EARTHQUAKE DYNAMICS
and
the PREDICTION of STRONG GROUND MOTION

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Different scales in earthquake dynamics

BB Seismic waves

(< 0.3 Hz λ> 5 km)

Macroscale

Hifi Seismic waves

(>0.5 Hz λ<2 km)

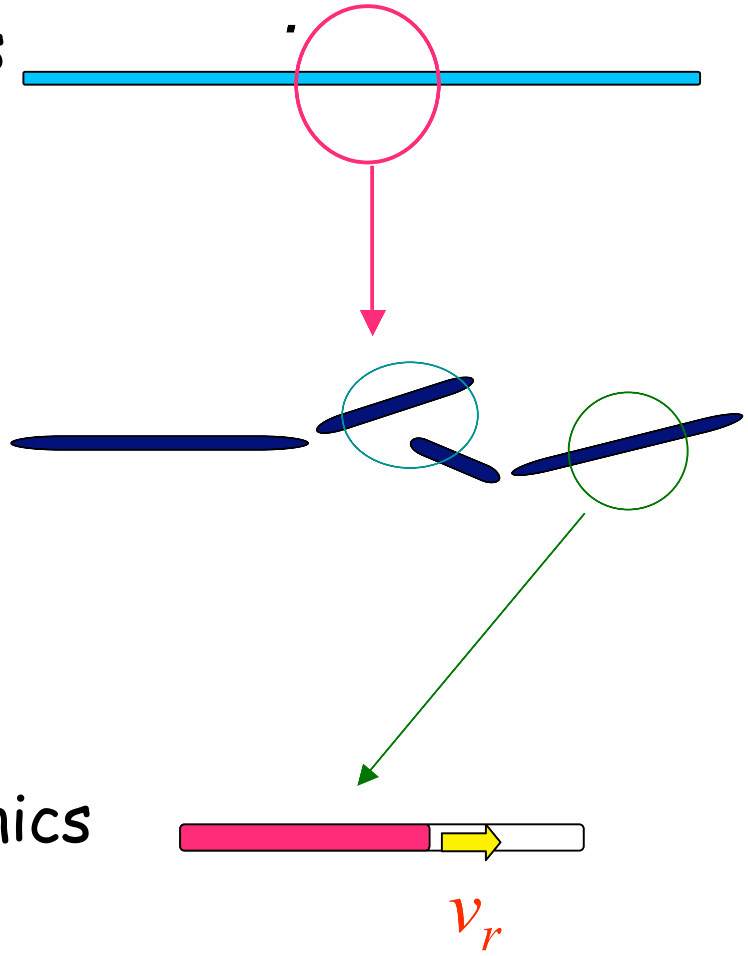
Mesoscale

Steady state mechanics

(non-radiative)

(λ< 100 m)

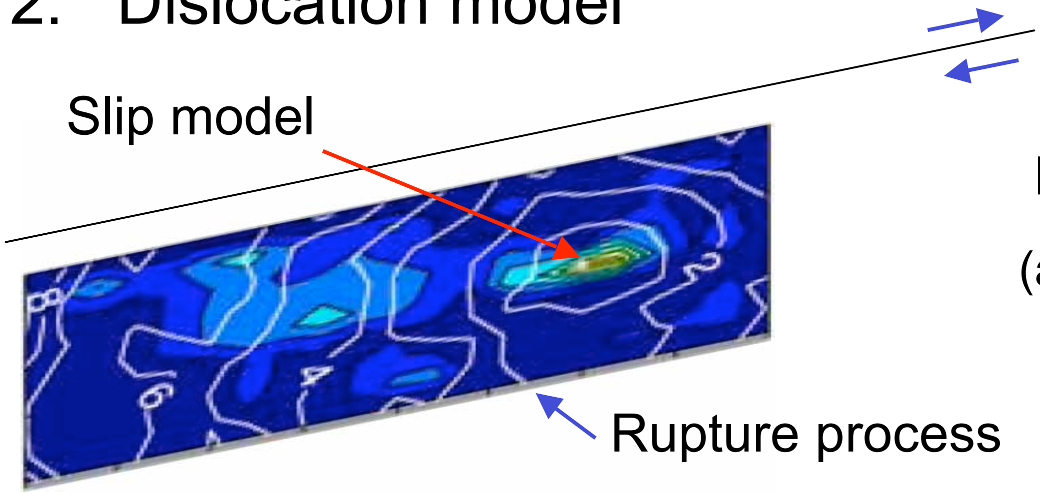
Microscale



Kinematic modeling

1. Elastic model + attenuation

2. Dislocation model



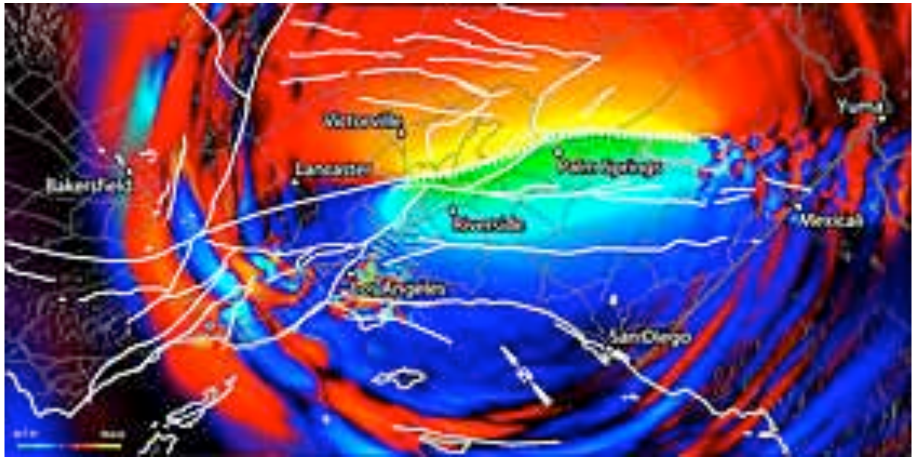
Parkfield 2004

(after Liu et al 2006)

3. Modeling program (and, of course a BIG computer)

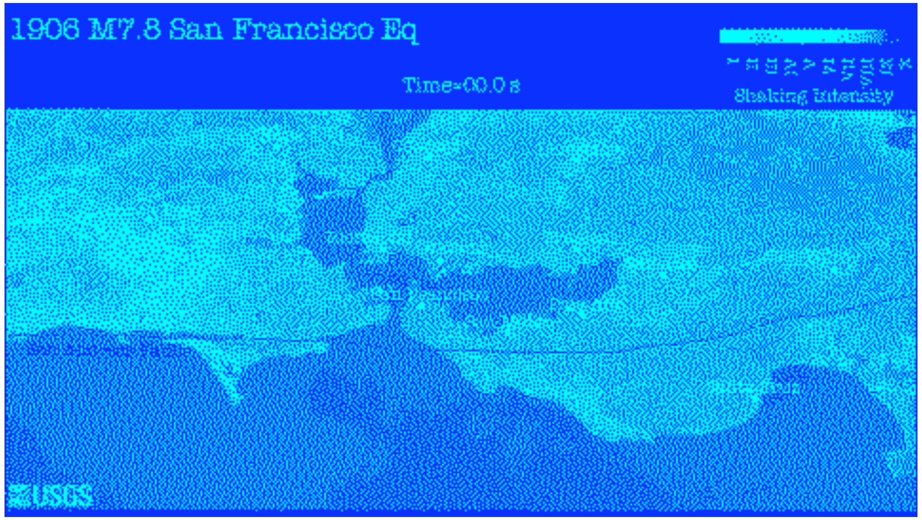
4. Seismic data

Macromodels for very large earthquakes



Terashake 2.1

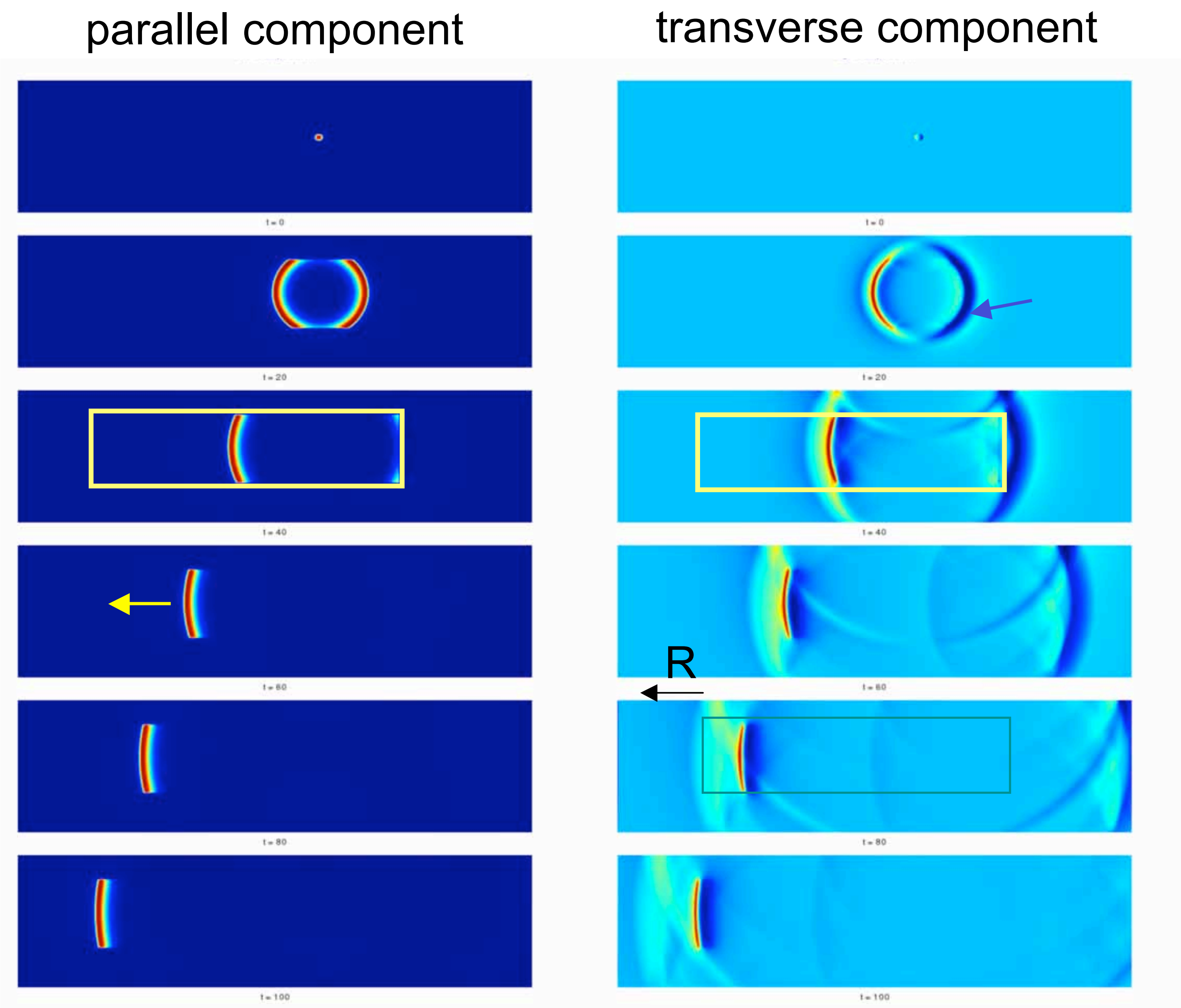
(Olsen, et al 2006)



San Francisco 1906

(Aagaard et al, 2006)

Modelling the classical Haskell model



Staggered

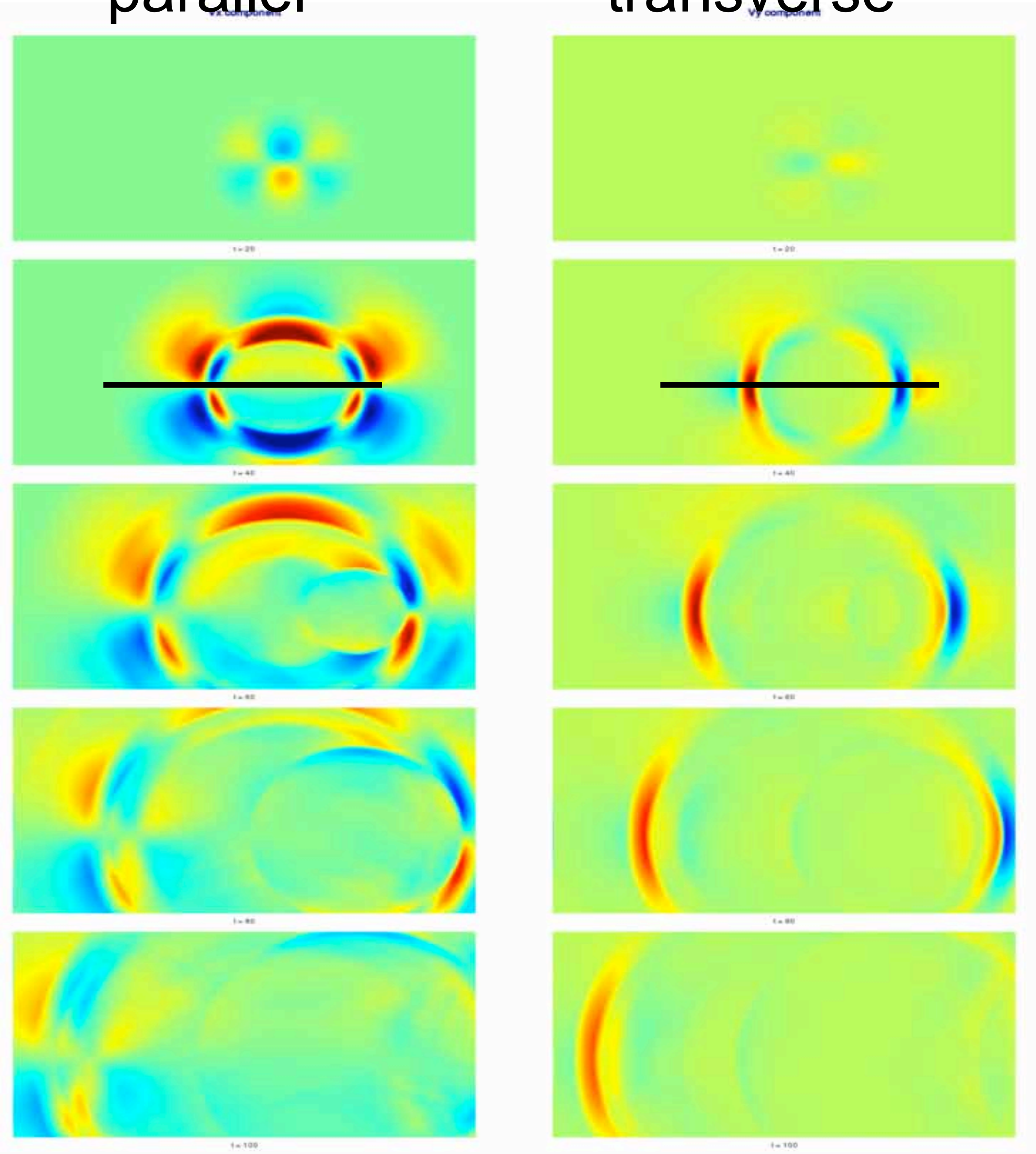
Grid FD

dx=100 m

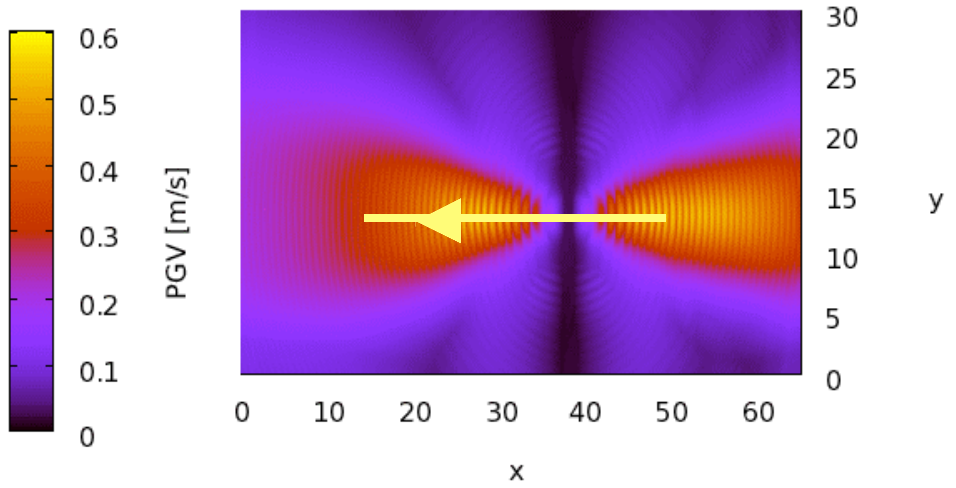
600x600x200

Surface velocities for Haskell model

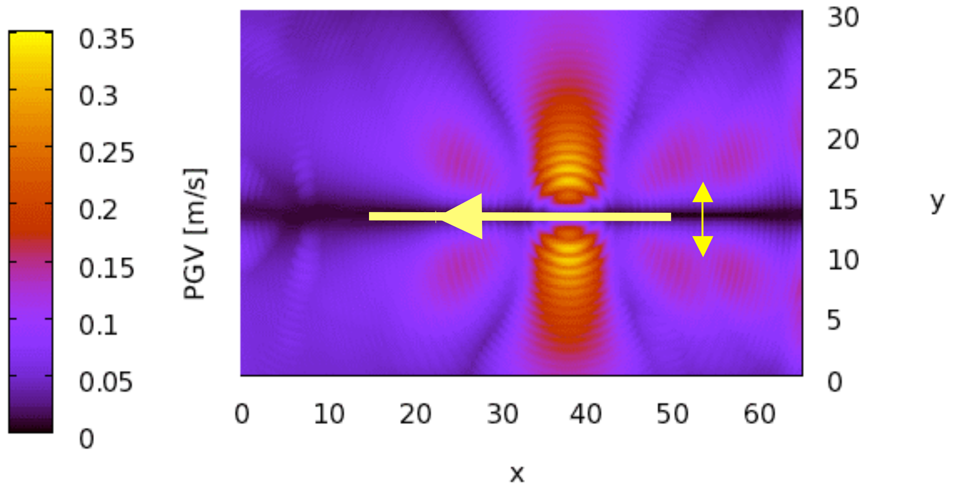
parallel transverse



Peak ground velocities for a Haskell-like model

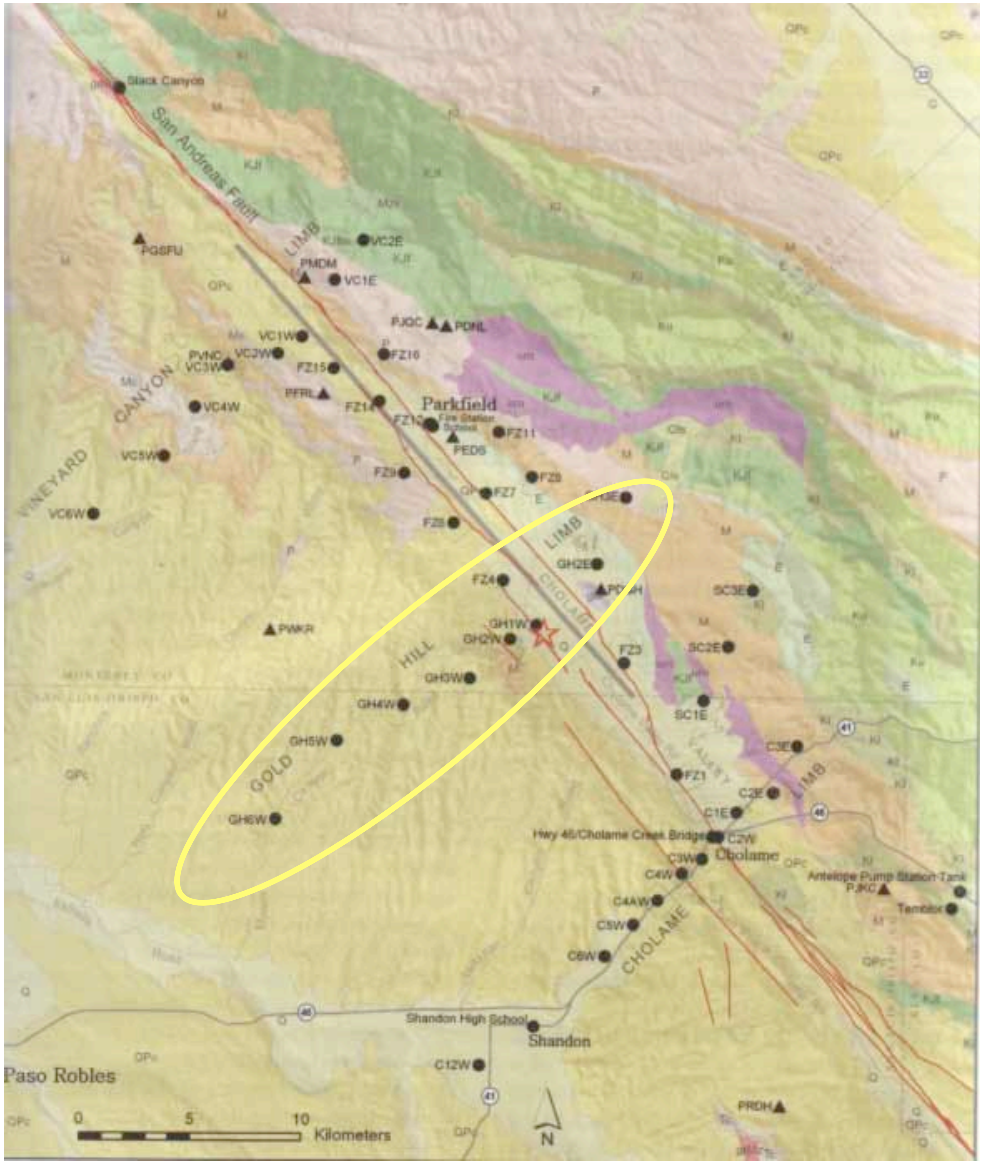


Transverse component



Parallel component

Wave propagation around and on a fault



Parkfield 2004

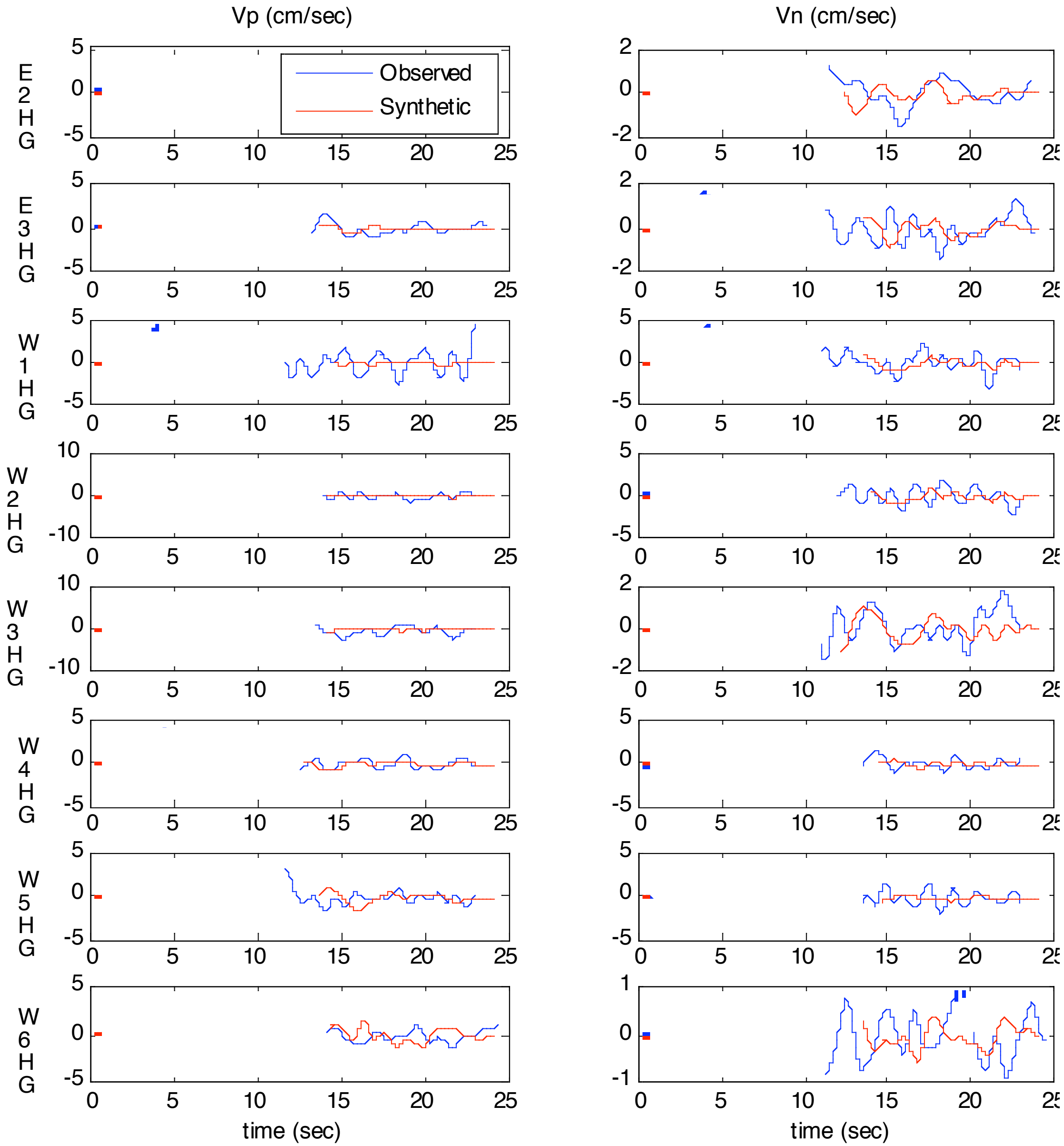
Kinematic model by
Liu, Custodio and
Archuleta (2006)

Modeling by Finite
Differences
Staggered grid
Thin B.C.

Full 4th order in space
No damping
dx=100m dt=0.01 Hz
Computed up to 3 Hz

Few hours in intel linux cluster

Parkfield 2004

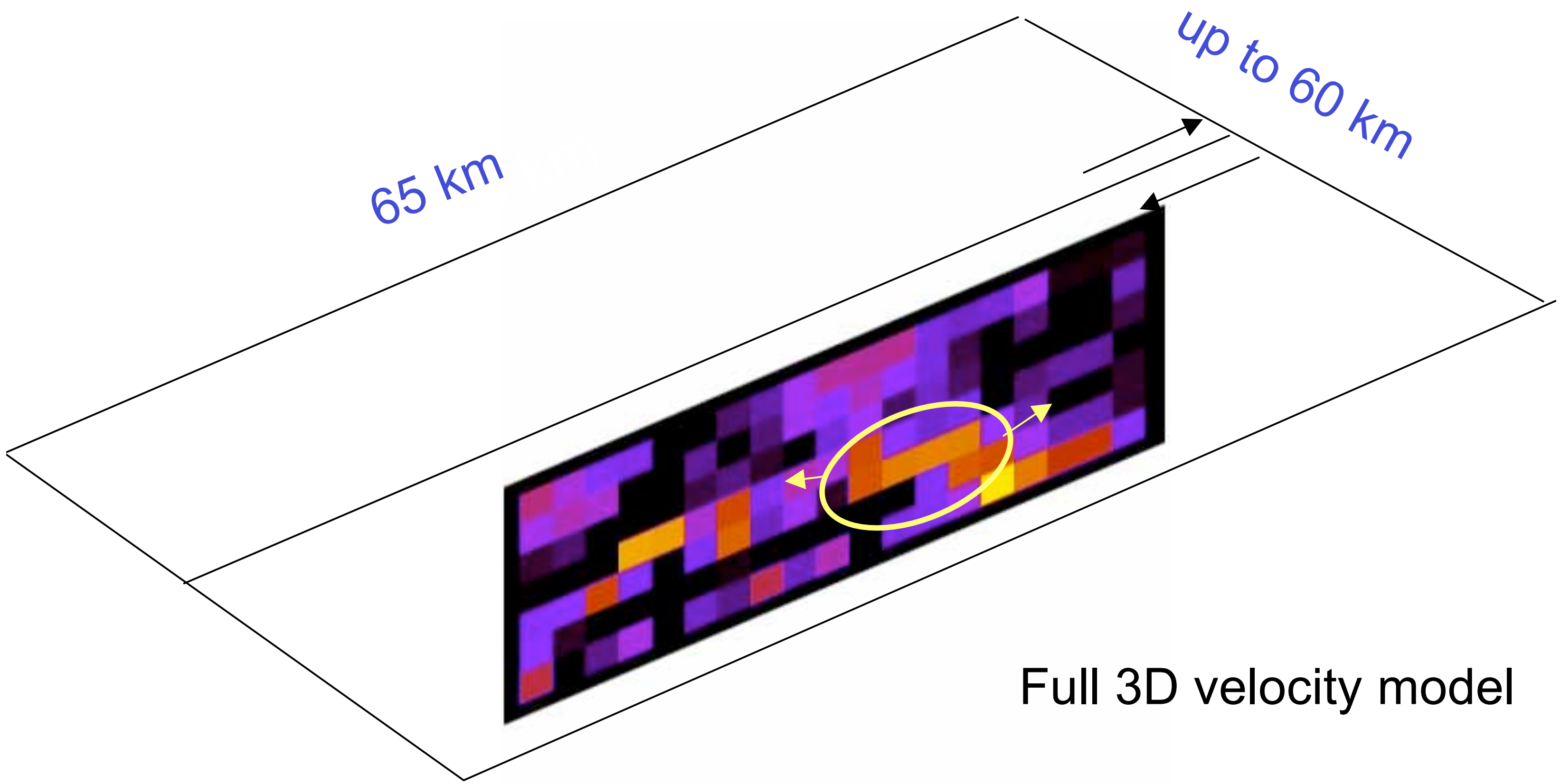


Data high pass filtered to 1 Hz.

Synthetics computed For the slip model of Liu et al up to 3Hz On a 100 m grid

Structure from Chen Ji 2005

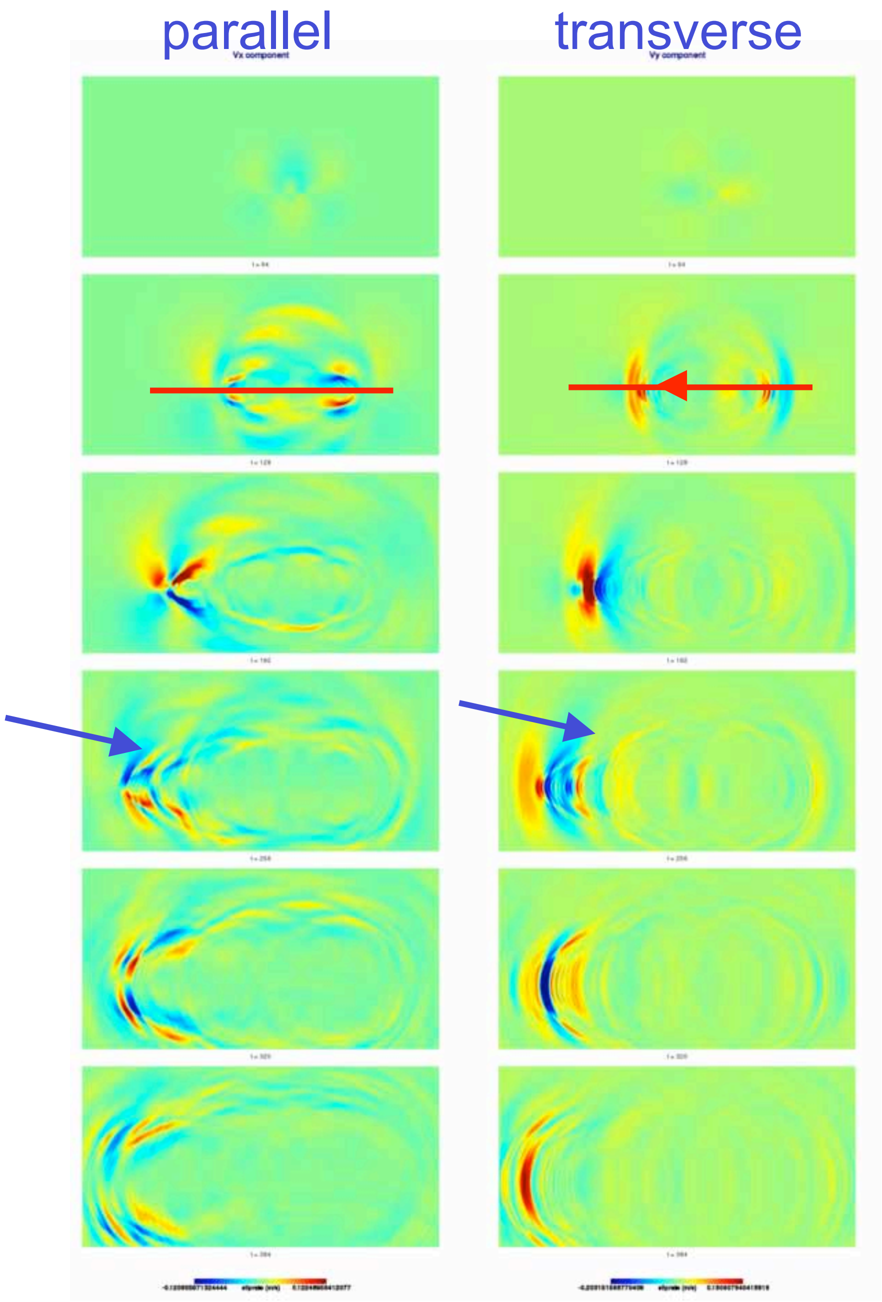
A very simplified version of Liu et al (2006) model



Full 3D velocity model

Resolution power up to 3 Hz

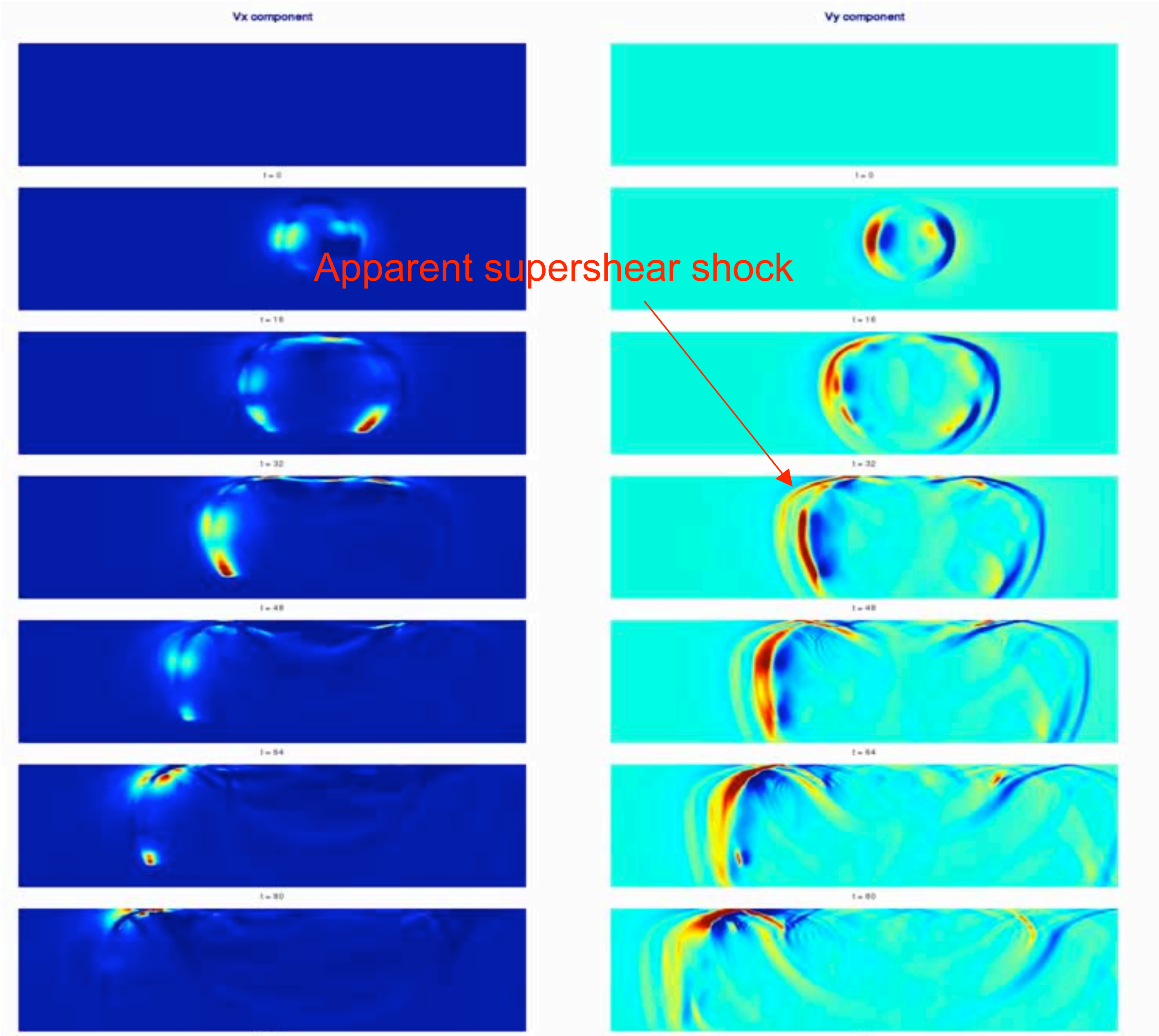
After K. Sesetyan, E. Durukal, R. Madariaga and M. Erdik



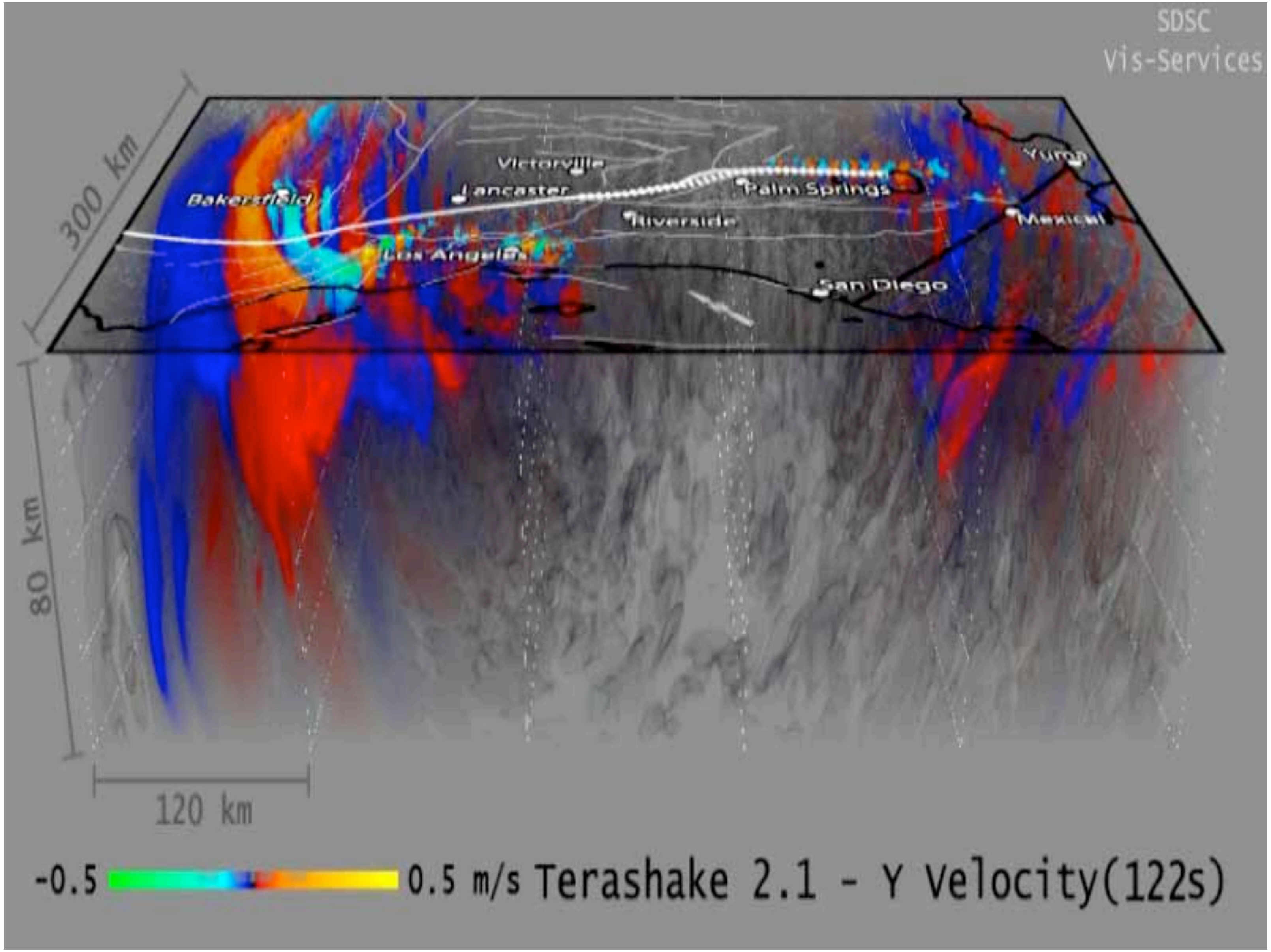
Surface velocities for Parkfield model

Apparent supershear shock
Due to low shear wave speeds
Near surface

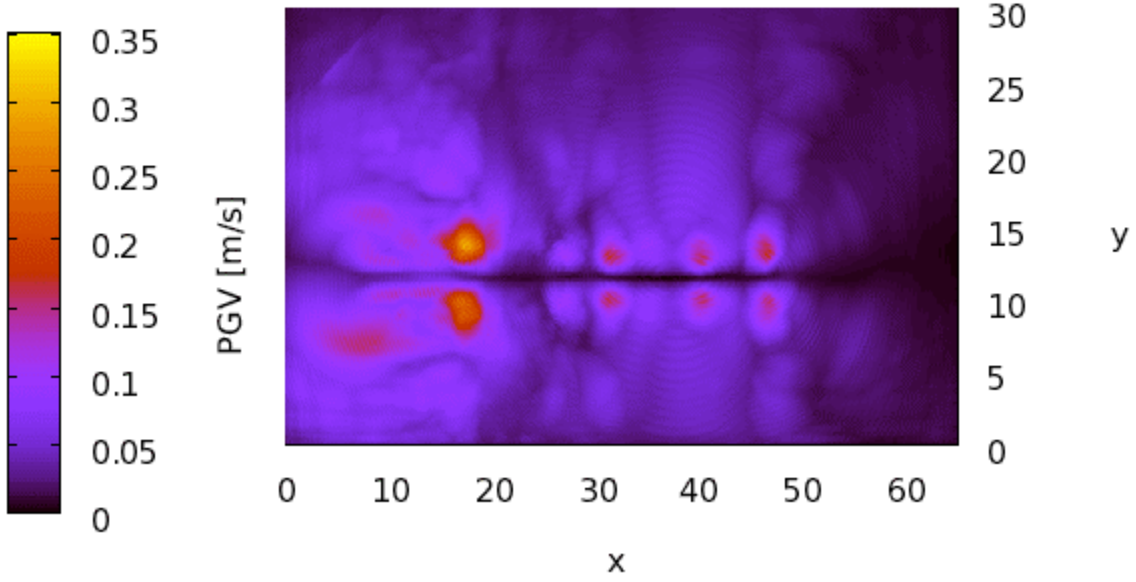
Kinematic model of Parkfield-like earthquake



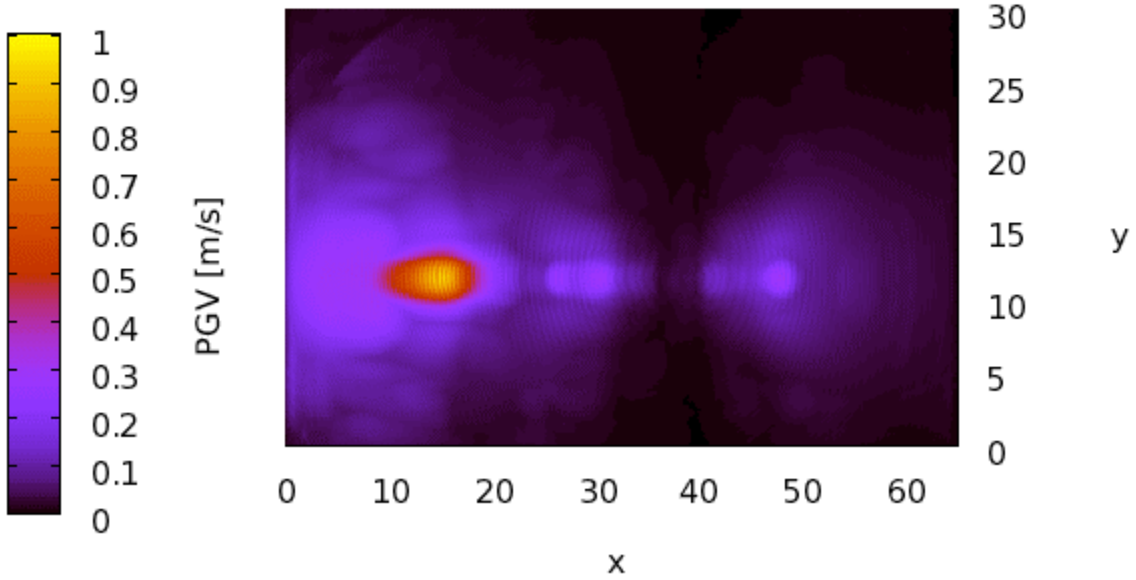
The role of surface waves



Peak ground velocities for a Parkfield-like model

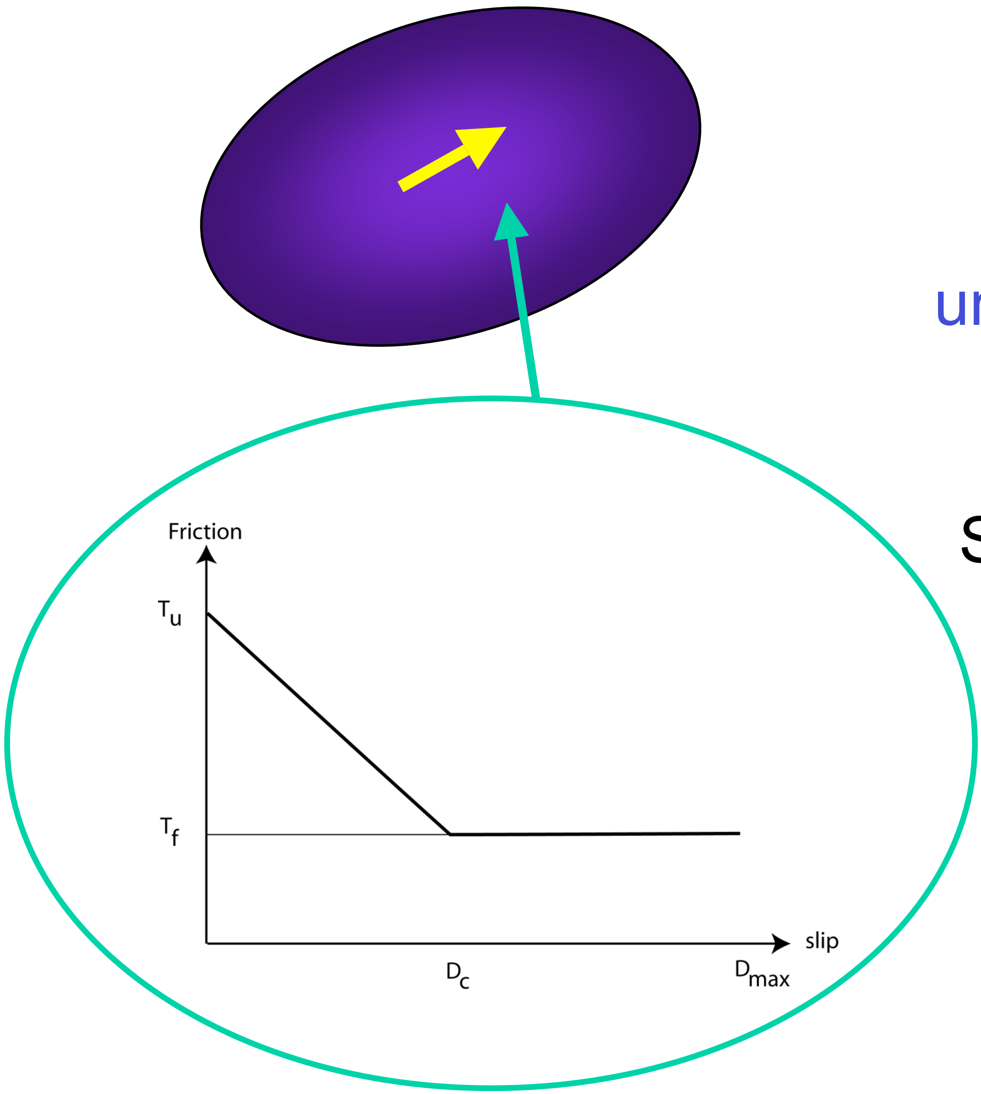


transverse component



longitudinal component

Earthquake dynamics

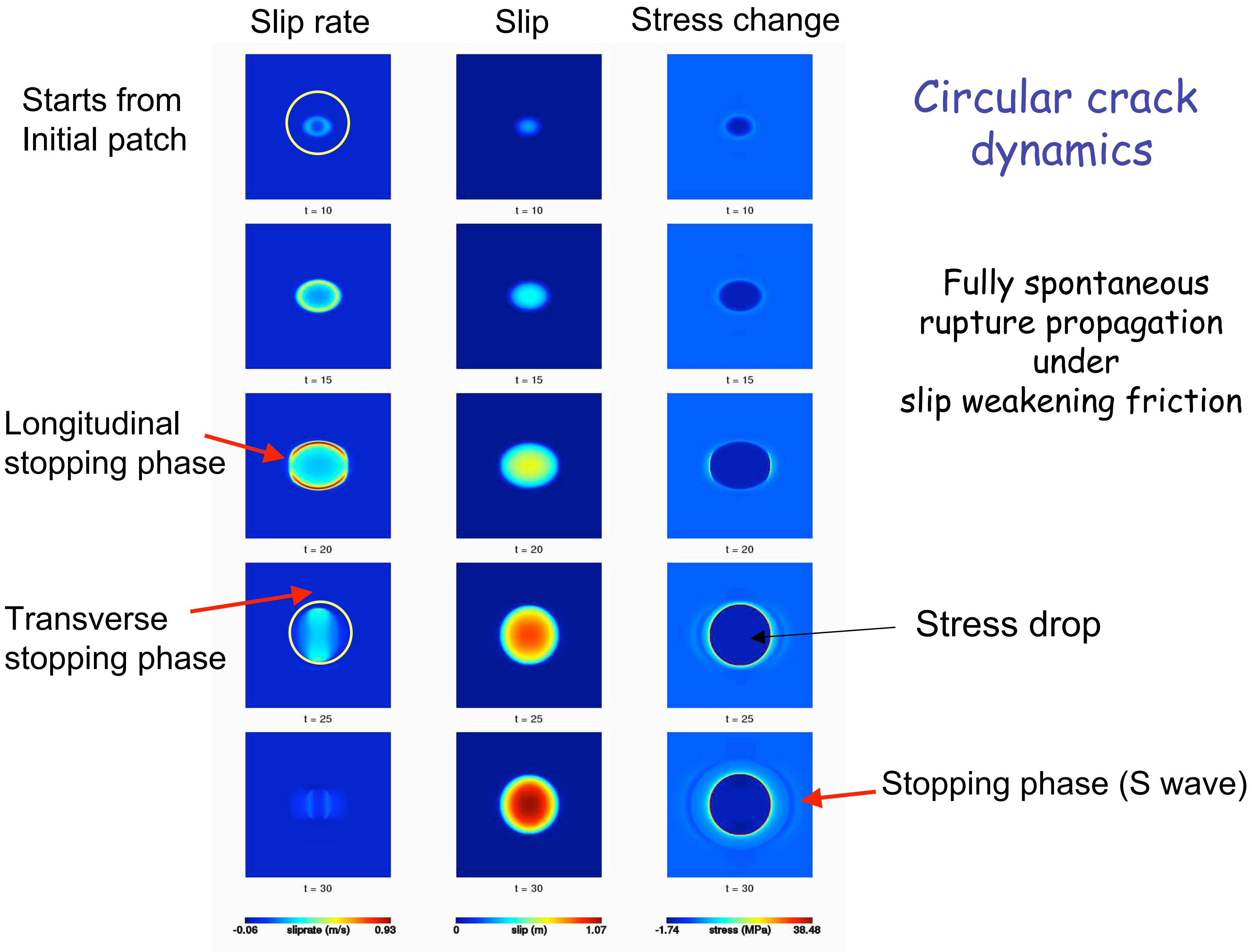


Slip is due to stress relaxation
under the control of friction

Slip evolution is controlled by geometry
and
stress relaxation

Circular crack dynamics

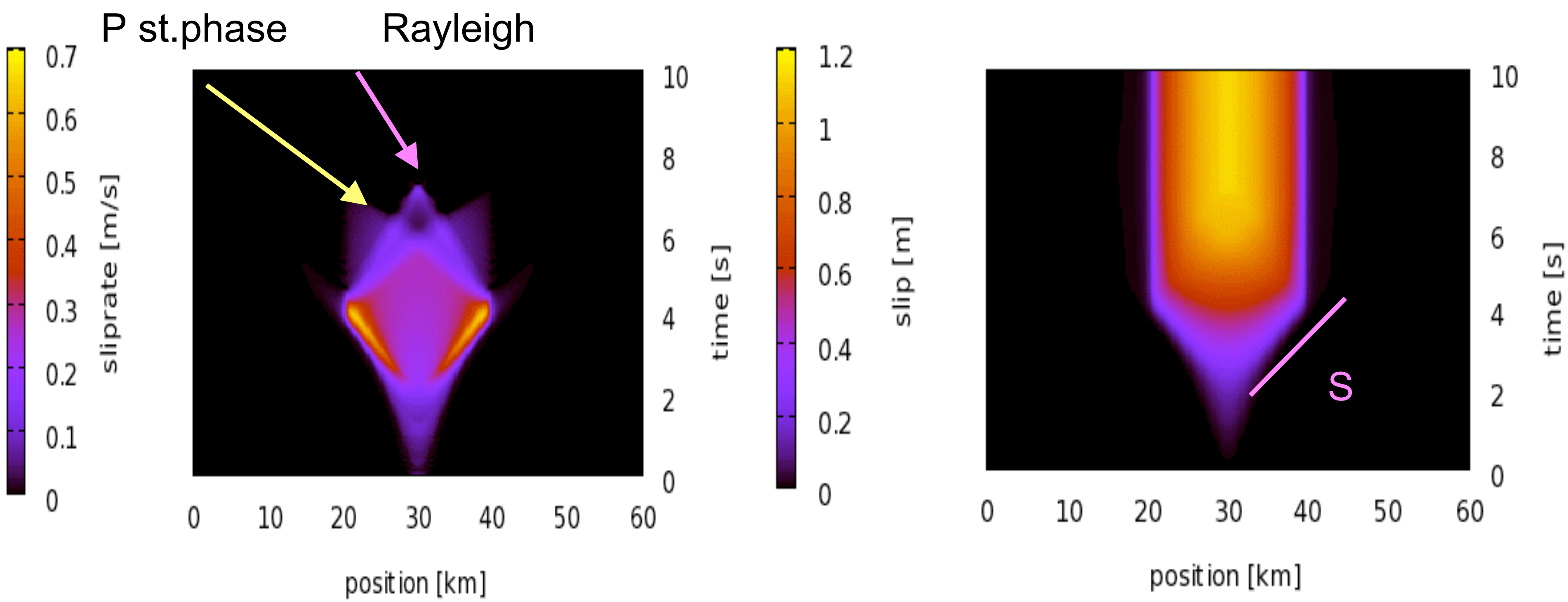
Fully spontaneous rupture propagation under slip weakening friction



Rupture process for a circular crack

Slip rate

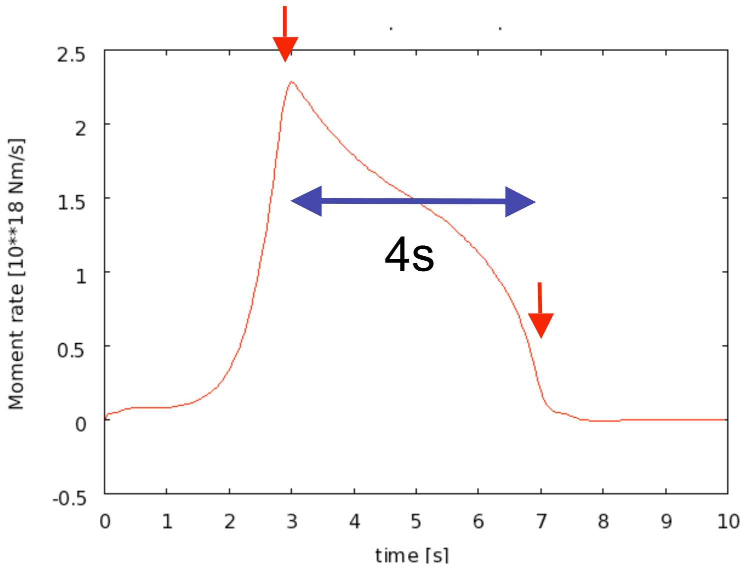
Slip



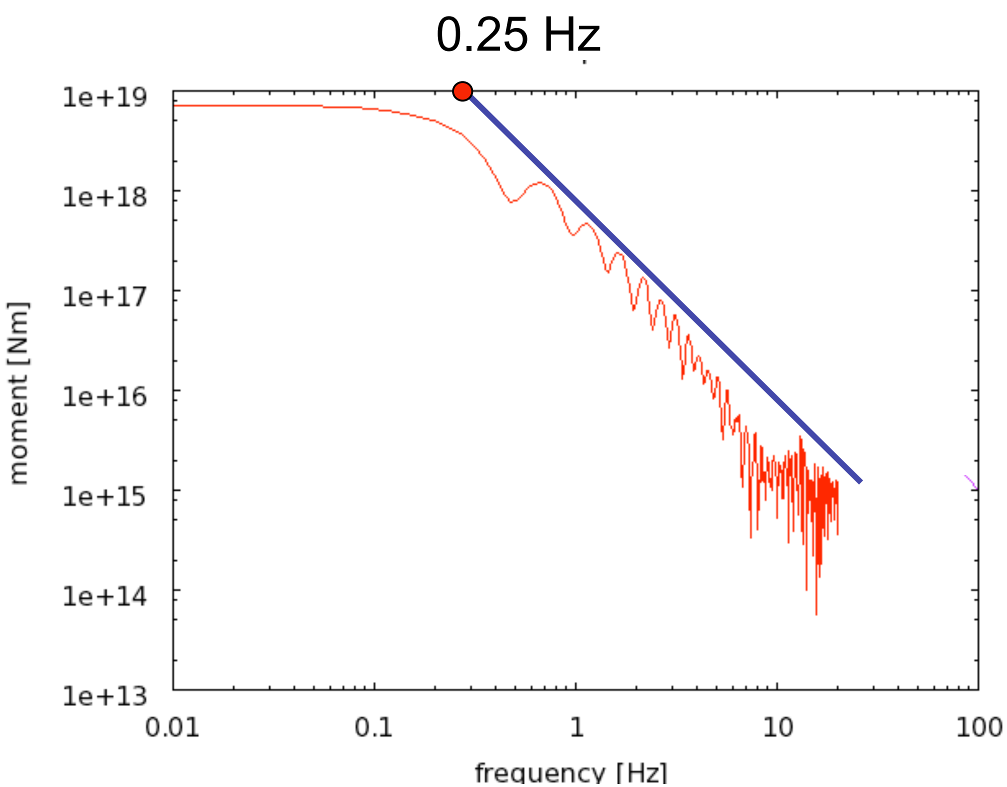
The rupture process is controlled by wave propagation!

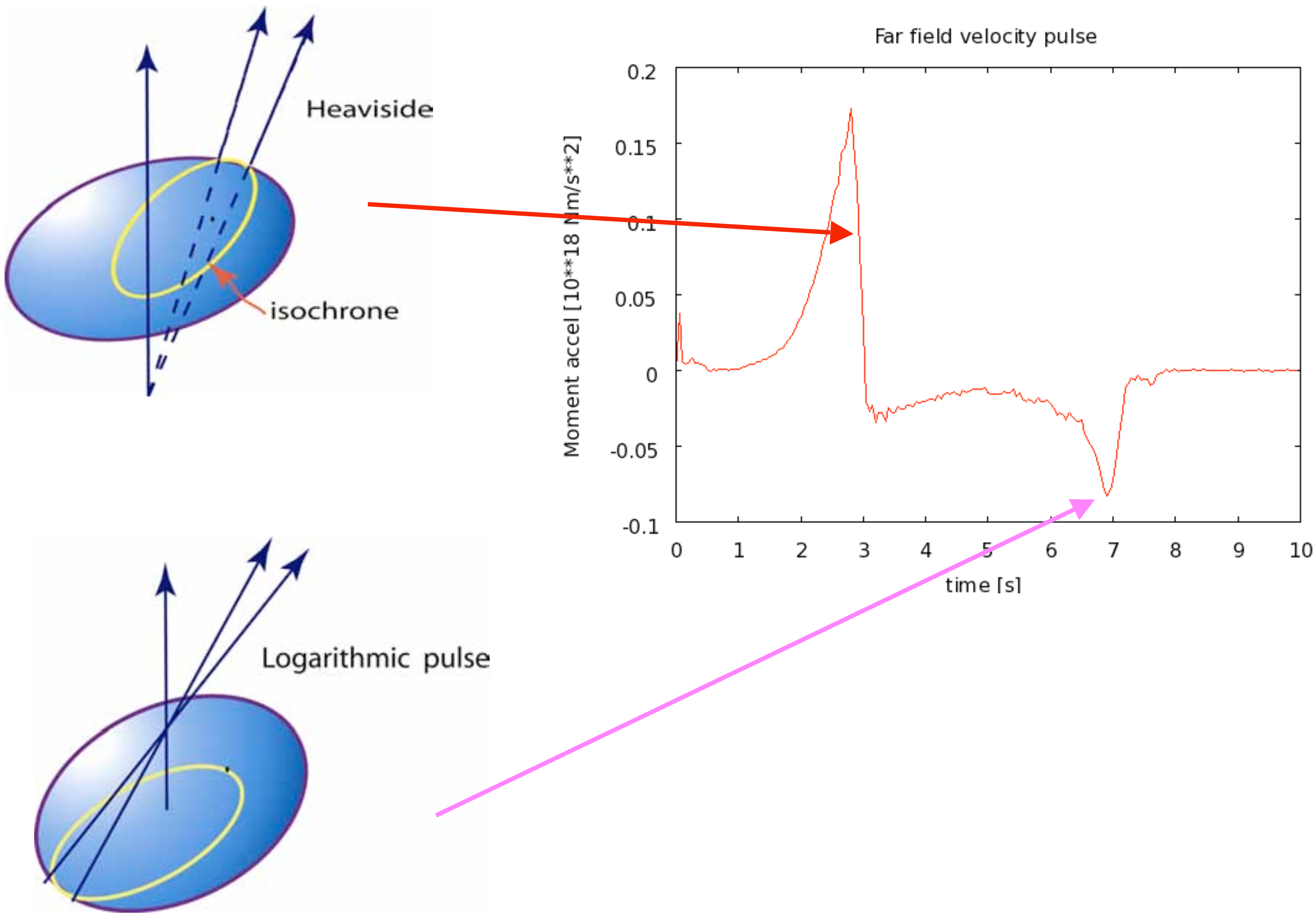
Far field radiation from circular crack

Displacement pulse

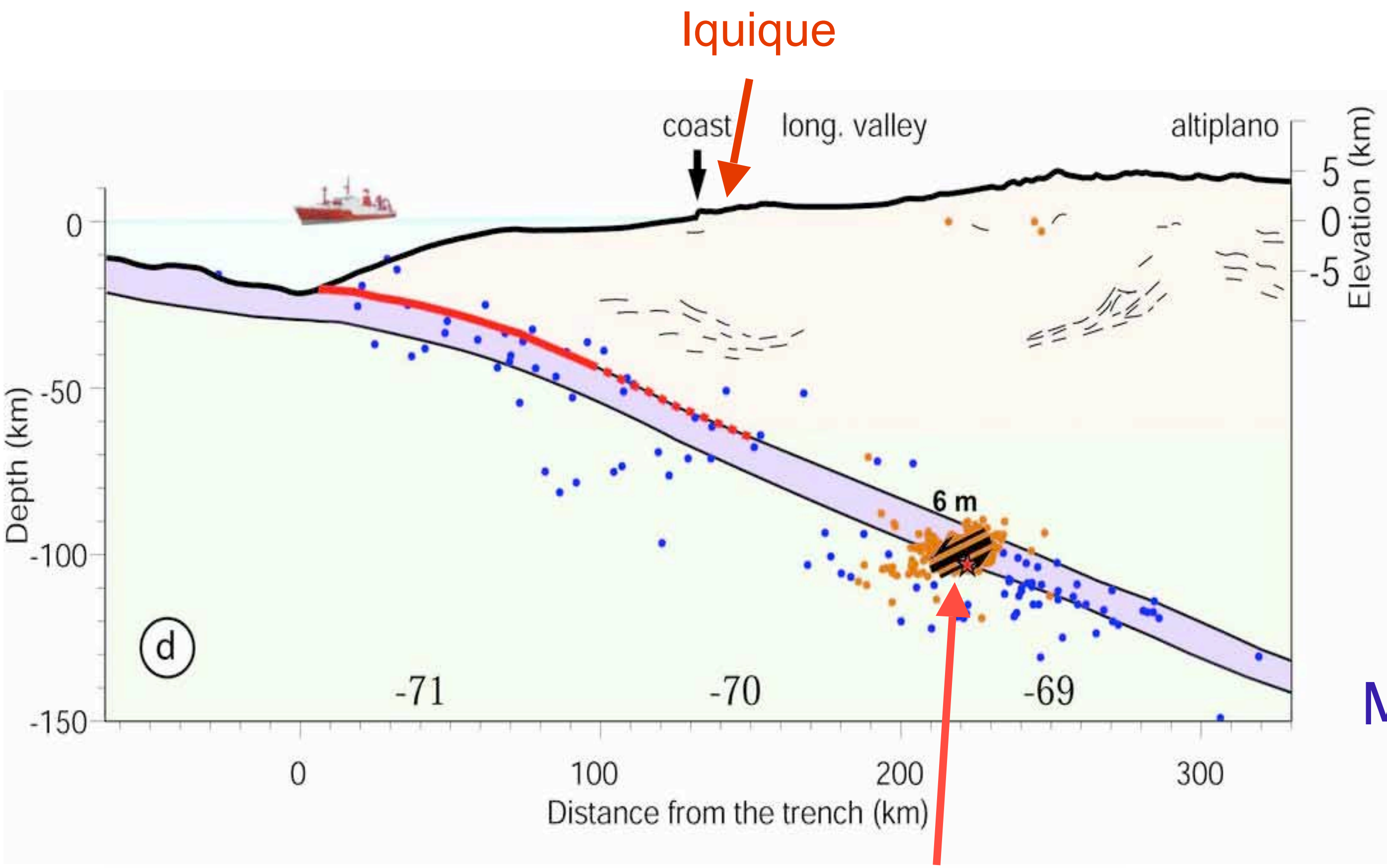


Spectrum




Heaviside
isochrone
Logarithmic pulse
Far field velocity pulse
Moment accel [10**18 Nm/s**2]
time [s]
0.2
0.15
0.1
0.05
0
-0.05
-0.1
0
1
2
3
4
5
6
7
8
9
10

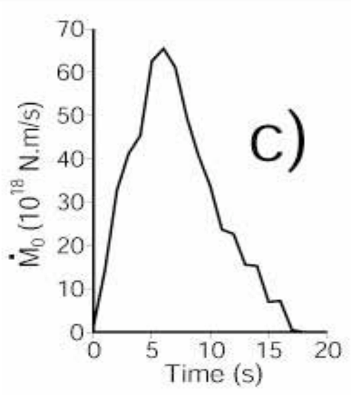
Example from Northern Chile Tarapacá earthquake

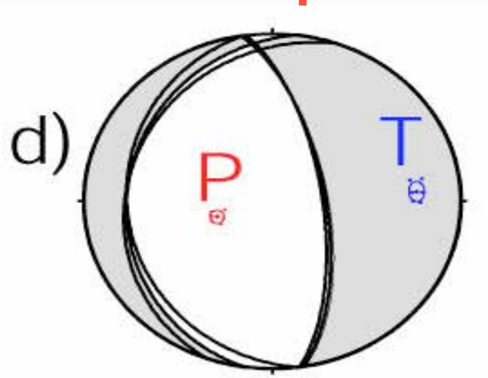


13 June 2005

M=7.8

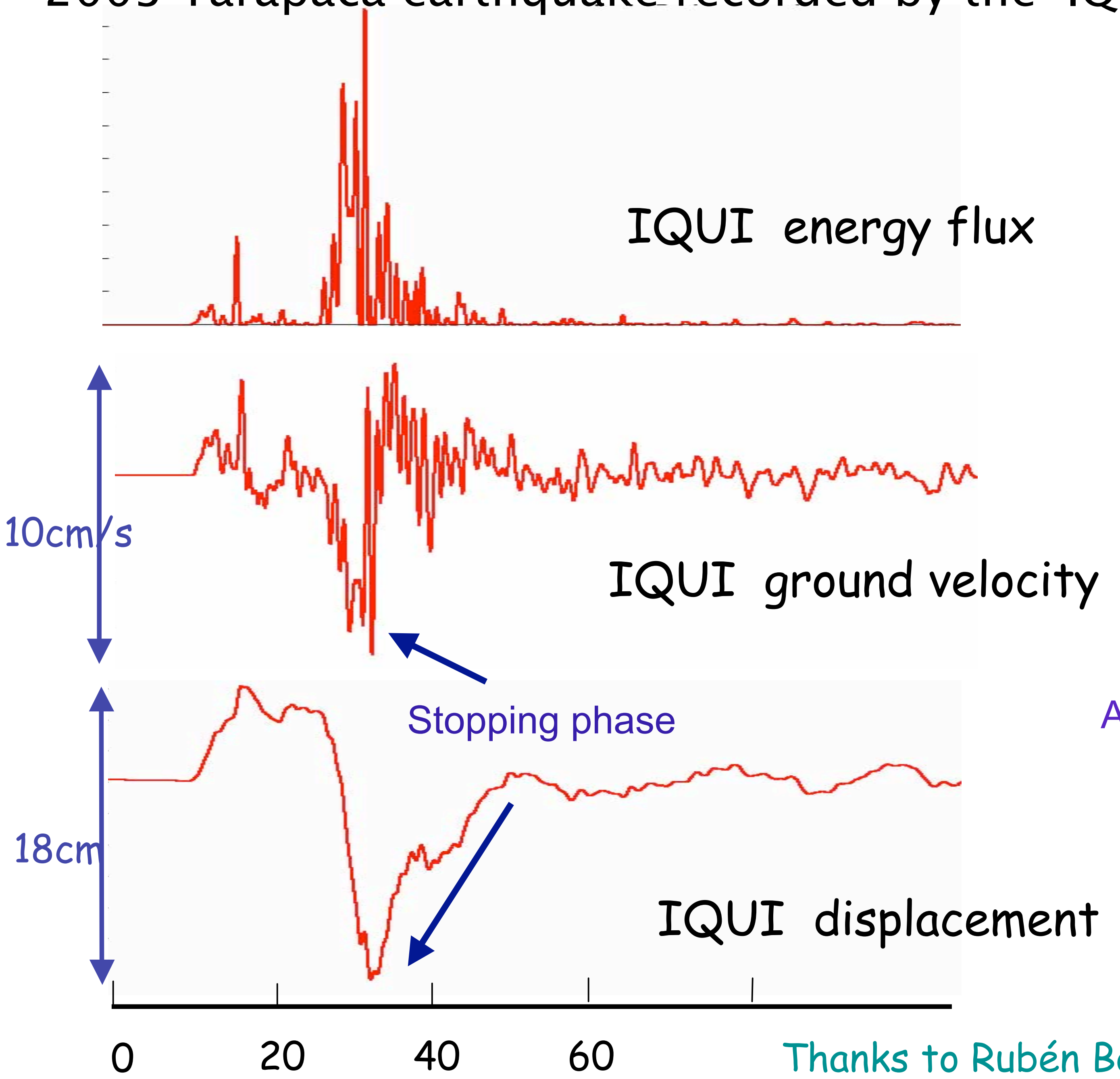
Mo = 5×10^{20} Nm





From Peyrat et al, 2006

2003 Tarapaca earthquake recorded by the IQUI accelerometer

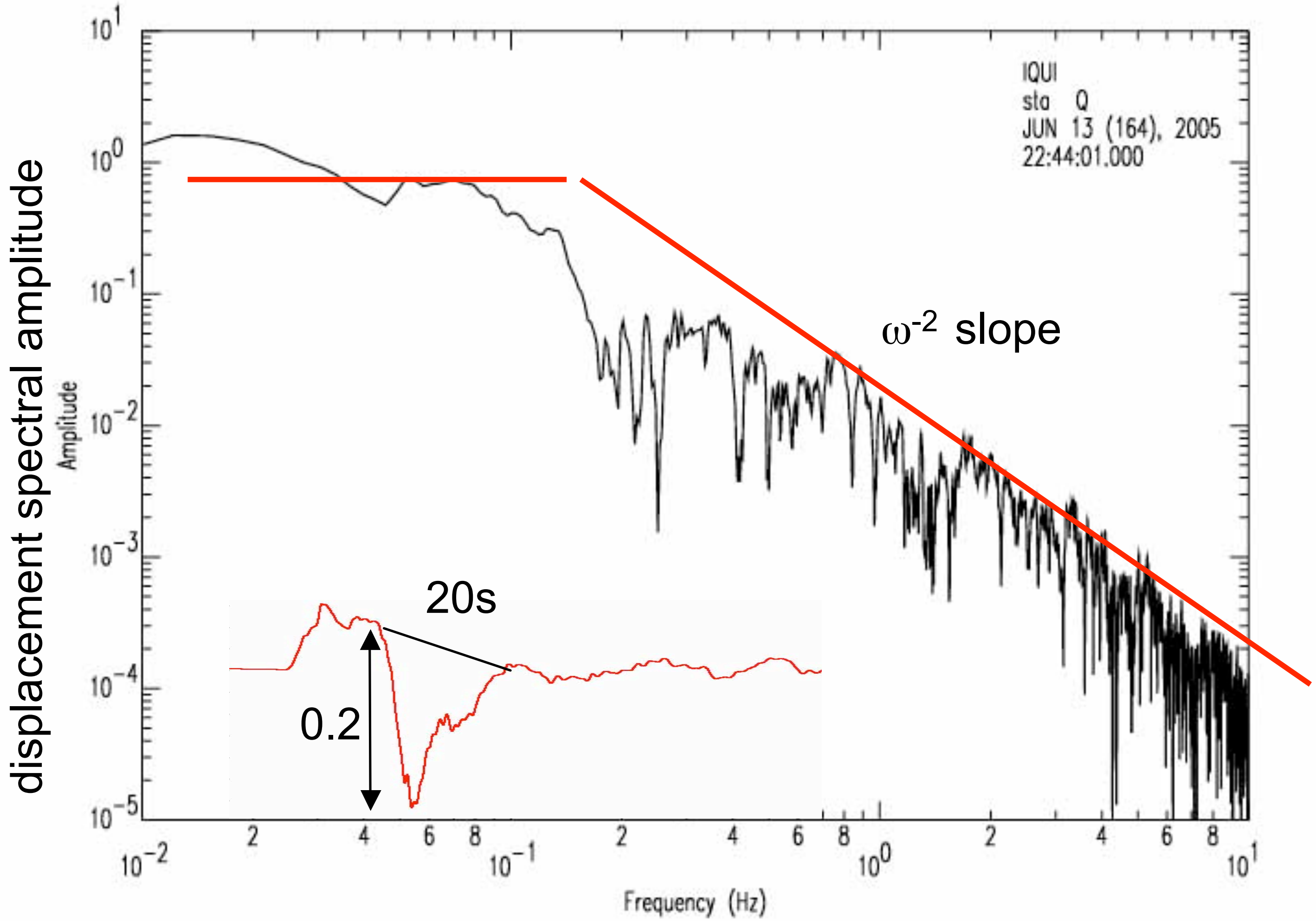


What are them?

Accelerogram filtered from 0.01 to 1 Hz and integrated

Thanks to Rubén Boroschev U de Chile

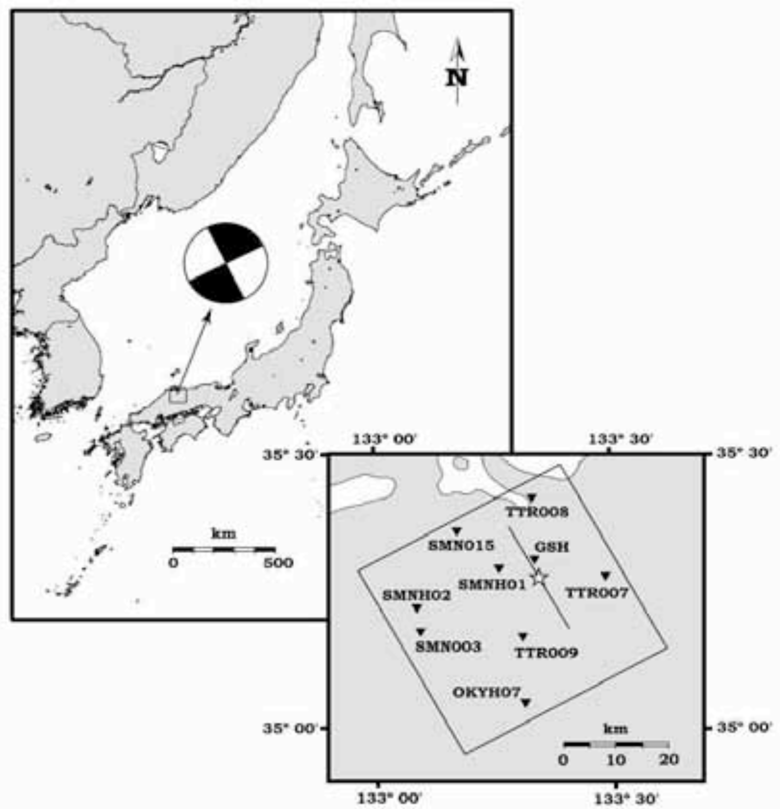
Spectrum of Tarapaca earthquake



CONCLUSIONS

- Seismic data has increased dramatically in quality and number.
- Opens the way to better kinematic and dynamic models
- Earthquake Modeling has become a well developed research field
- There are a number of very fundamental problems that need careful study (geometry, slip distribution, etc)
- Main remining problem: non-linear dynamic inversion

The 2000 Western Tottori earthquake

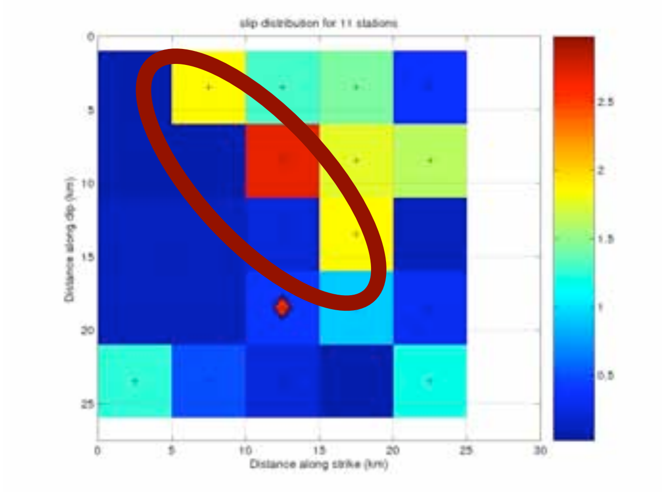


- Tottori accelerograms have absolute time

- Hypocentre determined directly from raw records

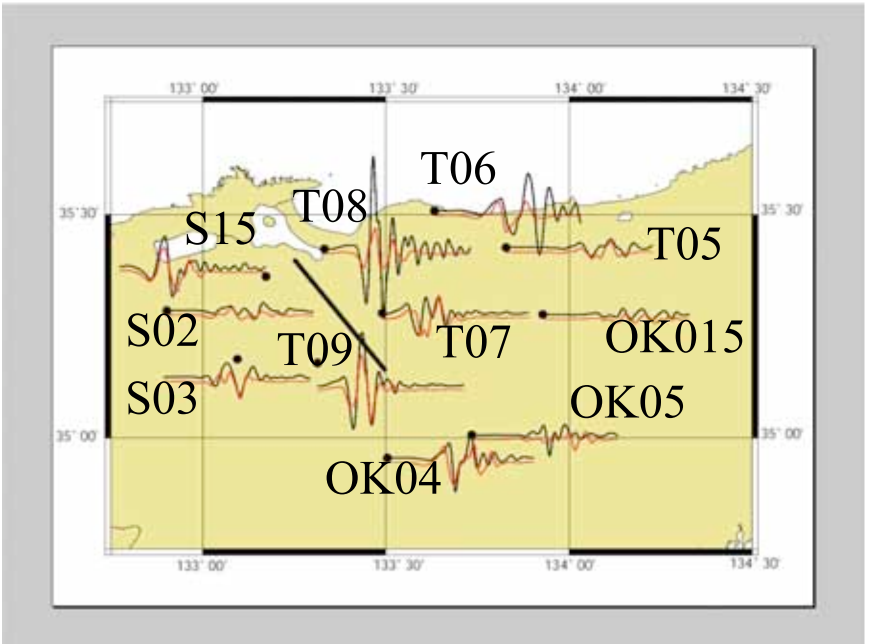
- **No surface rupture observation**
- **M_w 6.6~6.8**
- **Pure left-lateral strike slip event**
- **Hypocentral depth poorly constrained**

Kinematic inversion of Tottori earthquake



- Small slip around the hypocentre
- Slip increases towards the upper northern edge of the fault

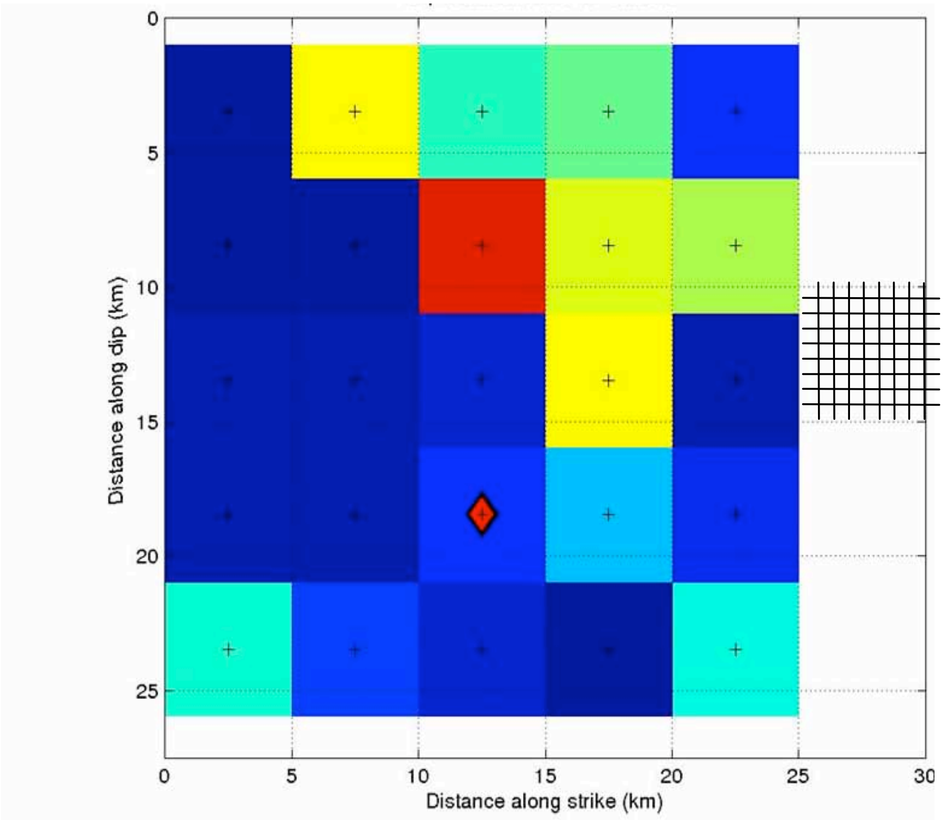
Velocity Waveforms



Good fit at nearfield stations (misfit=3.4 L^2)

The main problem with dynamic inversion

Inversion grid



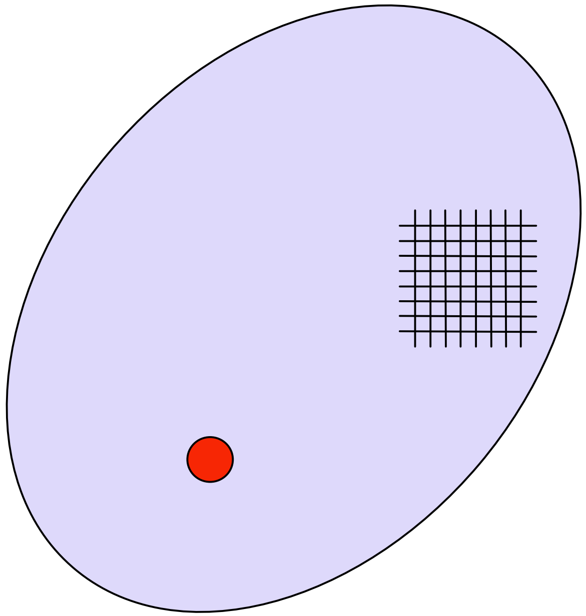
Computational grid

Inversion grid has about 30 elements (degrees of freedom)

Computational grid has > 1000 elements

This method was used by Peyrat and Olsen

Inversion of a simple geometrical initial stress field and/or friction laws

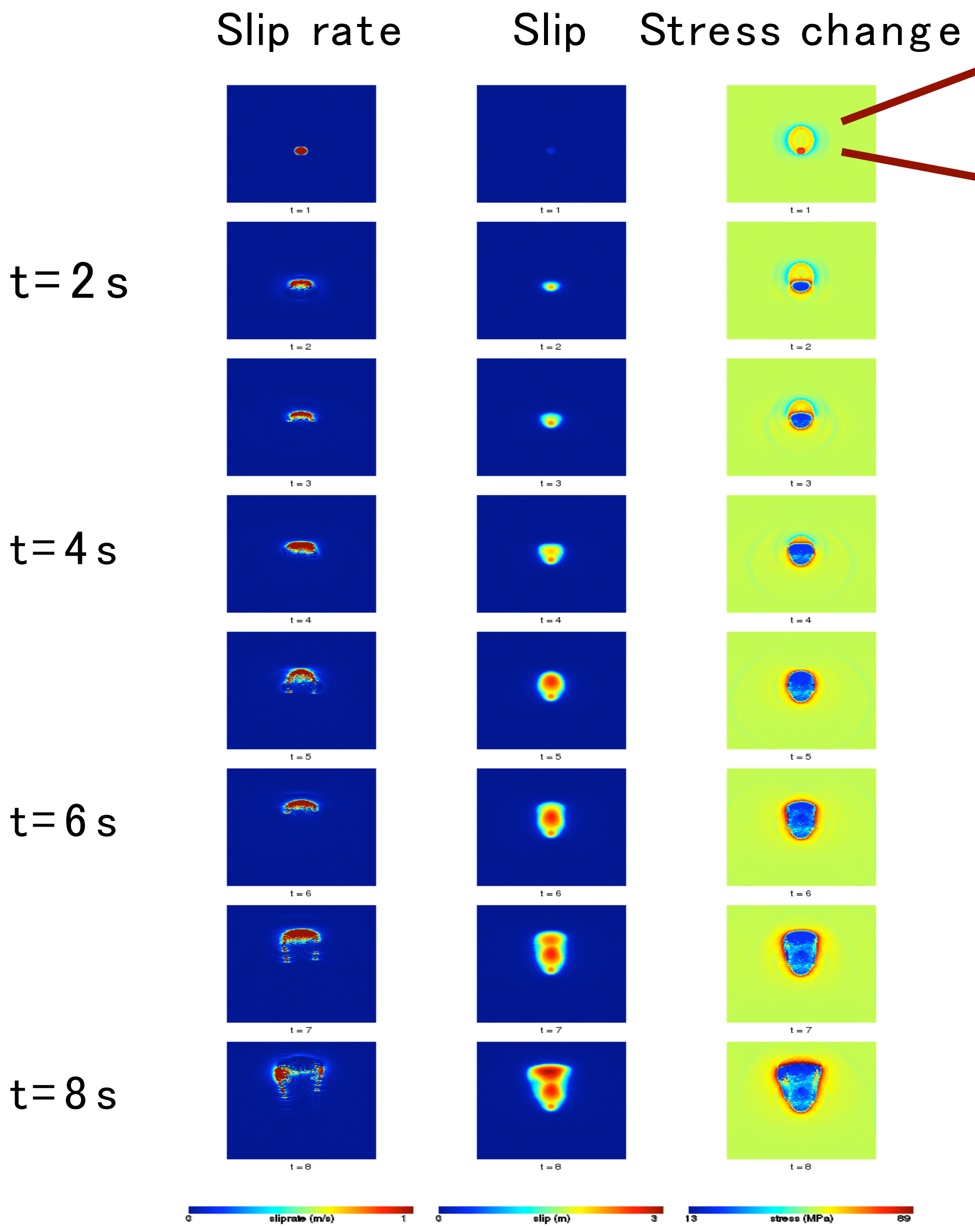


An ellipse has only 7 independent Degrees of freedom

Finite difference grid is independent of inverted object

Based on an idea by Vallée et Bouchon (2003)

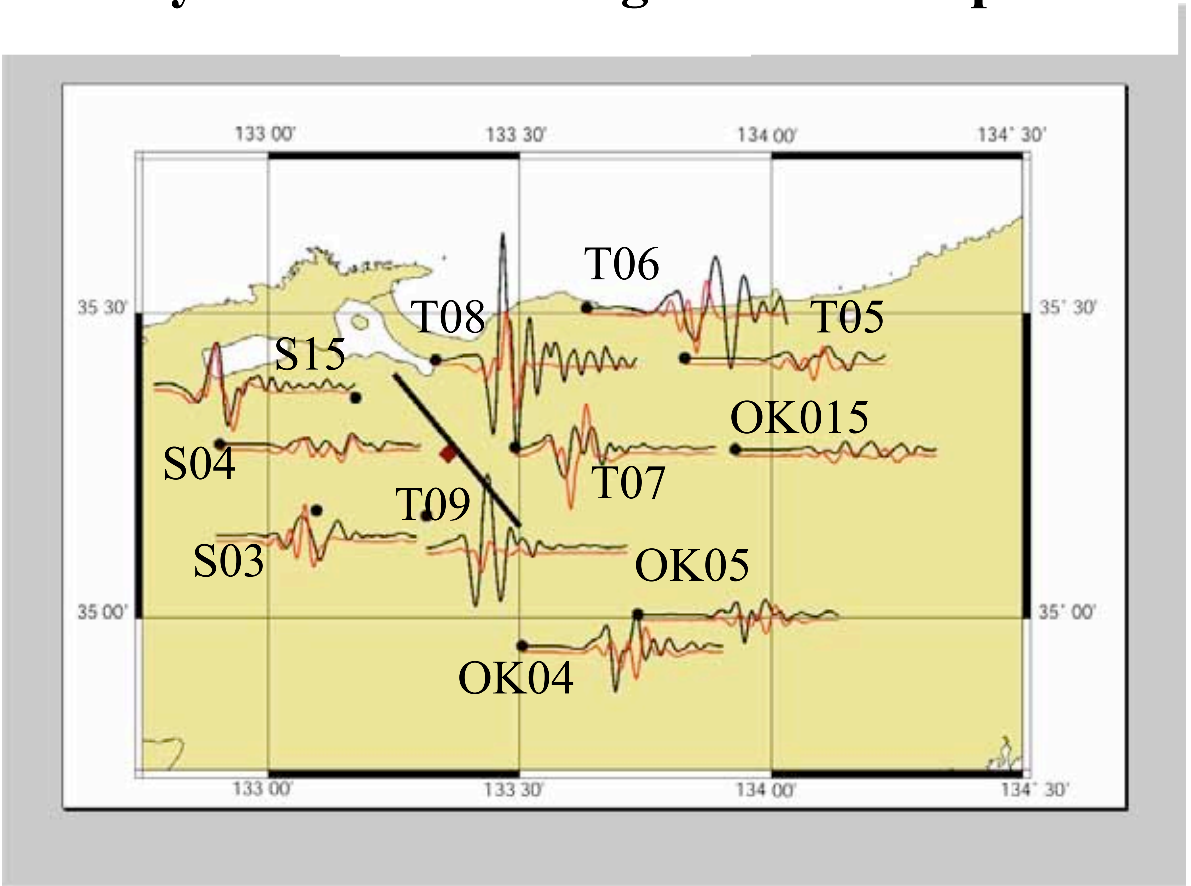
Dynamic modelling of Tottori



- The initial stress field
- Rupture is forced to start from an asperity located at 18 km in depth
- Then **we modify the elliptical slip distribution** until the rupture propagates and the seismograms are fitted

Main Results

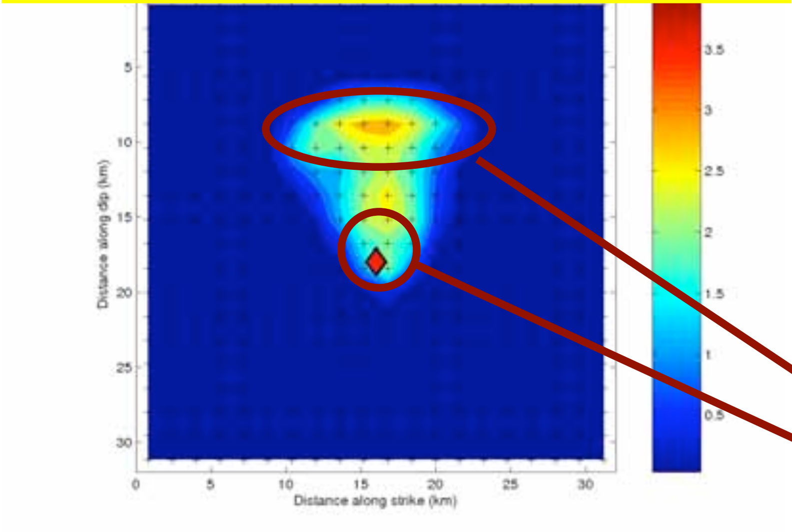
Velocity Waveform fitting for EW component



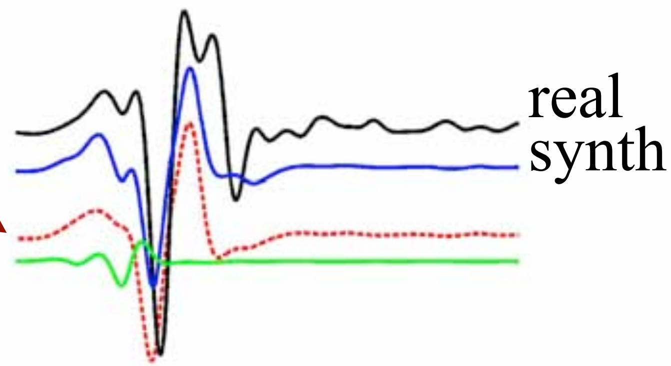
- Velocity waveforms fit observations less well than the kinematic model.
- For each station both amplitude and arrival phases match satisfactorily

Influence of different rupture patches

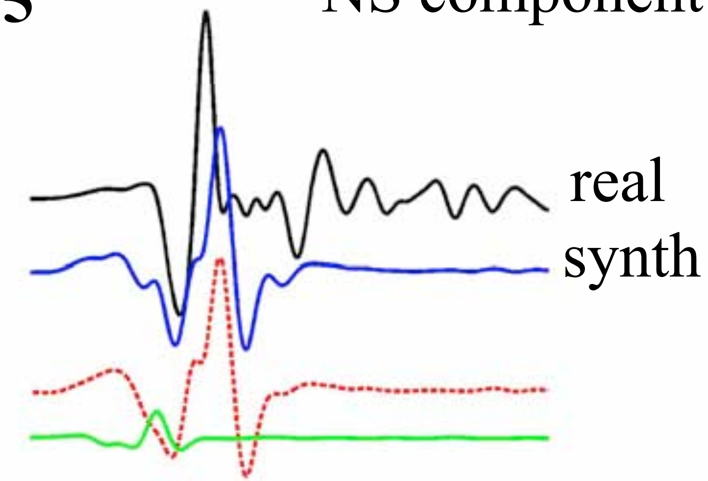
Final slip distribution



T09 NS component



S15 NS component



The stopping phase (red) exerts the primary control on the waveform

Outlook

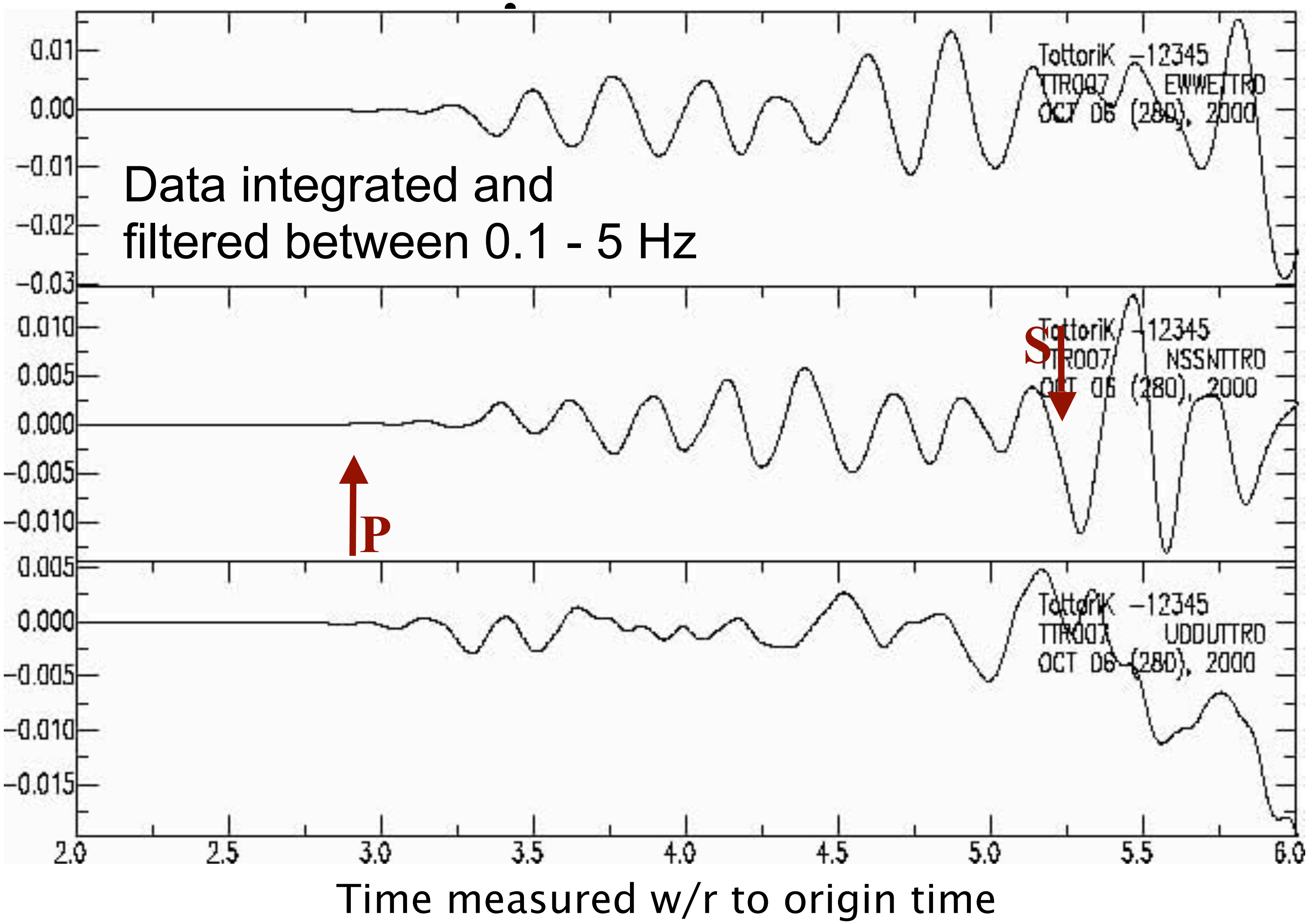
Two approaches to study the propagation of the Tottori earthquake:

- The **non linear kinematic inversion** gives a very good wavefits controlled by a **diagonal stopping phase**.

- The **dynamic rupture inversion** allows to fit very well both amplitude and arrival phases. The **horizontal stopping phase** controls the waveforms.

- A dynamic inversion with a slip distribution controlled by 2 elliptical patches is in progress.

Example of velocity data



We relocate the hypocentre close to 14 km depth