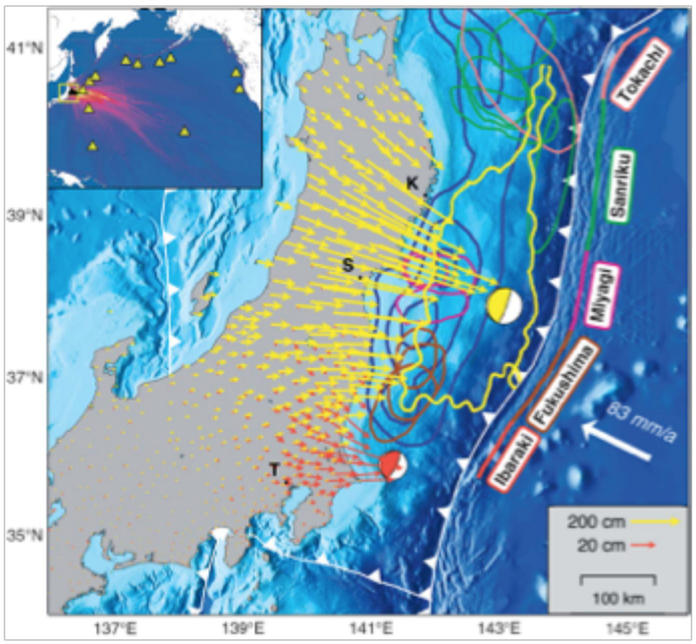
Monitoring Seismic Hazards

dv/v is observed to be ~ -1% after earthquakes

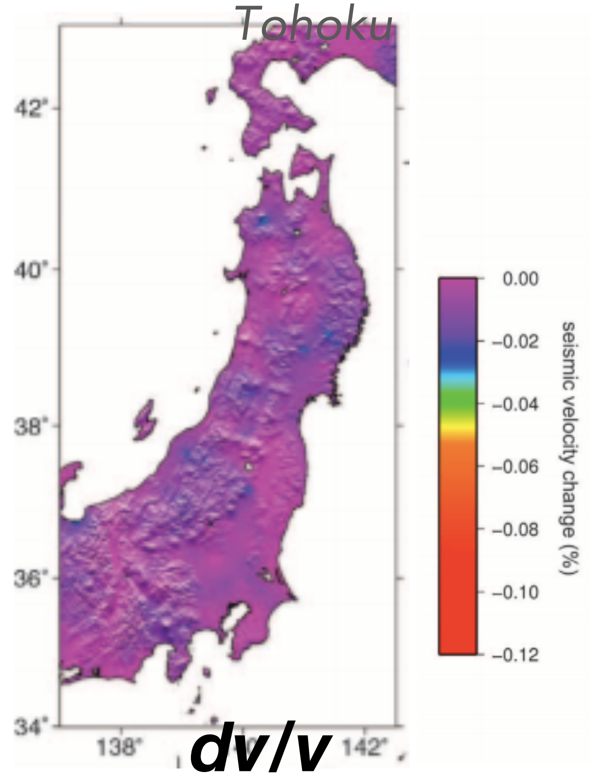


Brenguier et al., 2008

Monitoring Seismic Hazards



2011 Tohoku

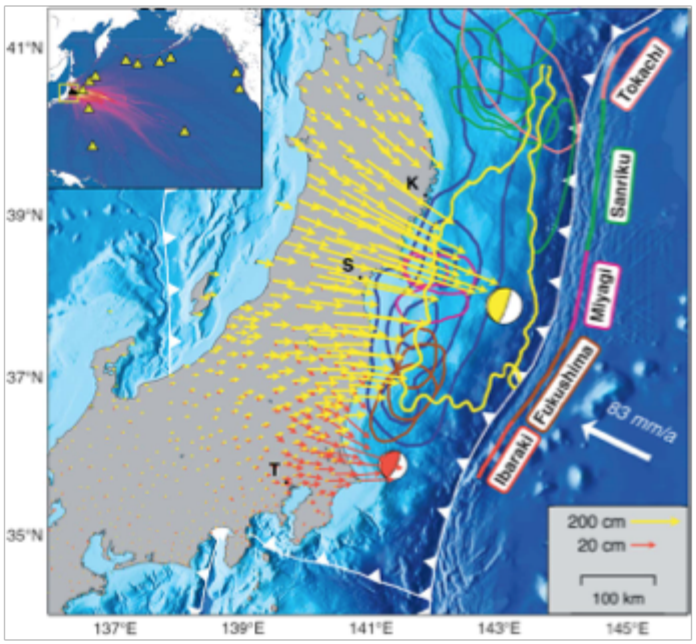


Geodetic

dv/v

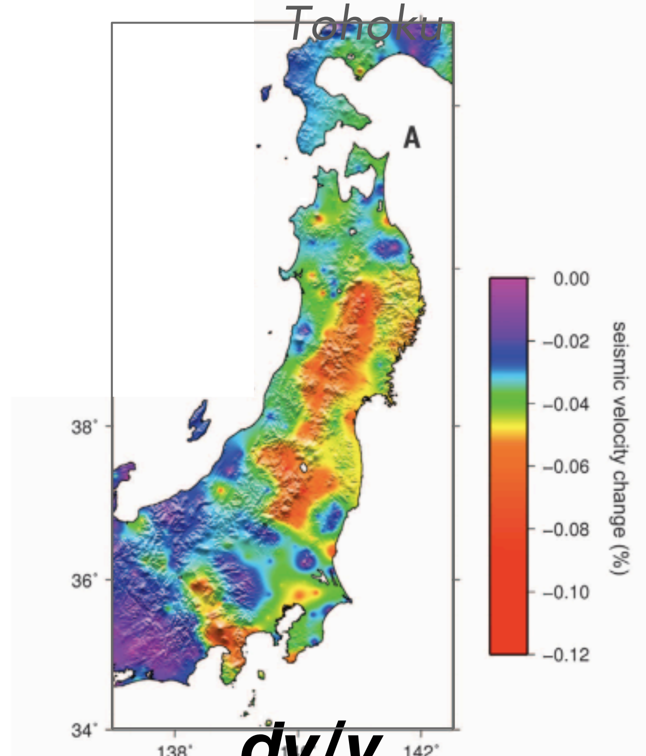
Simons et al., 2011; Brenguier et al., 2014

Monitoring Seismic Hazards



Geodetic

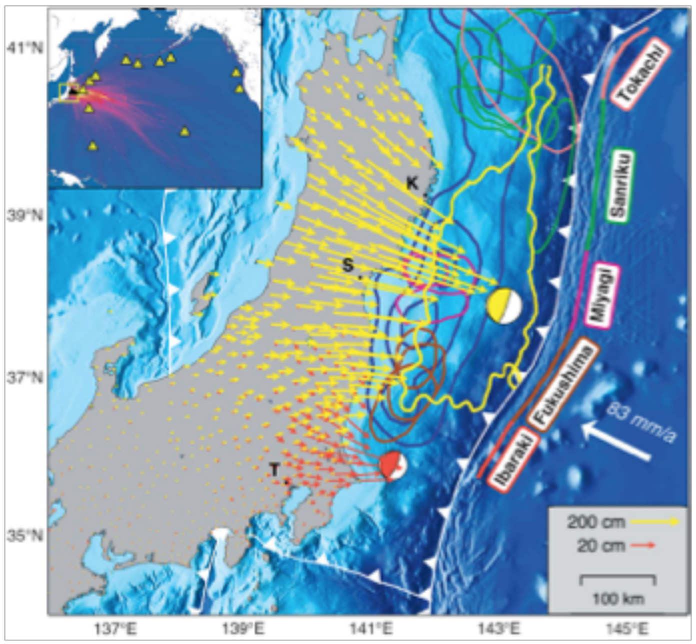
2011 Tohoku

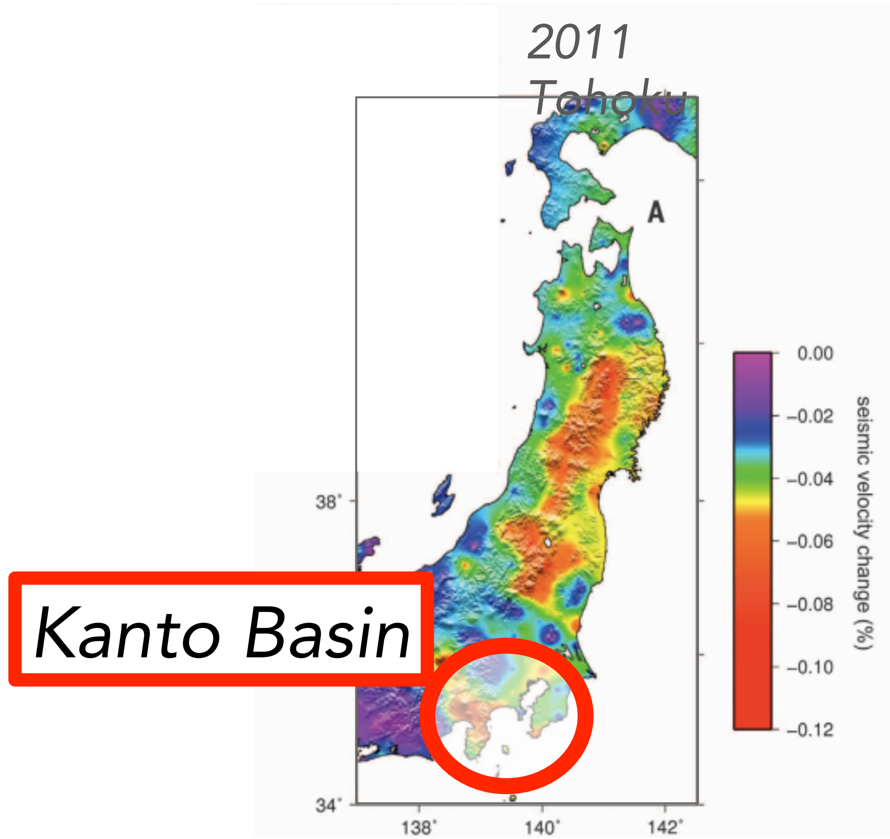


dv/v

Simons et al., 2011; Brenguier et al., 2014

Monitoring Seismic Hazards

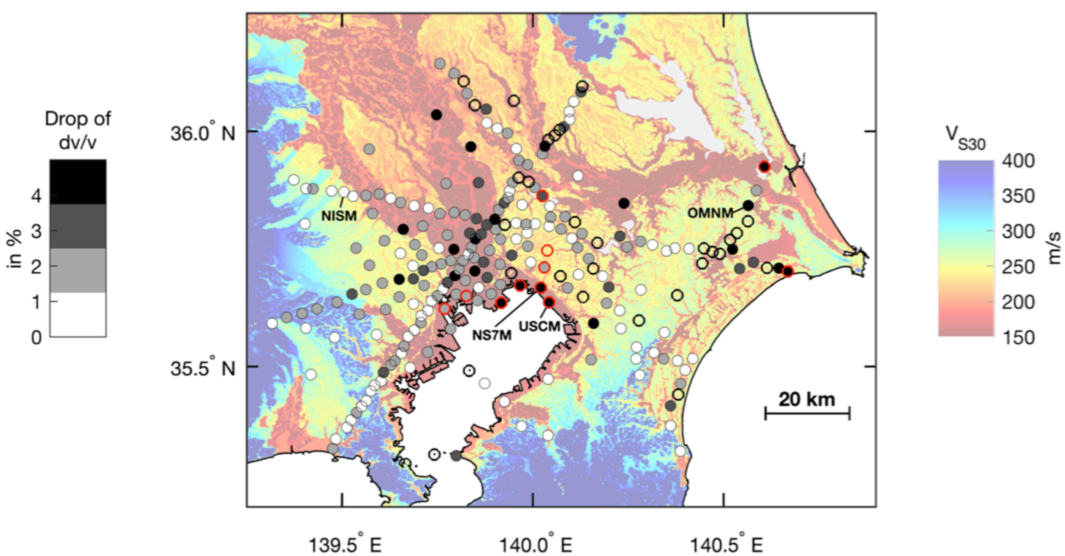




Geodetic

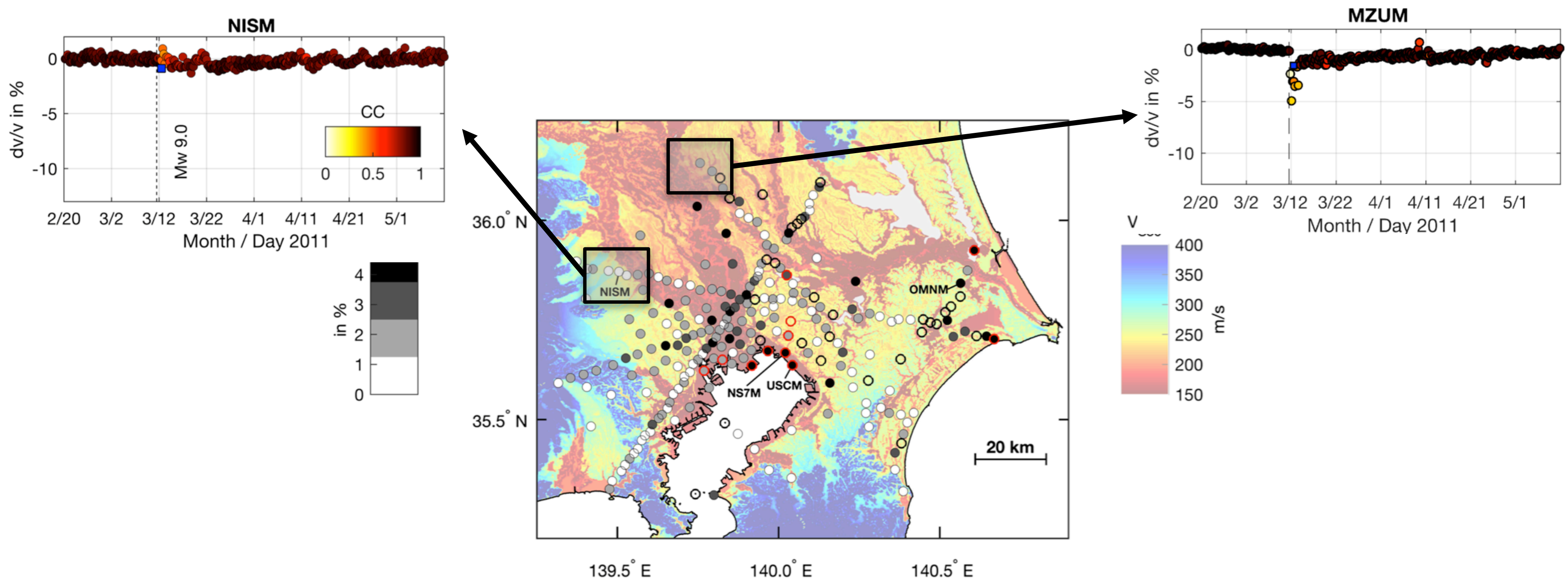
Simons et al., 2011; Brenguier et al., 2014

Monitoring Seismic Hazards: Strong Shaking



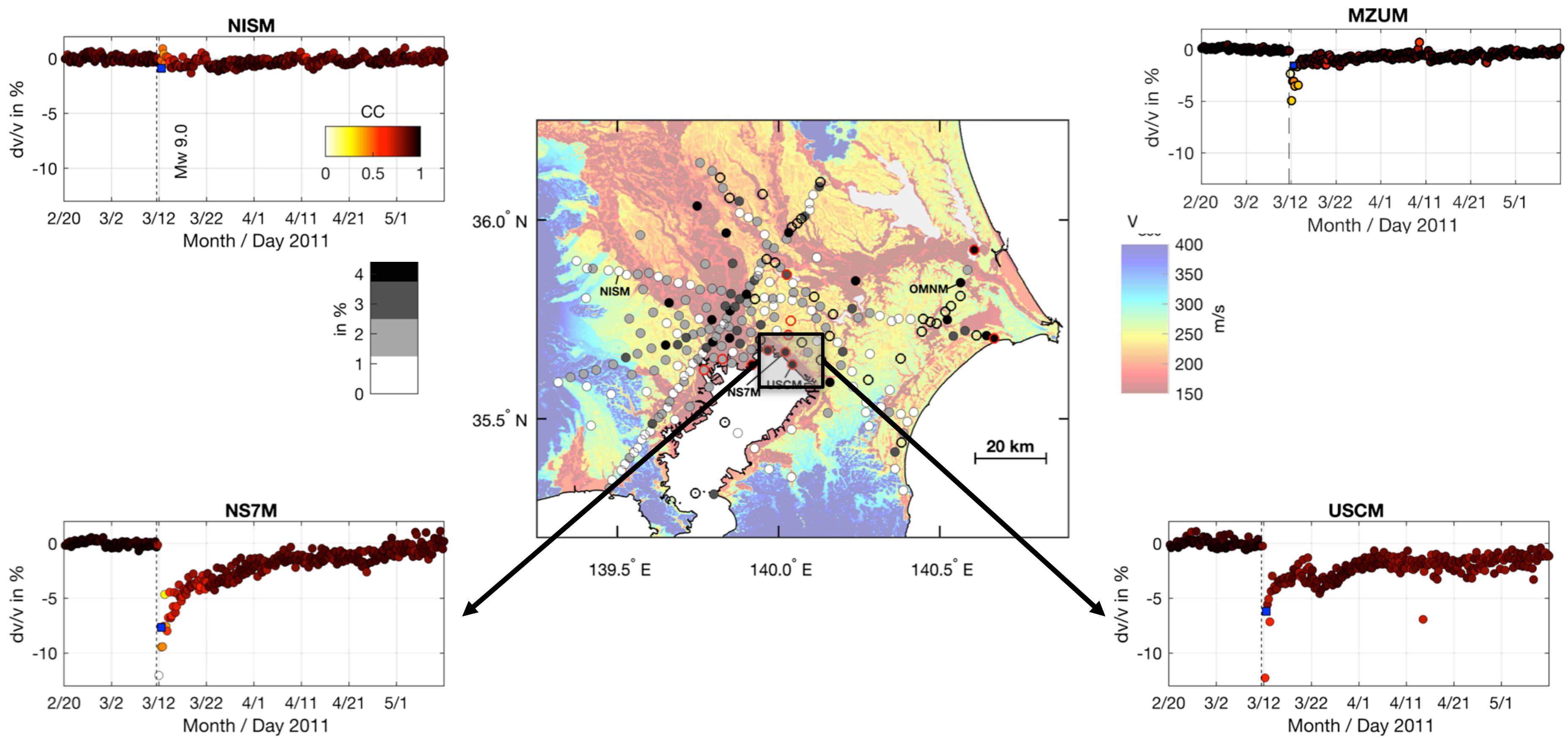
 Viens, Denolle, et al., 2018

Monitoring Seismic Hazards: Strong Shaking



Viens, Denolle, et al., 2018

Monitoring Seismic Hazards: Strong Shaking



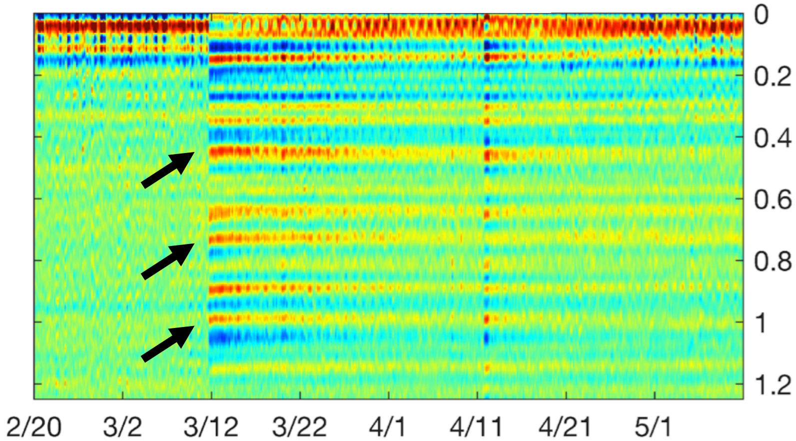
Viens, Denolle, et al., 2018

Monitoring Seismic Hazards

12% of sites are "too" decoherent

↓

Structural change



 Viens, Denolle, et al., 2018

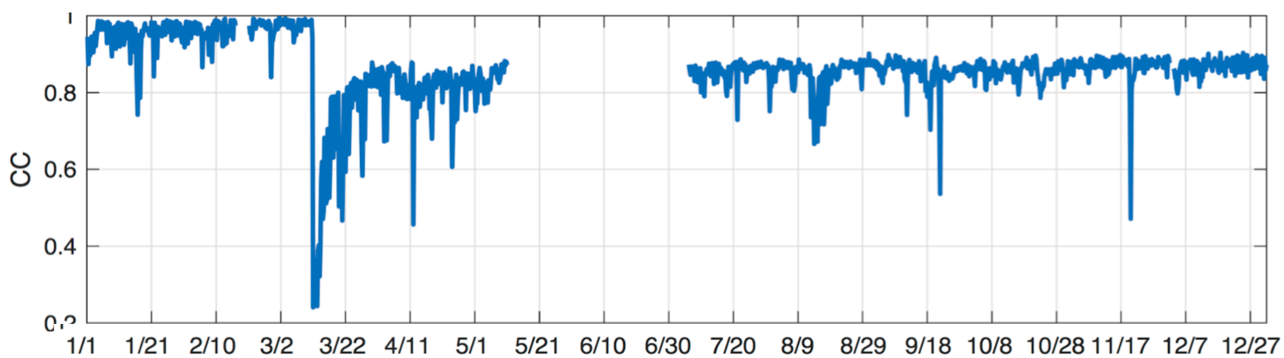
Monitoring Seismic Hazards

12% of sites are "too" decoherent

↓

Structural change

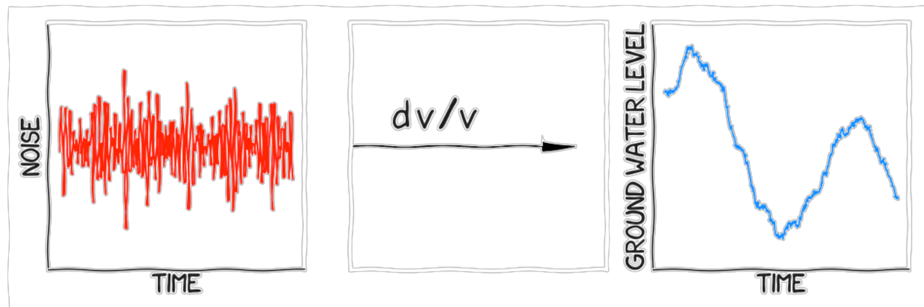
Decoherence and resettling of subsurface



Viens, Denolle, et al., 2018

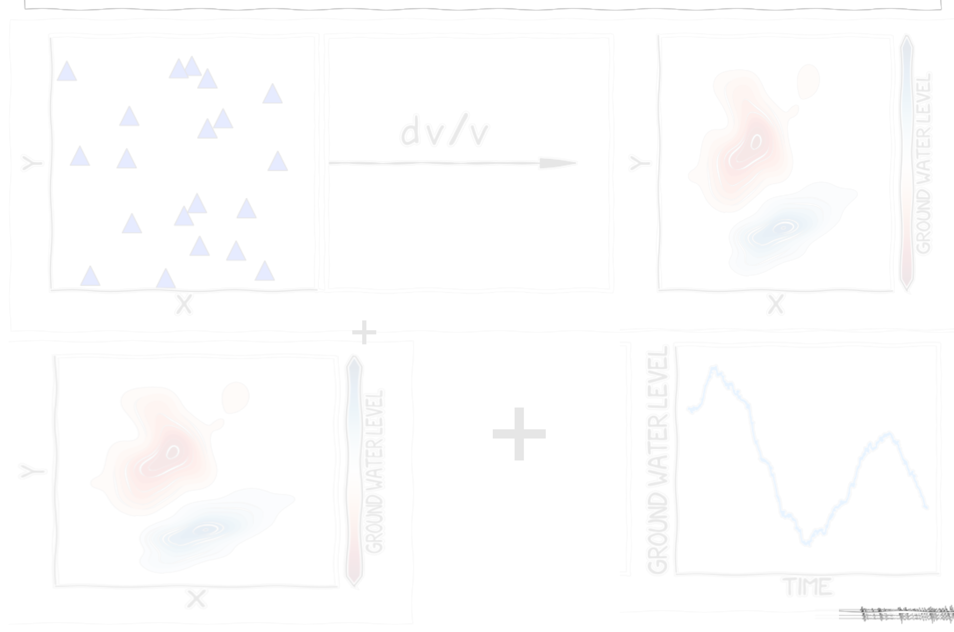
Monitoring the subsurface with Seismic Noise

1.Time



2. Space

3. 4D monitoring

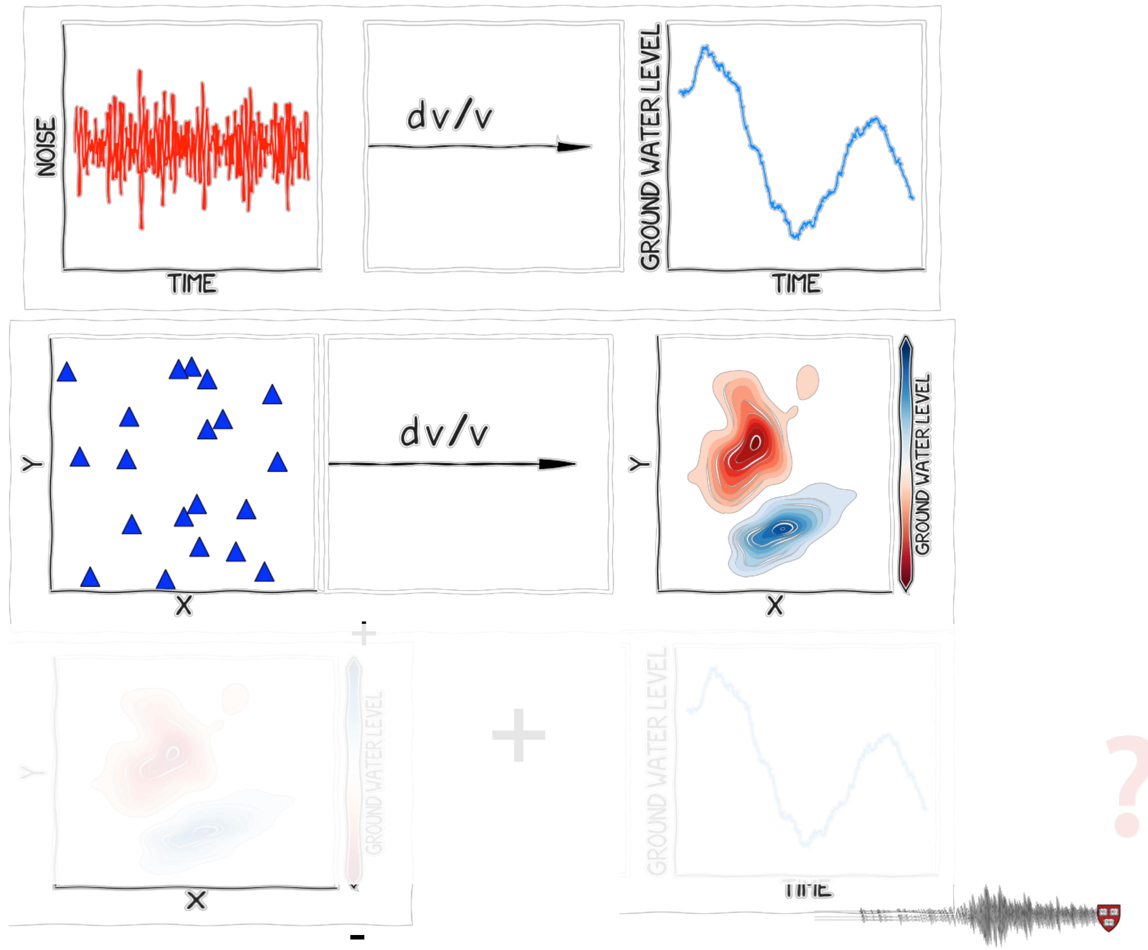


Monitoring the subsurface with Seismic Noise

1.Time

2. Space

3. 4D monitoring

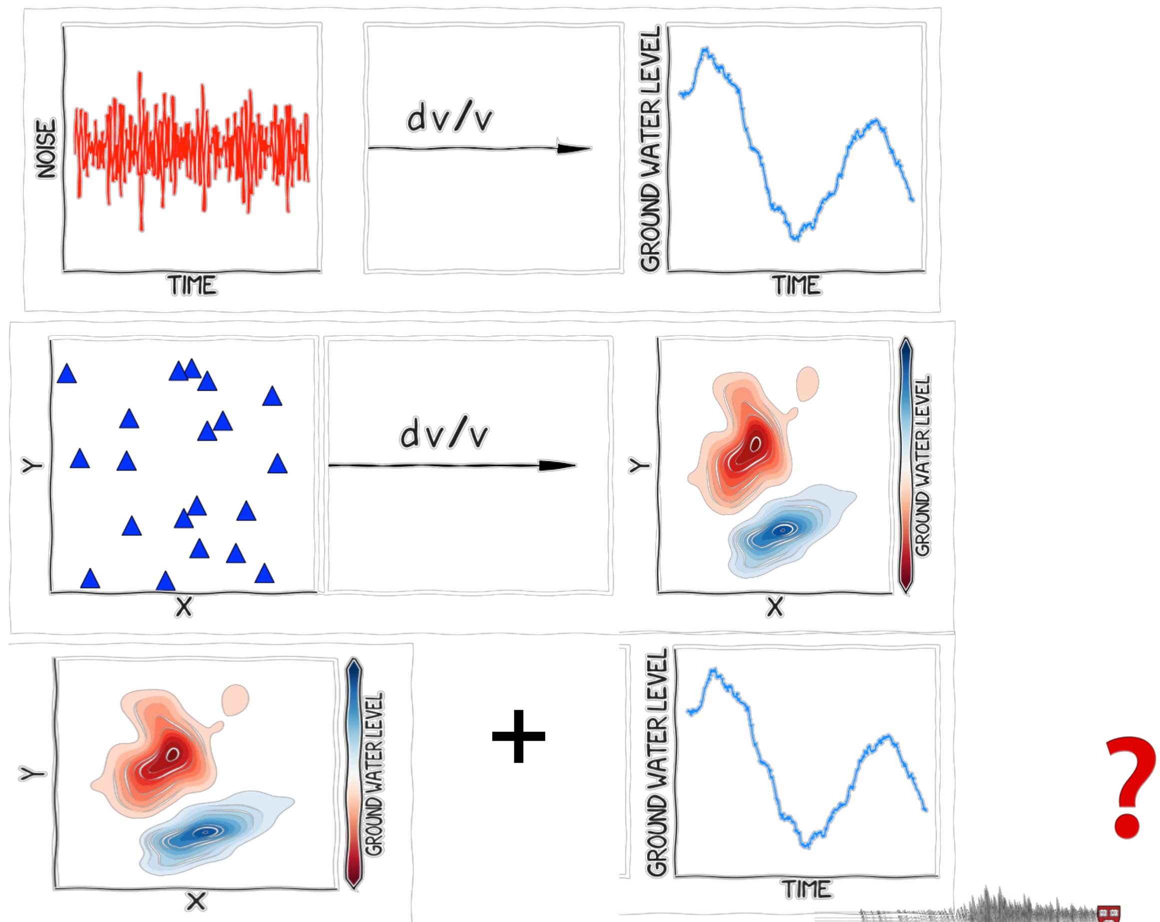


Monitoring the subsurface with Seismic Noise

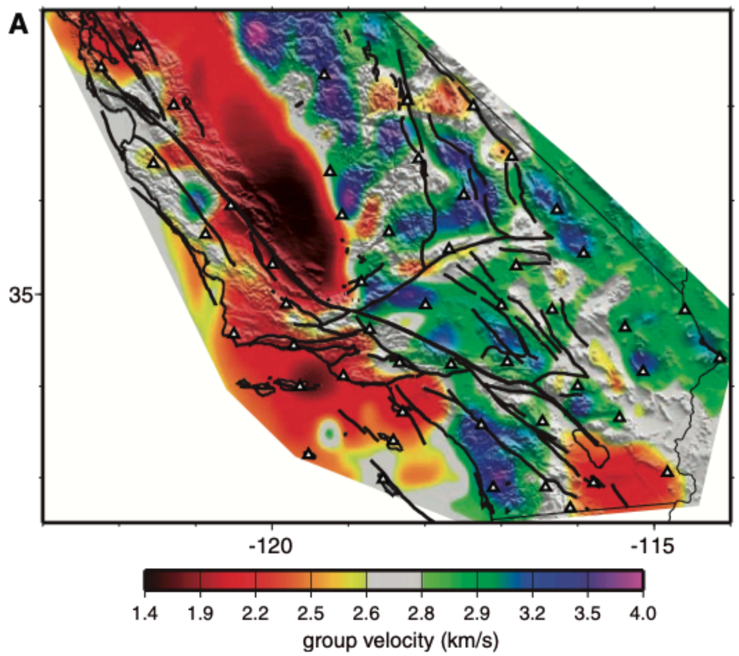
1.Time

2. Space

3. 4D monitoring



dv/v: Groundwater monitoring in Southern California



Static Noise Tomography

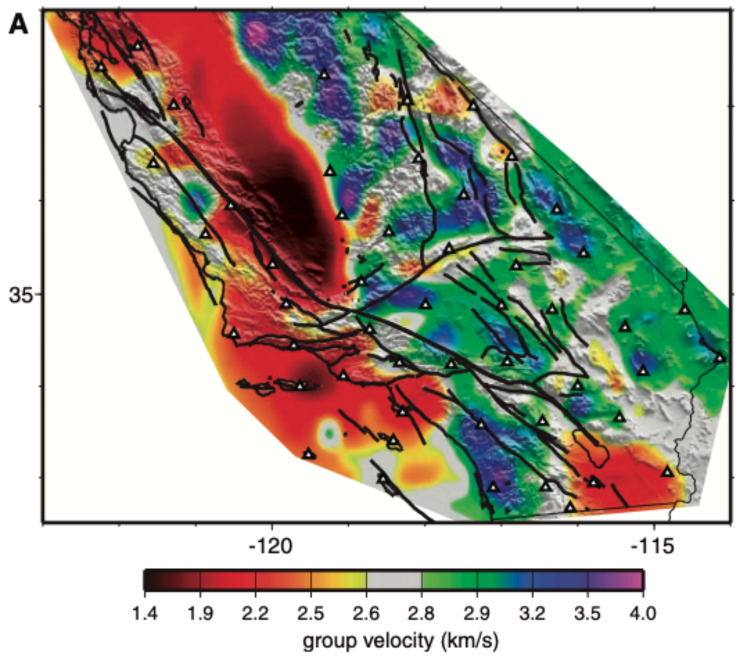
62 stations - 1 month

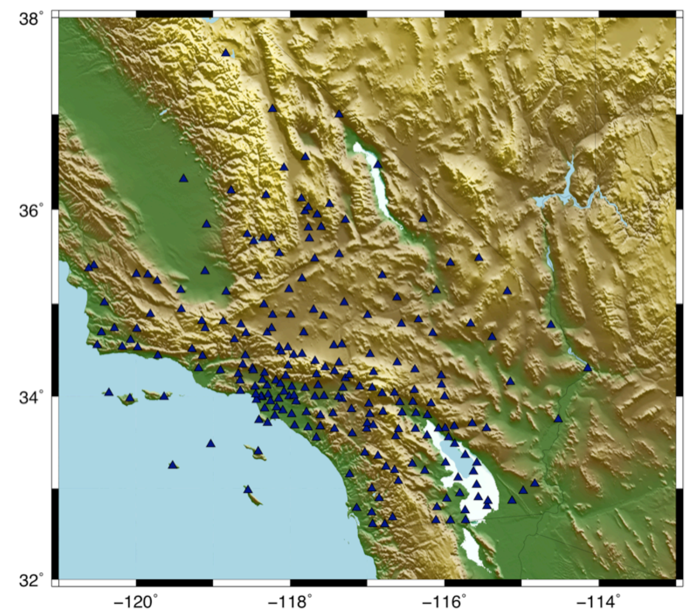
4D Noise Monitoring

250+ stations - 20 years

Shapiro et al., 2005

dv/v: Groundwater monitoring in Southern California





Static Noise Tomography

62 stations - 1 month

4D Noise Monitoring

250+ stations - 20 years

Shapiro et al., 2005

Data Download on the Cloud

SCEDC
SOUTHERN CALIFORNIA EARTHQUAKE DATA CENTER

Registry of Open Data on AWS

Southern California Earthquake Data

earthquake observation · earthquakes · seismology

Description

This dataset contains ground motion velocity and acceleration seismic waveforms recorded by the Southern California Seismic Network (SCSN) and archived at the Southern California Earthquake Data Center (SCEDC).

Update Frequency

Daily

License

SCEDC herby grants the non-exclusive, royalty free, non-transferable, worldwide right and license to use, reproduce and publicly display in all media public data from the Southern California Seismic Network. Please cite the SCEDC (doi:10.7909/C3WD3xH1) and SCSN (doi:10.7914/SN/CI) for any research publications using this data.

Documentation

https://scedc.caltech.edu/cloud/

Managed By

Southern California Earthquake Data Center

See all datasets managed by Southern California Earthquake Data Center.

Resources on AWS

Description
Seismic waveform data (miniSEED format)

Resource type
S3 Bucket

Amazon Resource Name (ARN)
`arn:aws:s3:::scedc-pds`

AWS Region
`us-west-2`

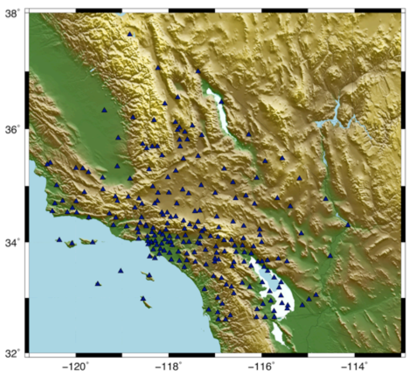
Data Download on the Cloud

SCEDC SOUTHERN CALIFORNIA EARTHQUAKE DATA CENTER

Registry of Open Data on AWS

Southern California Earthquake Data

earth observation | earthquakes | seismology



100+ TB Data

S3

Unlimited Compute

EC2

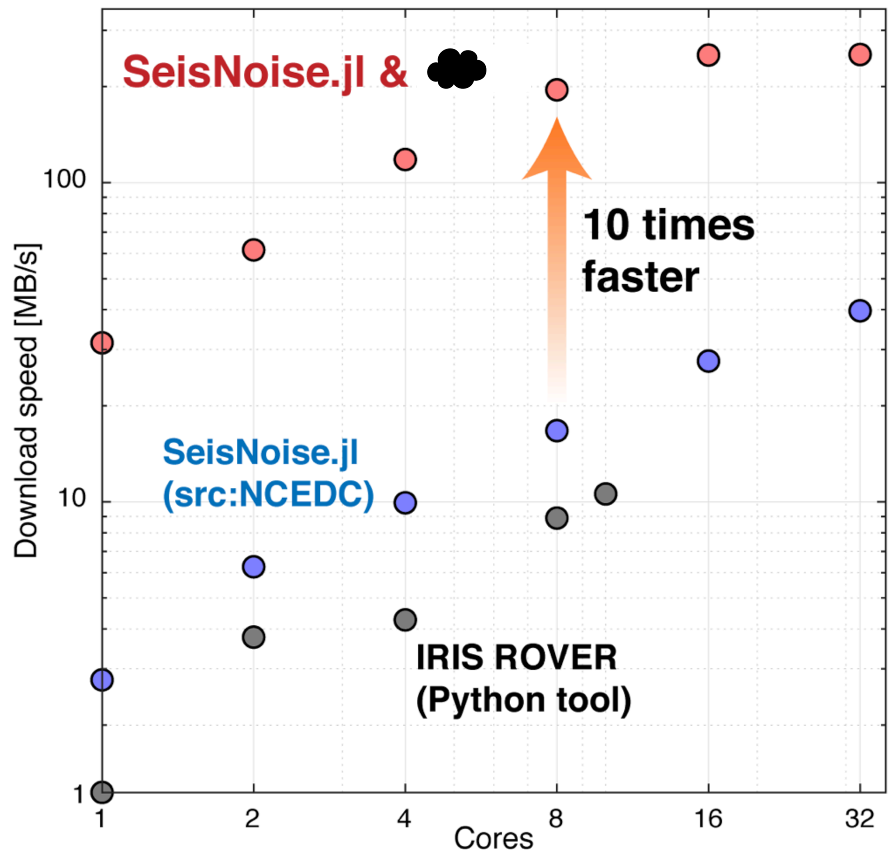
Data Download on the Cloud

Waveforms downloads are

10 - 100x

faster on cloud

Clements et al., in prep



What is needed to monitor with Seismic Noise?

Long-term measurements

→ ***Permanent** installations*

Denser instrumentation

→ ***Dense** station spacing, **high** sample rates*

High-performance data sharing and computing

→ ***Cloud** storage and processing*

Thank you!