Modelos de fuente sismica finita

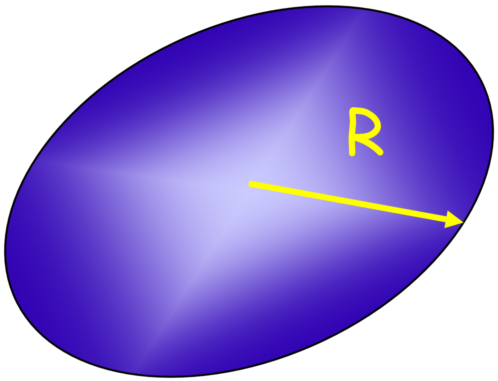
Modelo de falla circular

Modele de Haskell

Nacimiento de la dinamica de la fuente

A principios de los años 1970 :

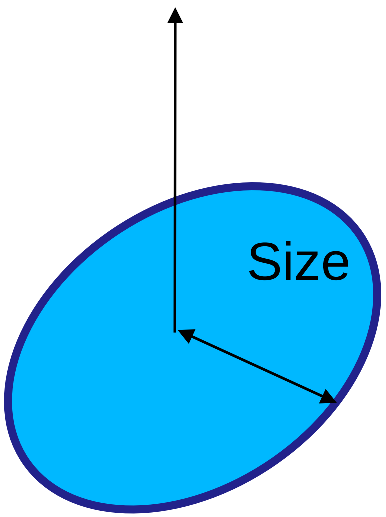
- Aki (1967) Scaling law of earthquake spectra
- Kostrov (1964, 1966) Circular crack, 2D crack, Energy
- Brune (1970) Circular crack body wave spectrum
- Madariaga (1976) put together all this.



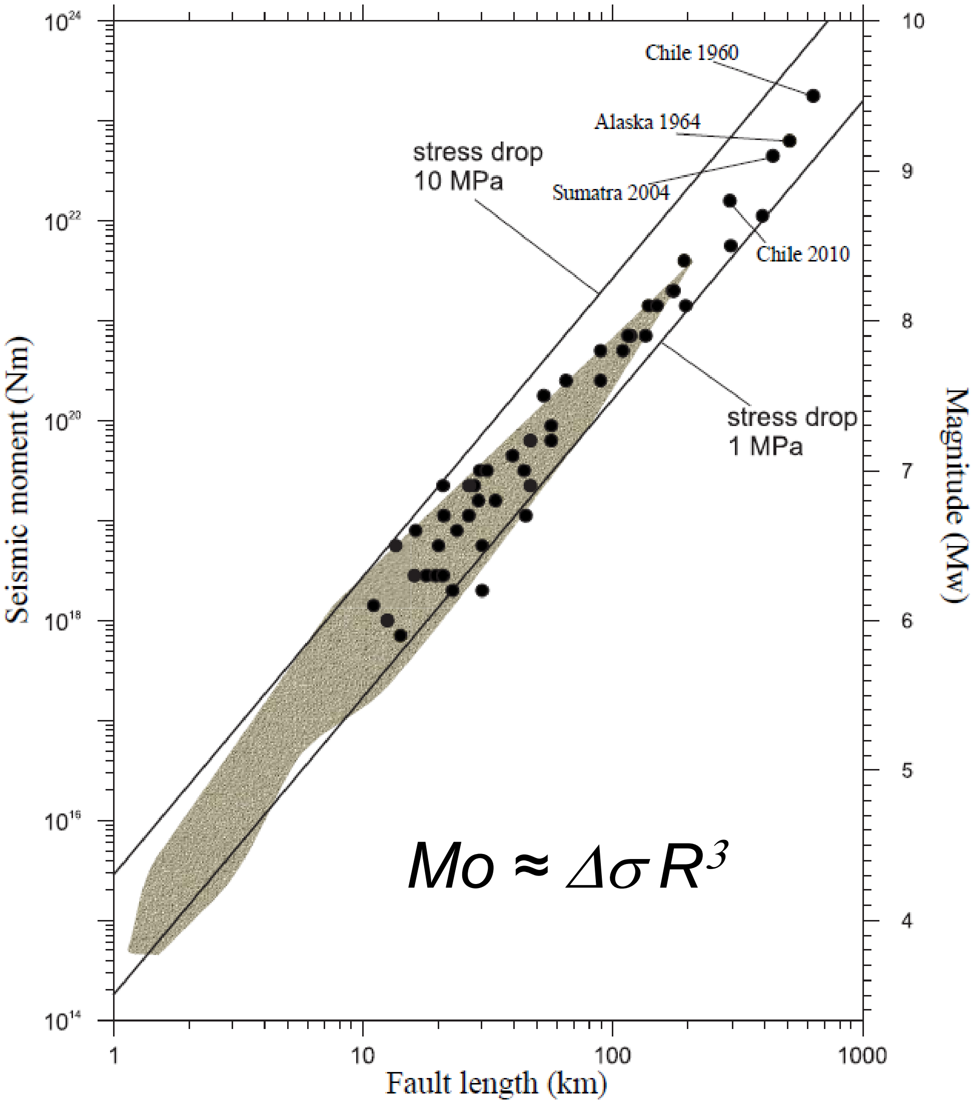
2 Parametros:
Mo
R

No definen la velocidad de ruptura

Ley de escalamiento de Aki



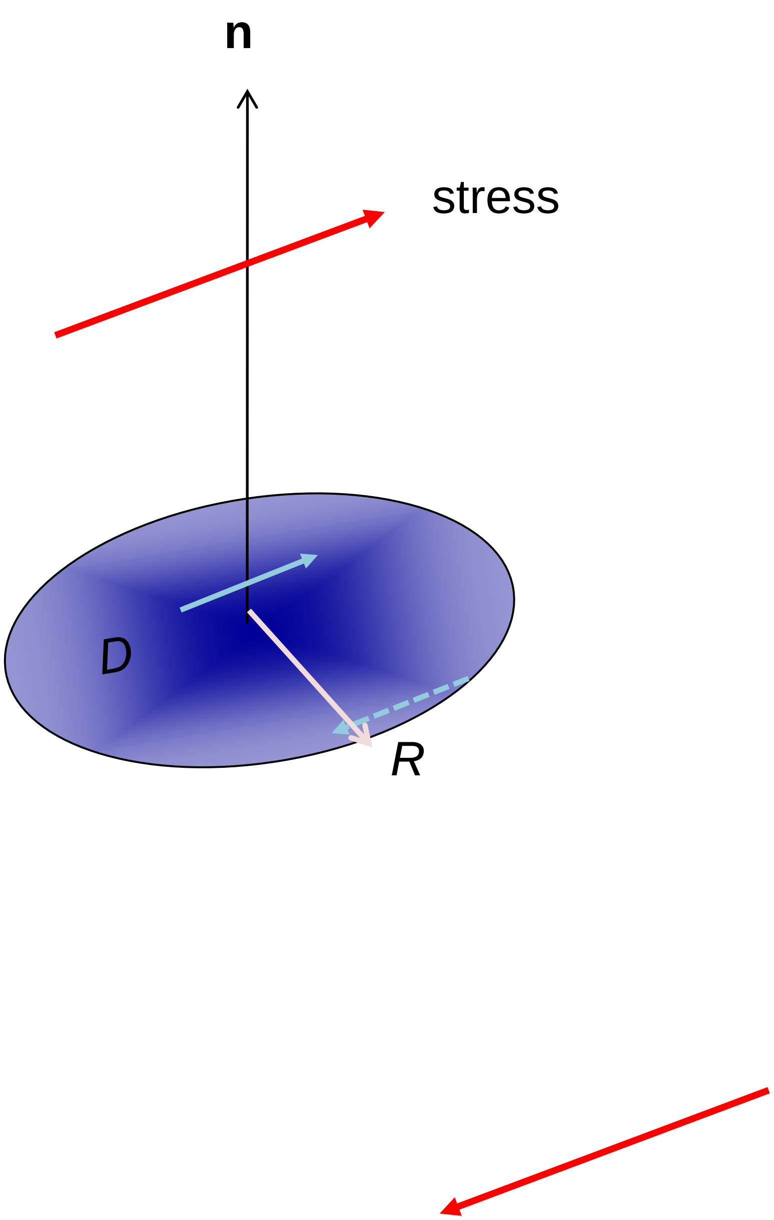
Hay una sola escala de longitud:
Radio R o L



Ley de escala de los terremotos

$$\log_{10} M_0(Nm) = 1.5M_w + 9.3$$

Magnitude (M_w)	Moment (Nm)	Longueur (km)	Durée (s)	Glissement (m)
10	10^{24}	1000?	300?	100?
9	3.10^{22}	300	100	30
8	10^{21}	100	30	10
7	3.10^{19}	30	10	3
6	10^{18}	10	3	1



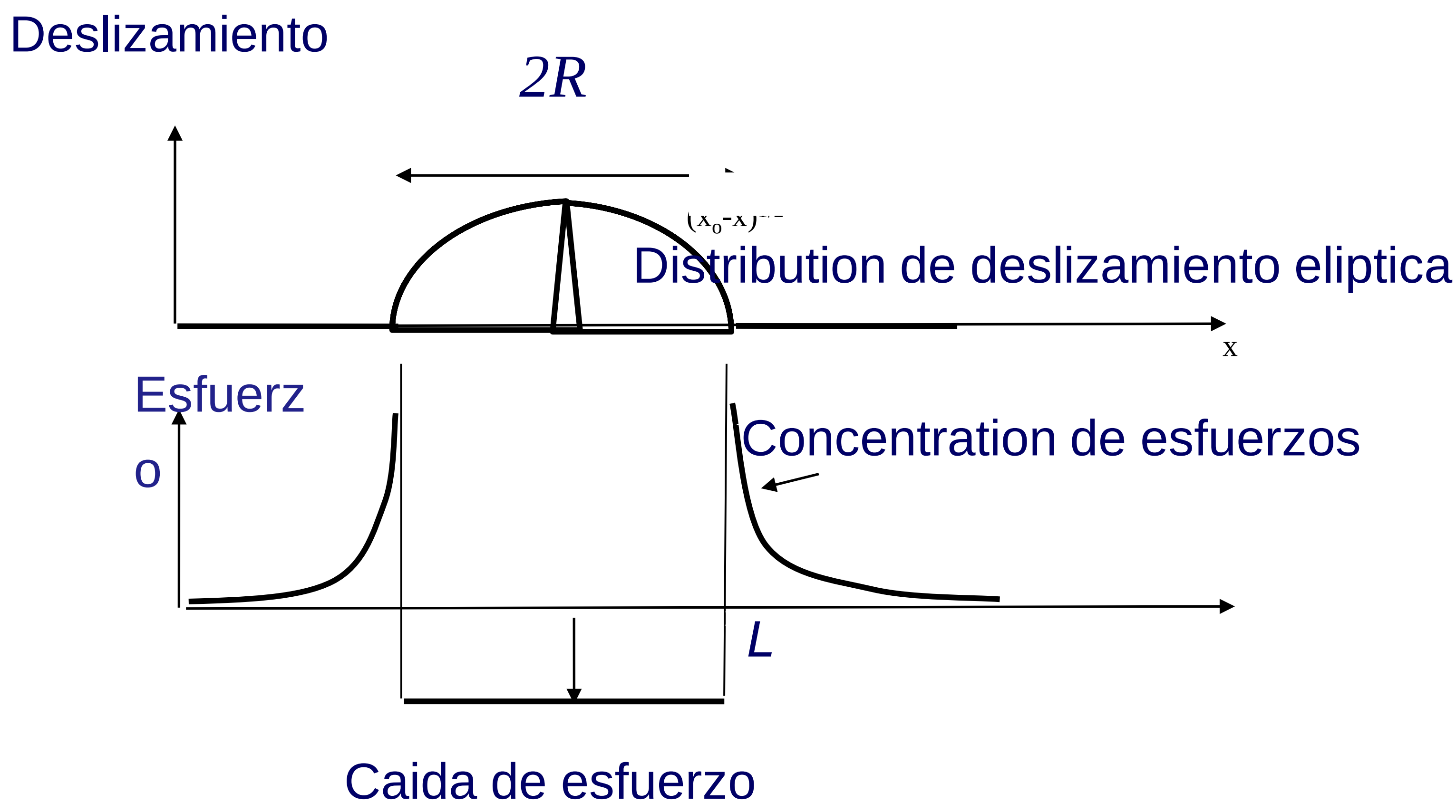
Slip of a circular crack

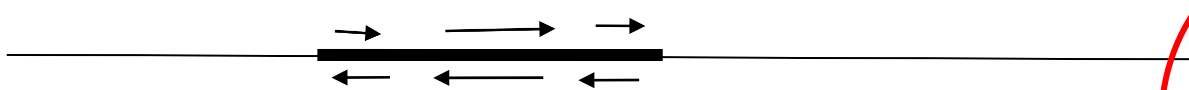
$$D(r) = \frac{24}{7\pi}\frac{\Delta\sigma}{\mu}\sqrt{R^2 - r^2}$$

Average slip

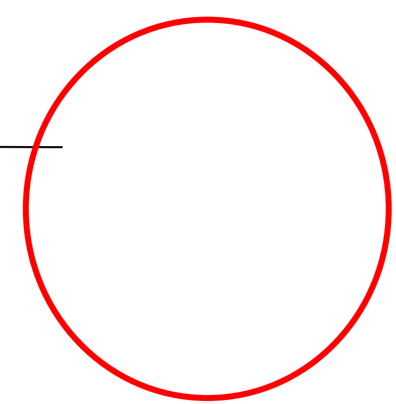
$$\overline{D} = \frac{16}{7\pi}\frac{\Delta\sigma}{\mu} R$$

Modelo de ruptura sismica circular (3D)





$$D(r) = \frac{24}{7\pi}\frac{\Delta\sigma}{\mu}\sqrt{R^2 - r^2}$$



Modelo de fisura circular estática

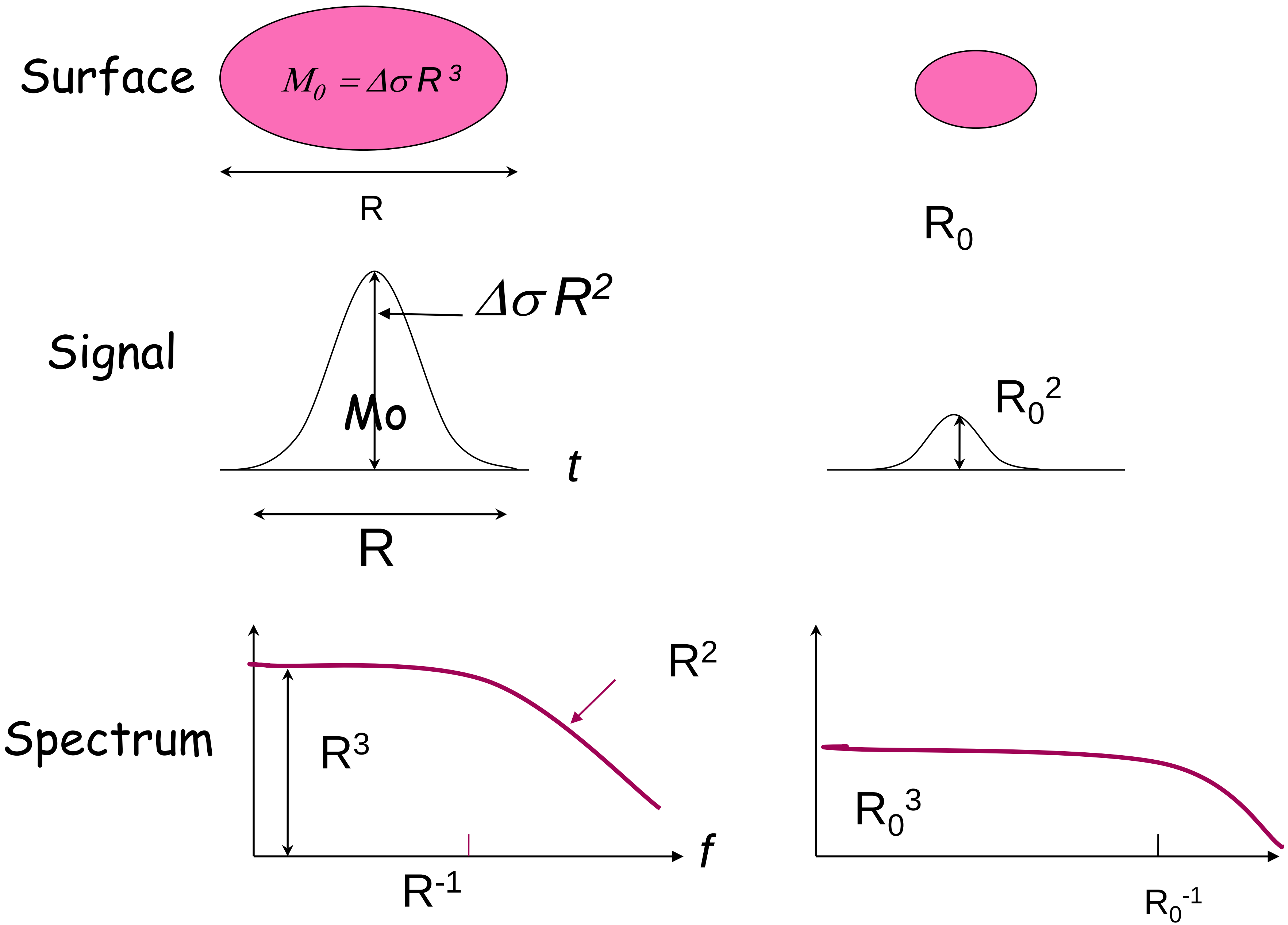
Deslizamiento $$D(r) = \frac{24}{7\pi}\frac{\Delta\sigma}{\mu}\sqrt{R^2 - r^2}$$

Deslizamiento medio $$\overline{D} = \frac{16}{7\pi}\frac{\Delta\sigma}{\mu} R$$

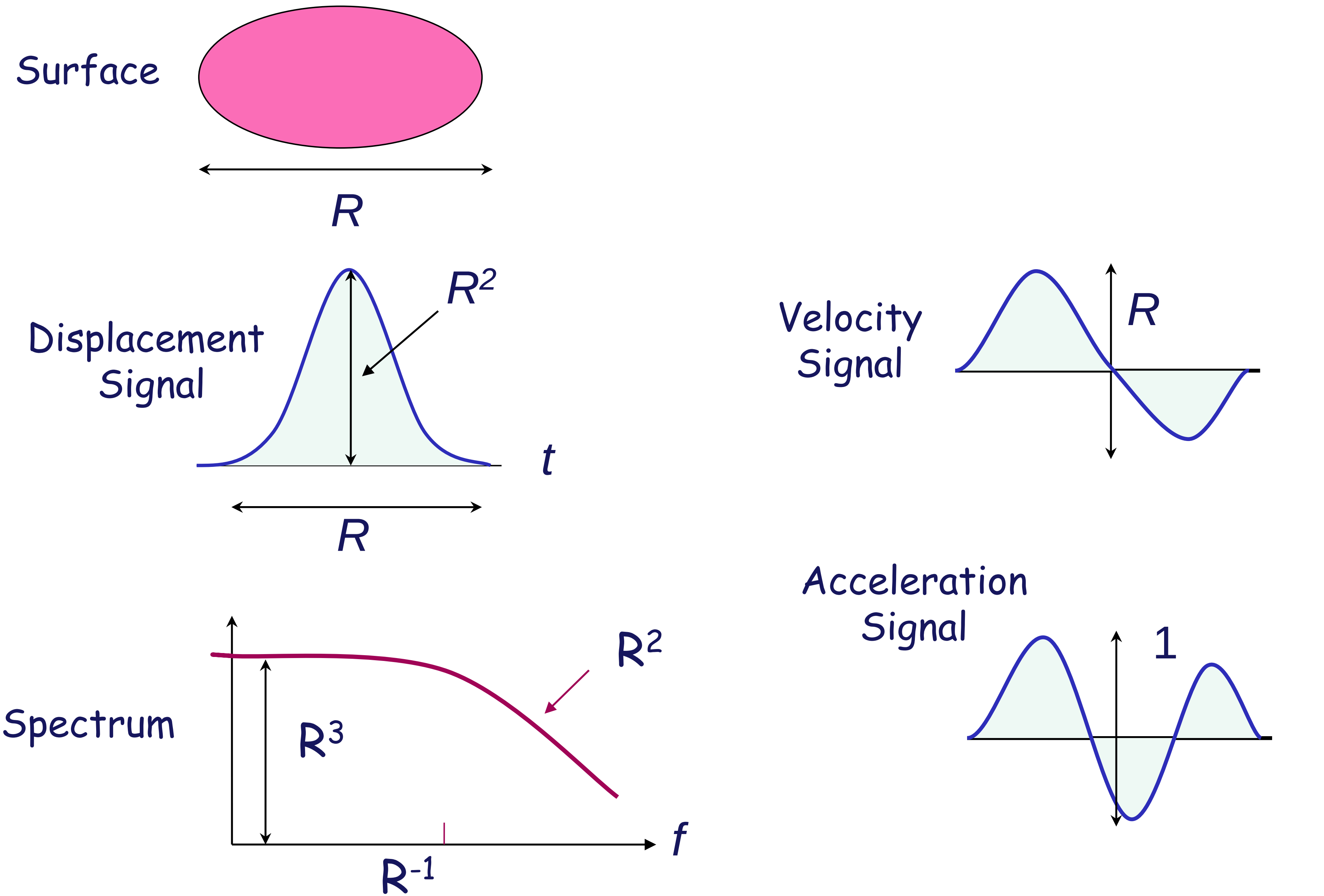
Momento sísmico $$M_0 = \frac{16}{7}\Delta\sigma R^3$$

Energia de deformacion $$\Delta W = \frac{8}{7}\frac{\Delta\sigma^2}{\mu} R^3$$

Fundamentals of earthquake scaling



Fundamentals of earthquake scaling



Modelo de escalamiento de la fuente

Deslizamiento medio

$$\overline{D} = \frac{16}{7\pi} \frac{\Delta\sigma}{\mu} R$$

Momento sísmico

$$M_0 = \frac{16}{7} \Delta\sigma R^3$$

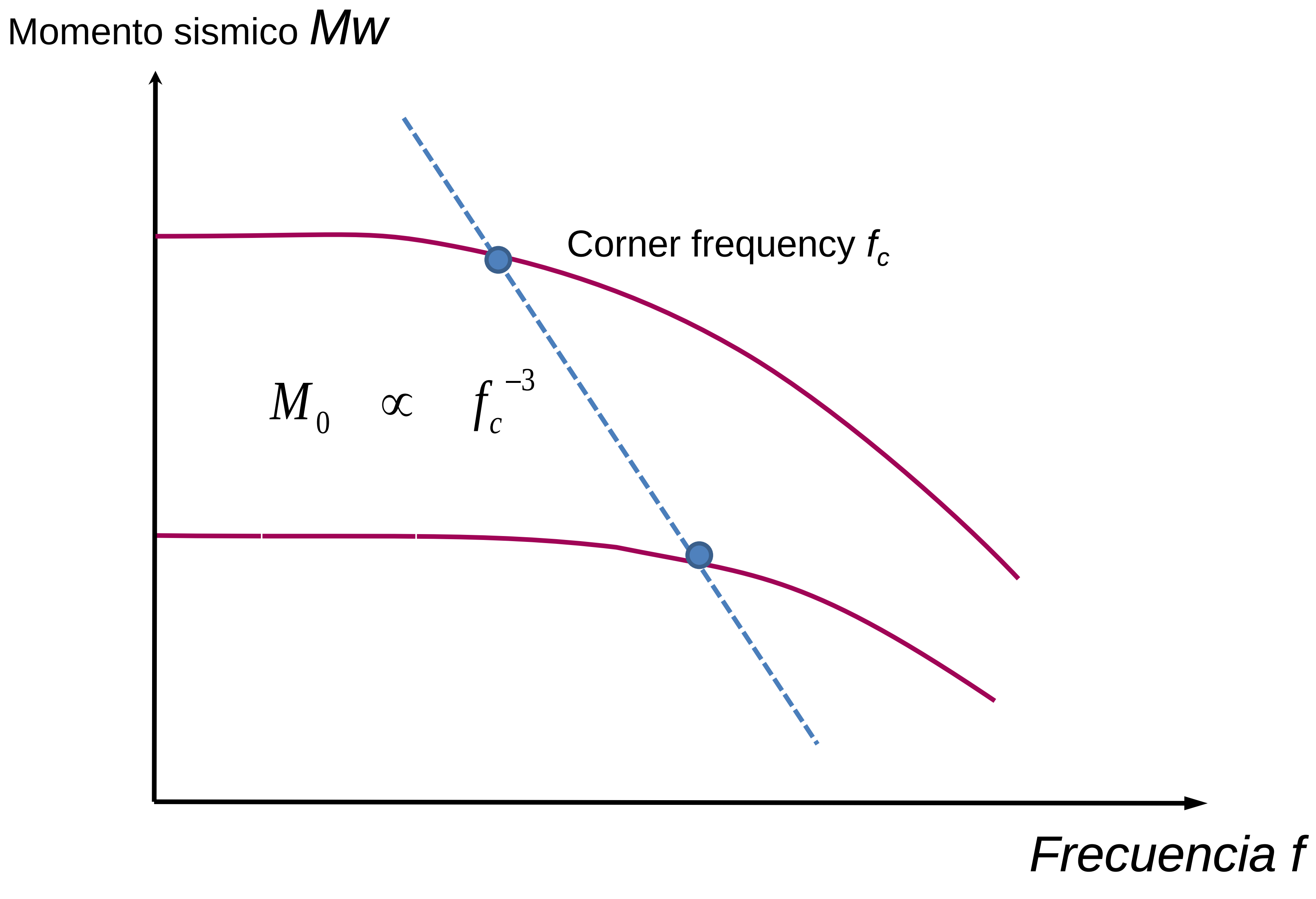
Frecuencia esquina

$$f_c = 0.37 \frac{\beta}{R}$$

Momento vs. frecuencia

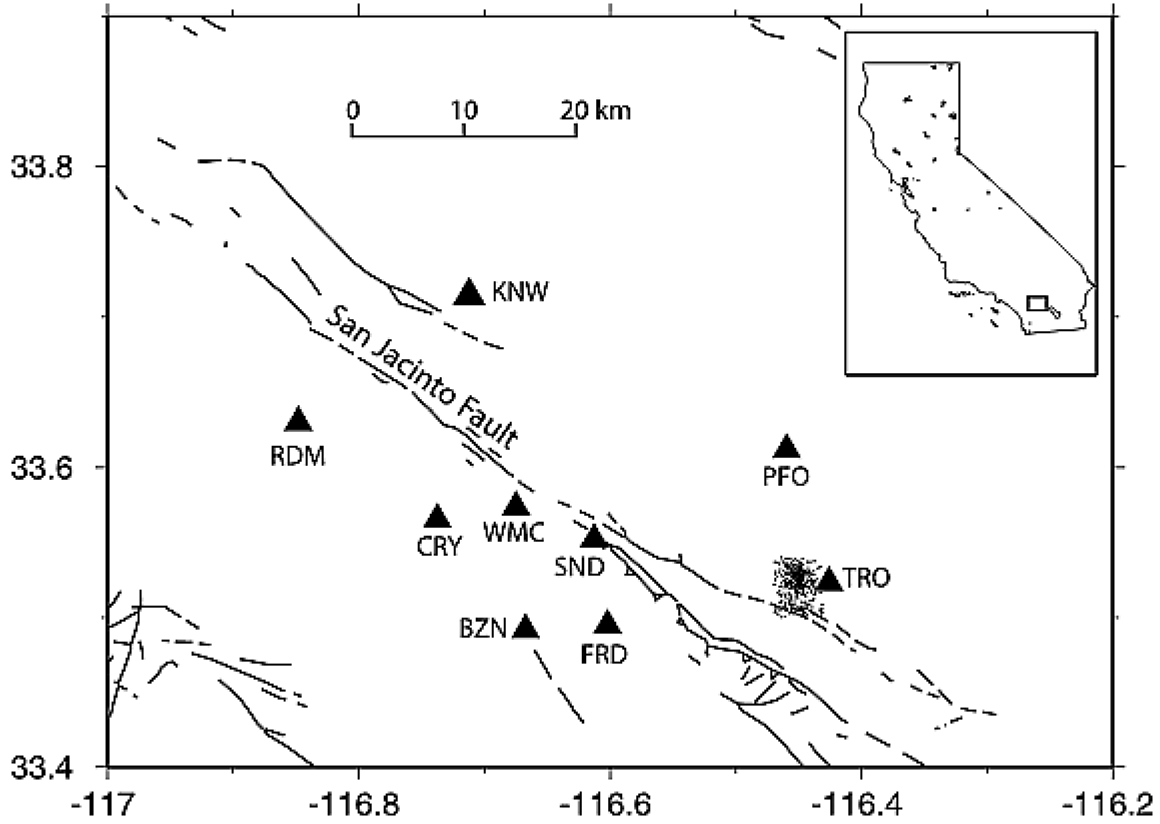
$$M_0 \propto f_c^{-3}$$

Escalamiento de momento y corner frequency

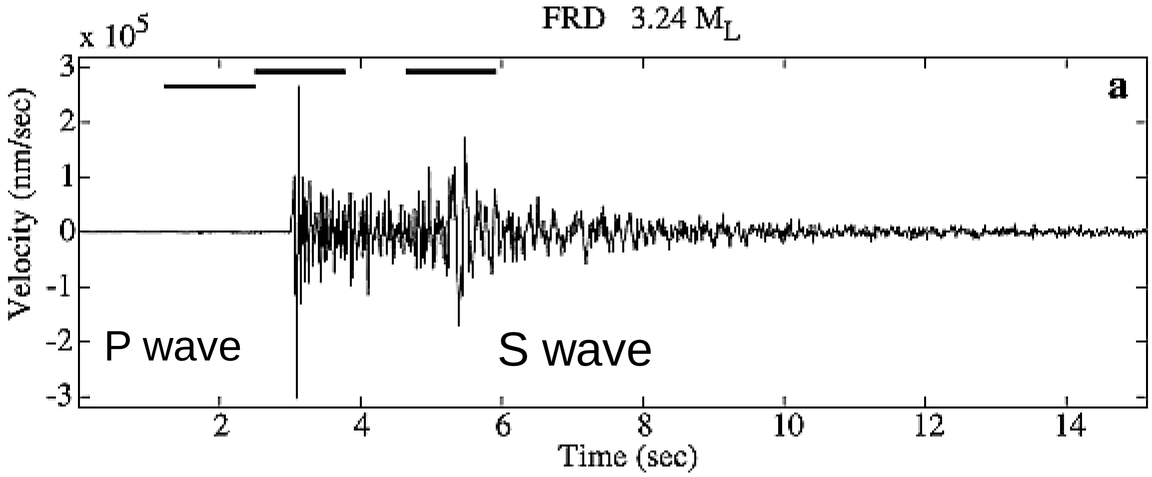


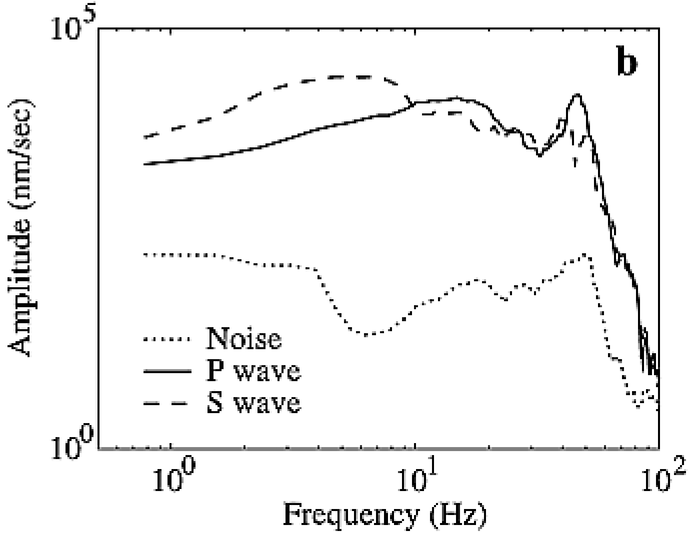
Modern test of earthquake scaling law

Prieto, Shearer and Vernon, JGR, 2004

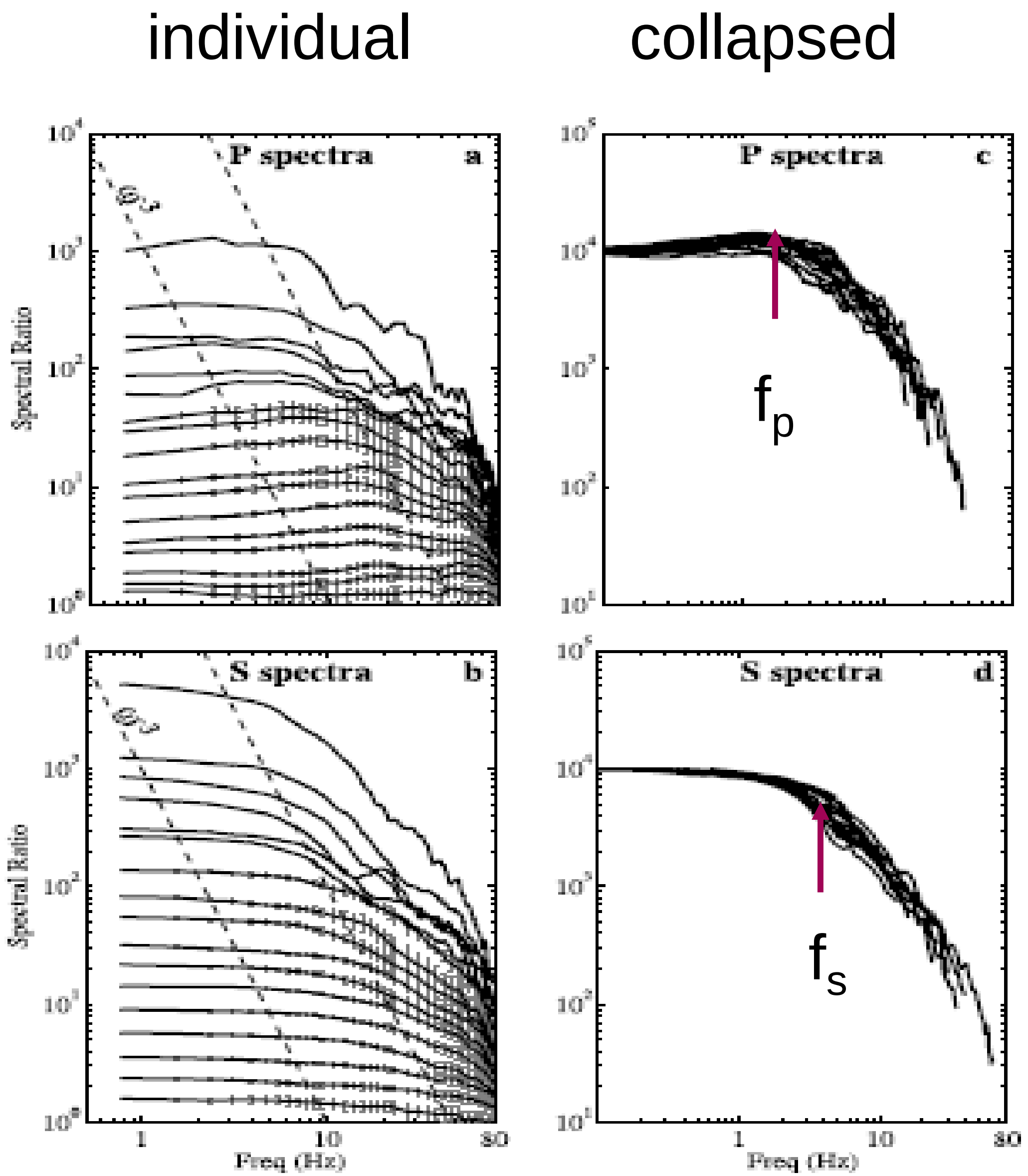


Spectral analysis of California earthquakes





Modern tests of earthquake scaling law



Test by Prieto et al
JGR, 2004

$$f_p / f_s = 1.6$$

Circular crack model

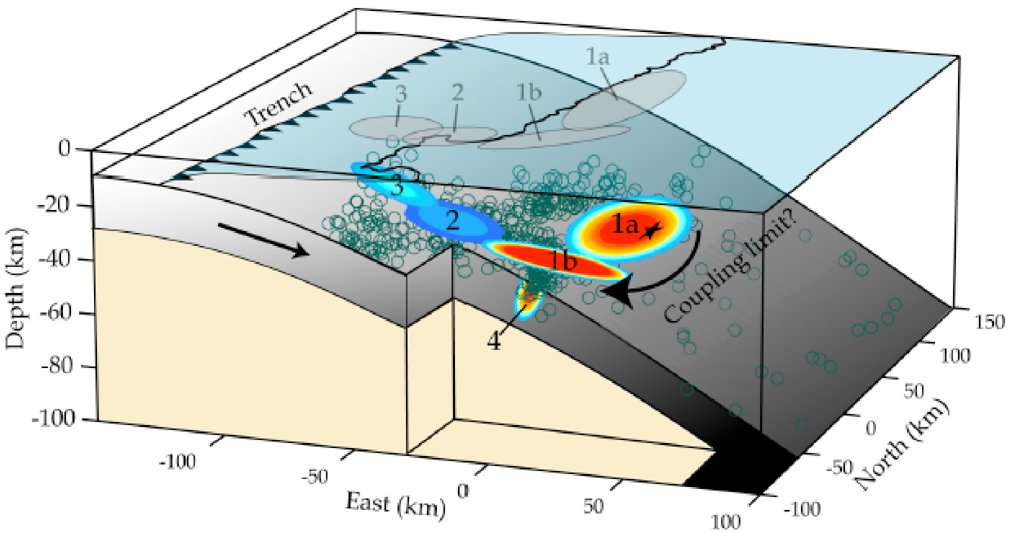
$$f_p / f_s = 1.7$$

(Madariaga, 76)

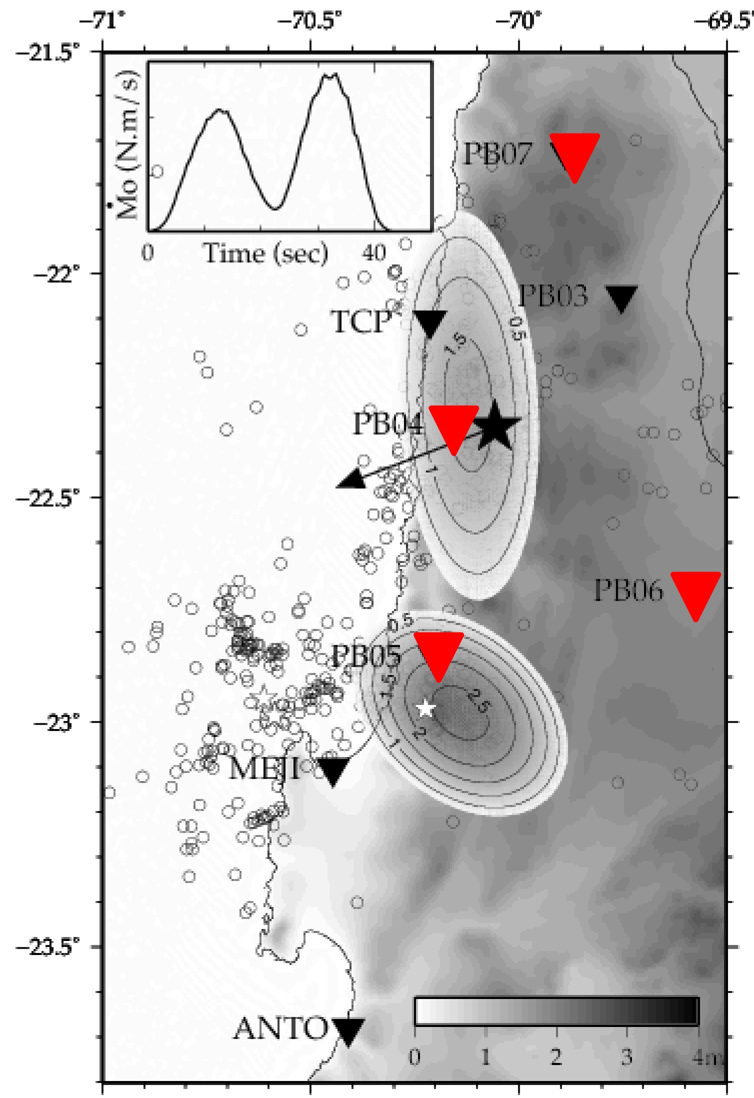
The Tocopilla Earthquake of 21 November 2007

A double event at the bottom
of the plate interface

Mw=7,8 Mo = 2,5 10^{20} Nm

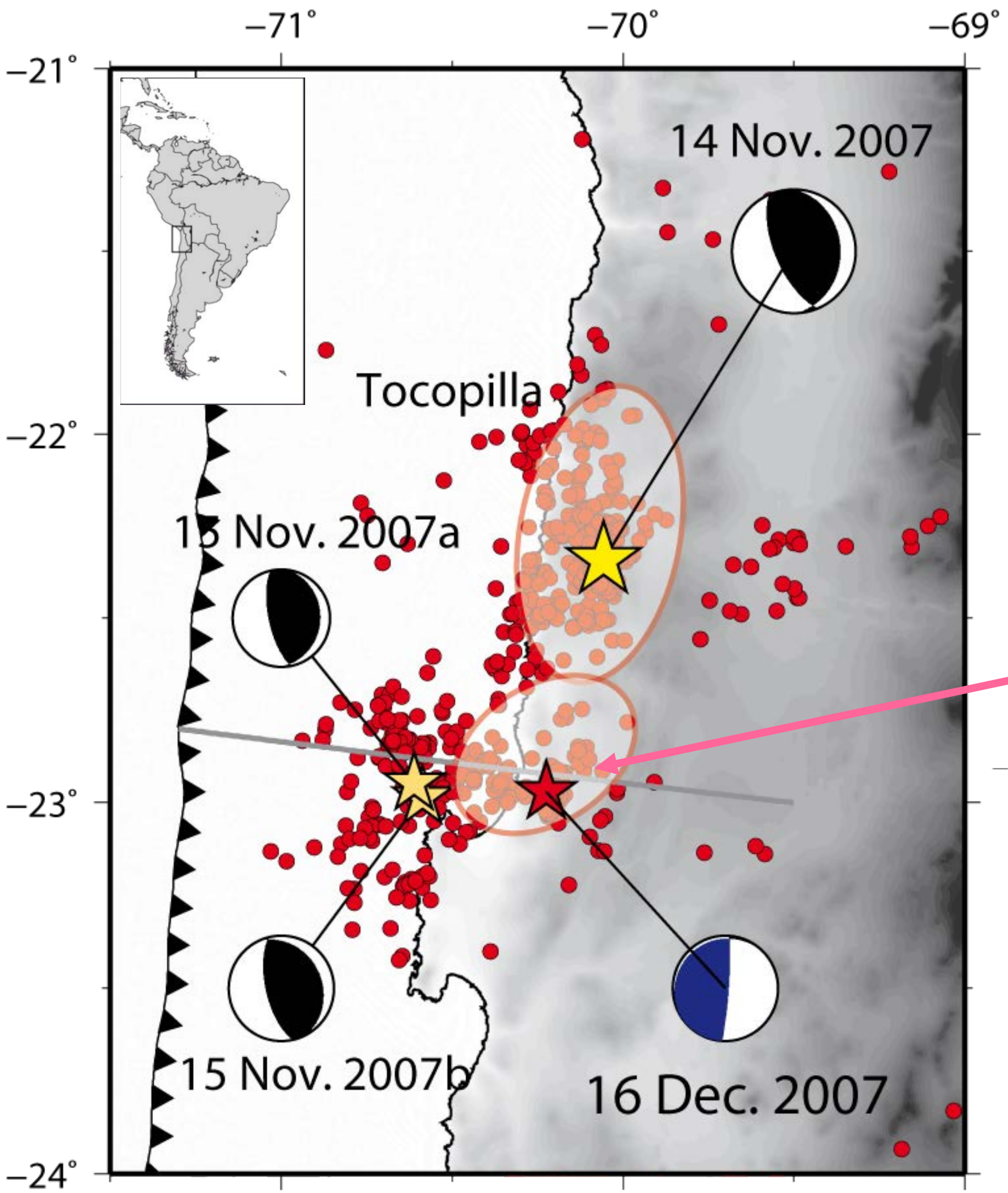


From Peyrat et al (GJI 2010)



Inverted triangles accelerograms
In red PBO stations used for this study

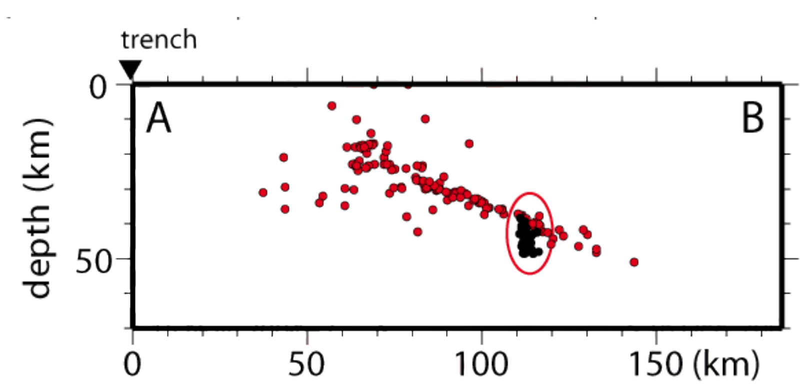
The Tocopilla earthquake sequence in Northern Chile



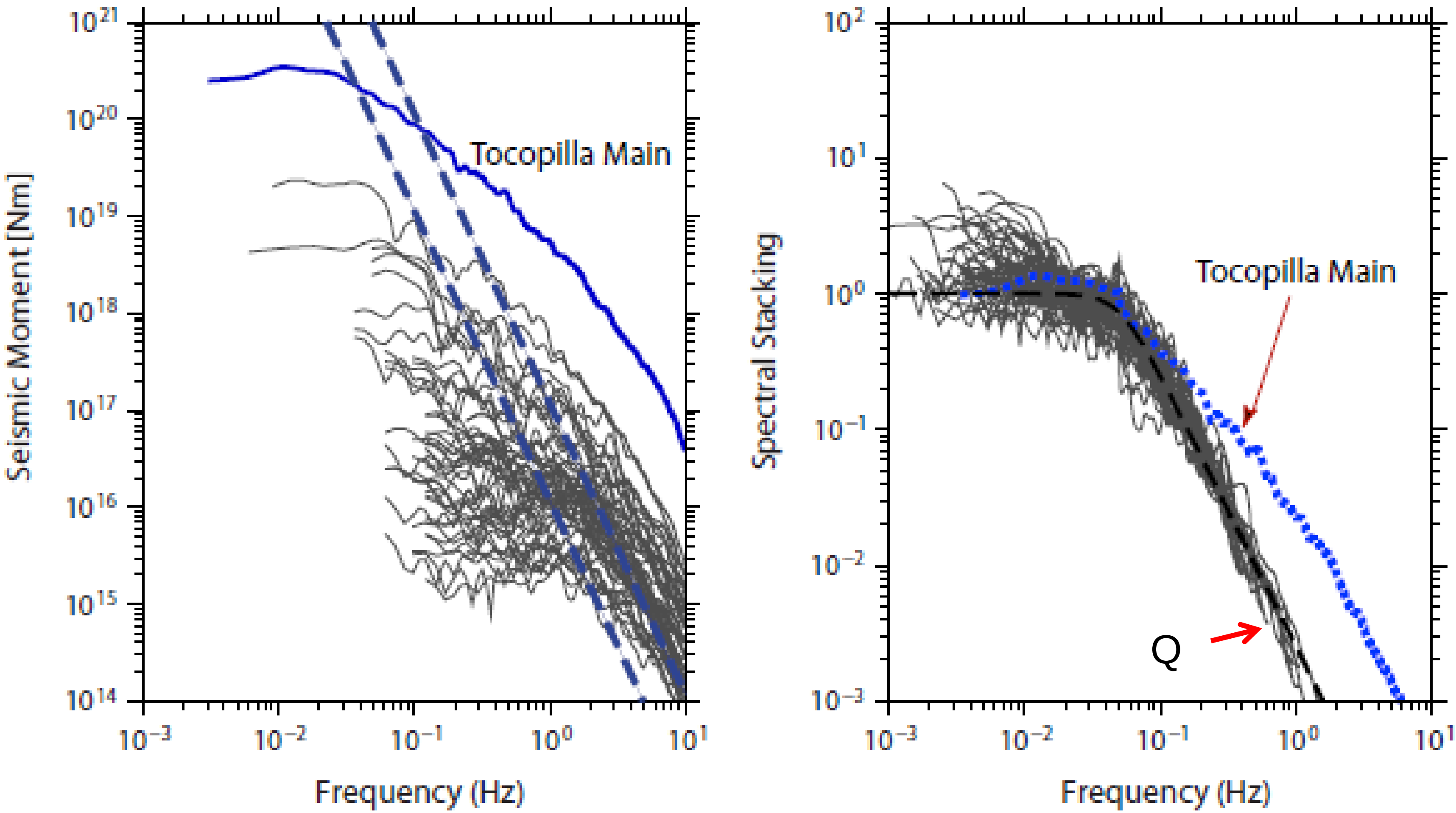
Main event Mw 7.7
on 14 November 2007

Two main aftershocks on
15 November 2007

Deep slab push aftershock
16 December 2007

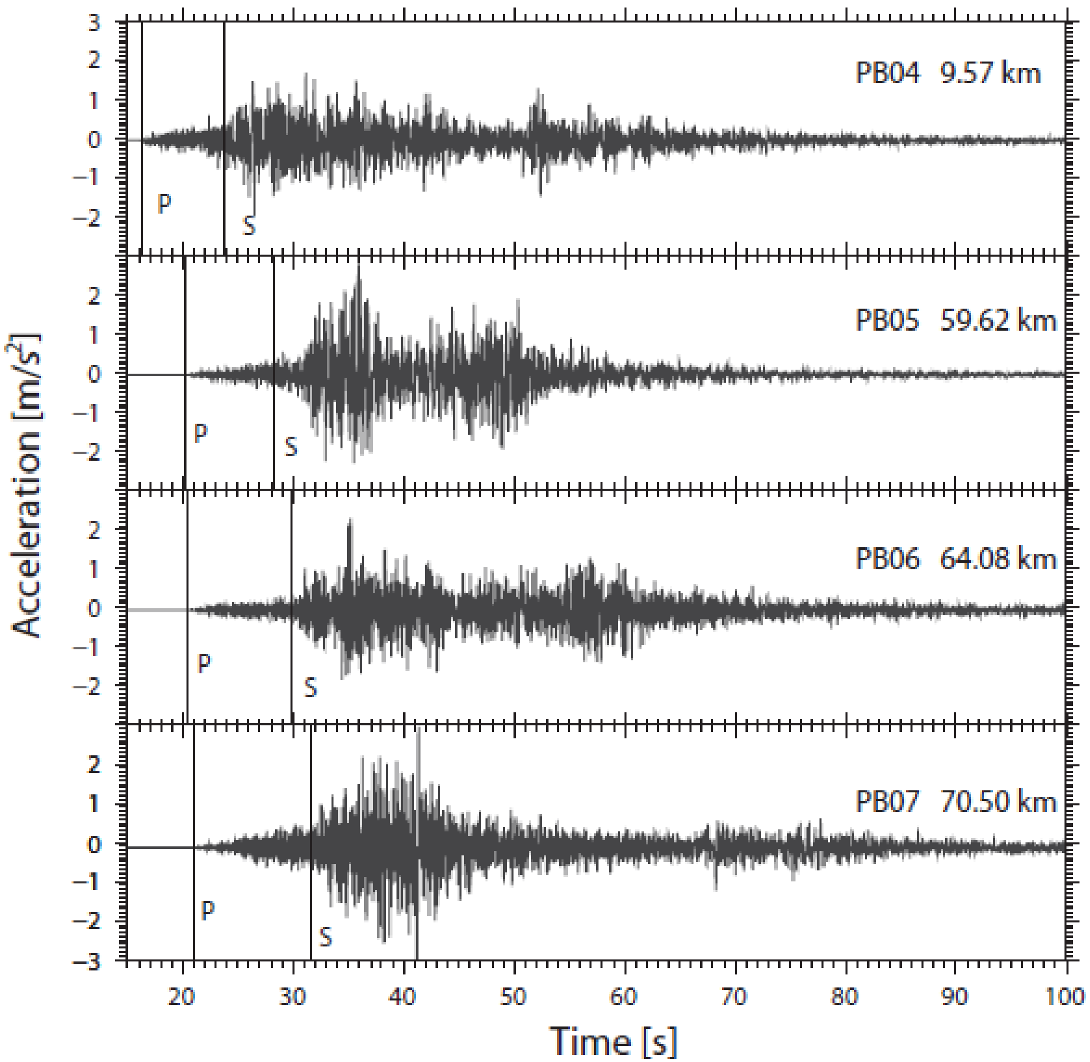


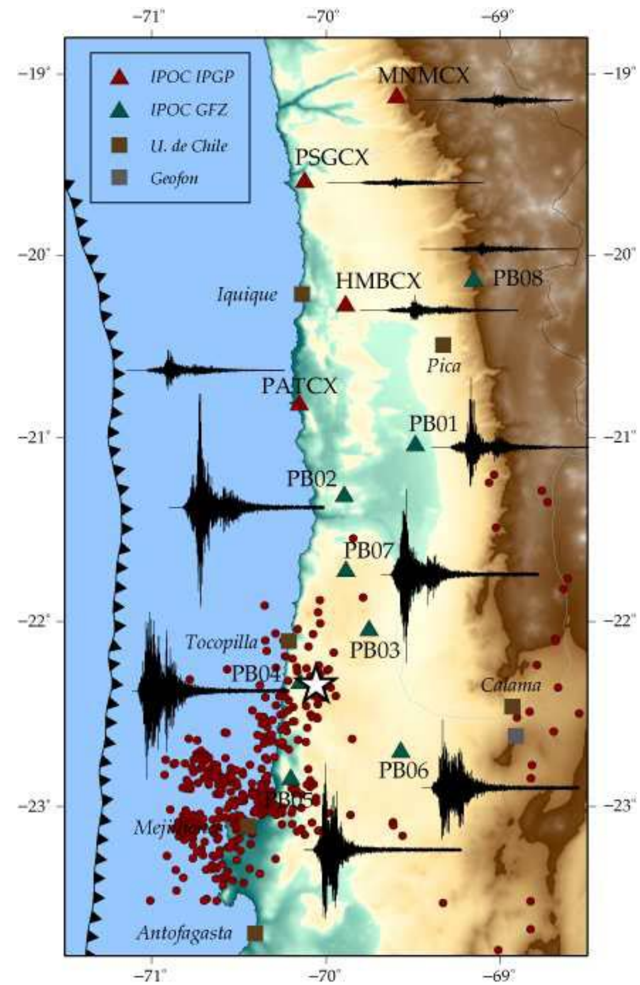
Spectral stack of a set Tocopilla aftershocks



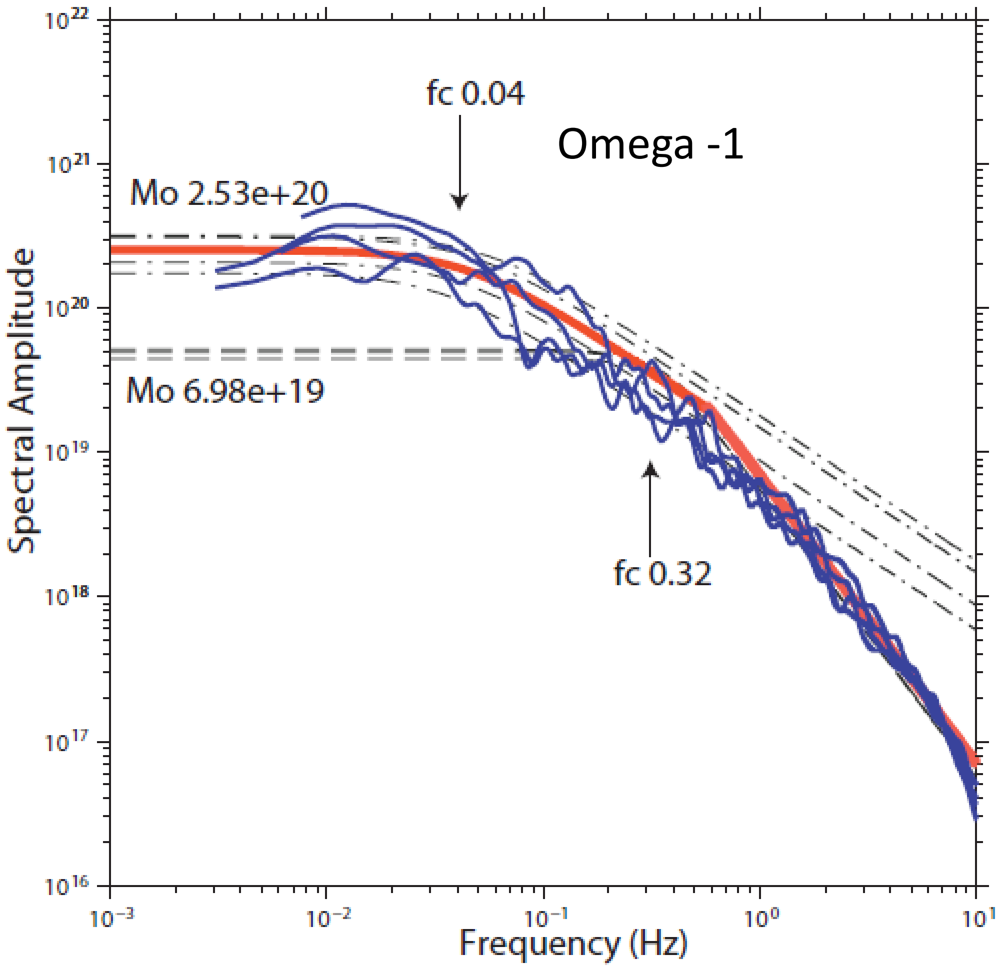
From Lancieri et al (GJI 2012)

Acccelerograms of the main Tocopilla earthquake





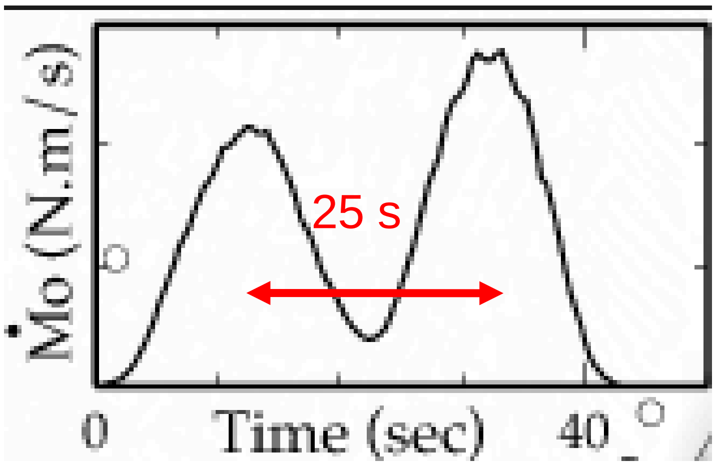
Espectro de desplazamiento del Terremoto de Tocopilla de 2007 observado en 4 estaciones de la red PBO



Stations

PB04
PB03
PB05
PB07

Moment rate

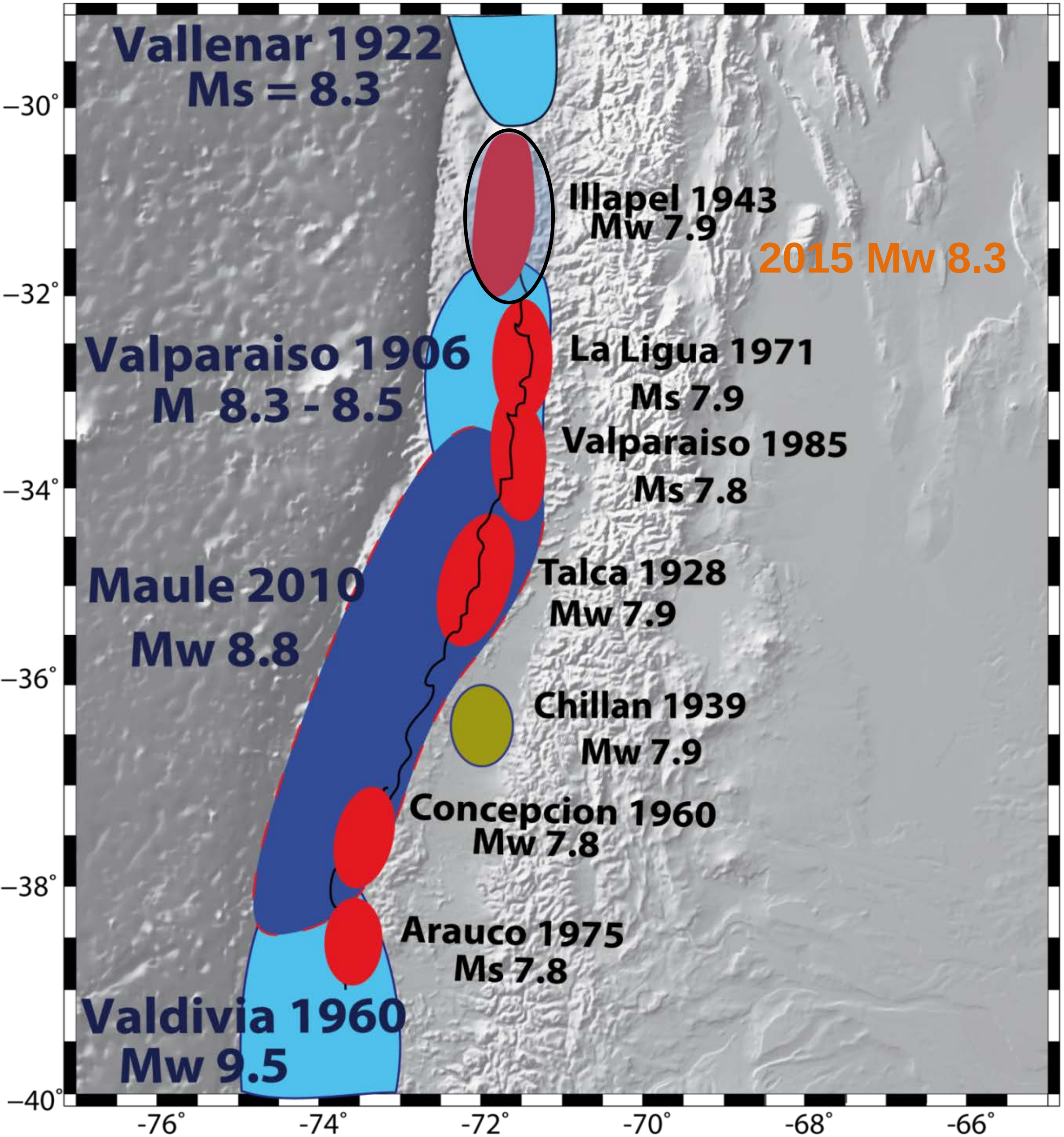


From Lancieri et al (GJI 2012) and Peyrat et al (GJI 2010)

How to model an earthquake: Maule 27 Febrero 2010

Ch. Vigny

Central Chile Seismicity since 1906

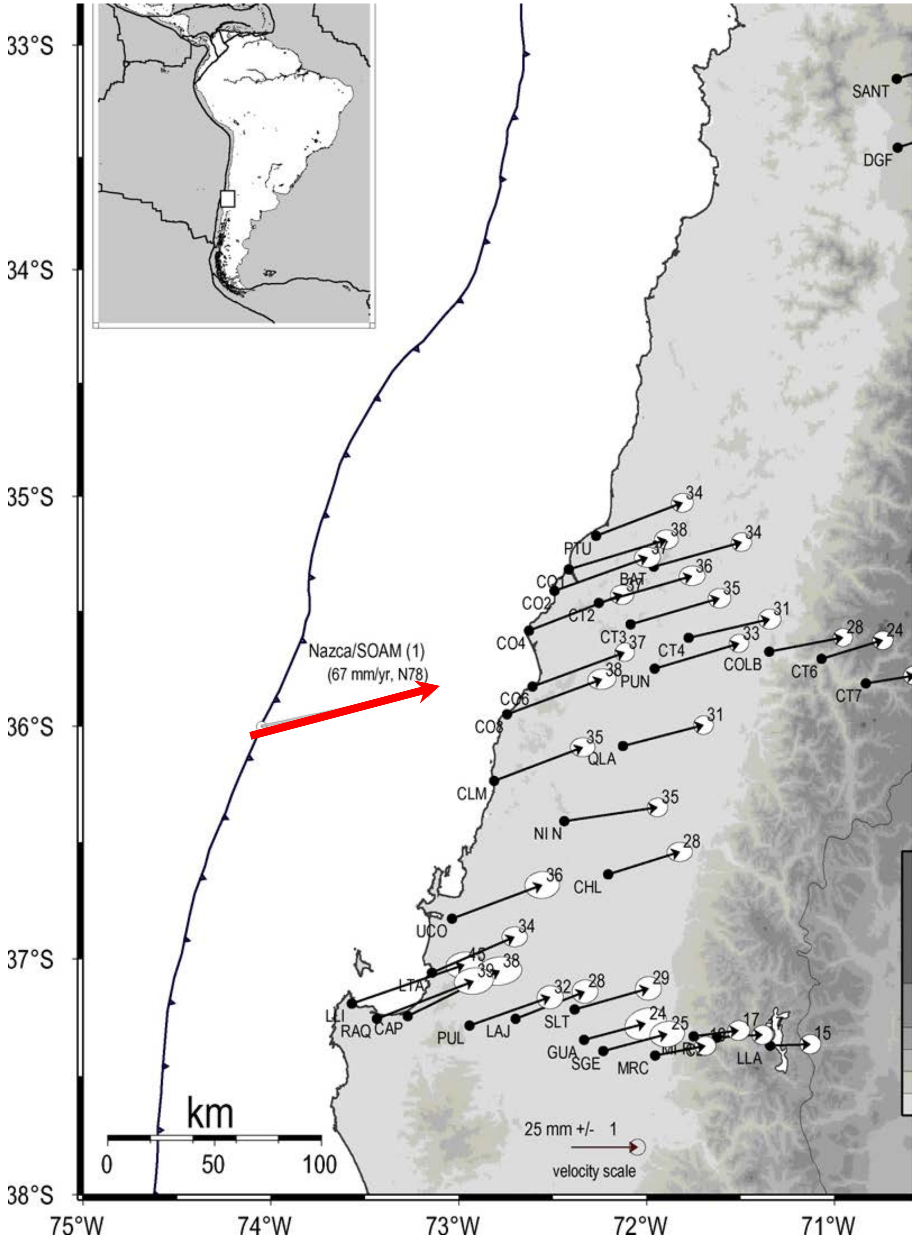


Central Chile

Mw>7.8

From Campos et al, 2002

Preseismic deformation from GPS

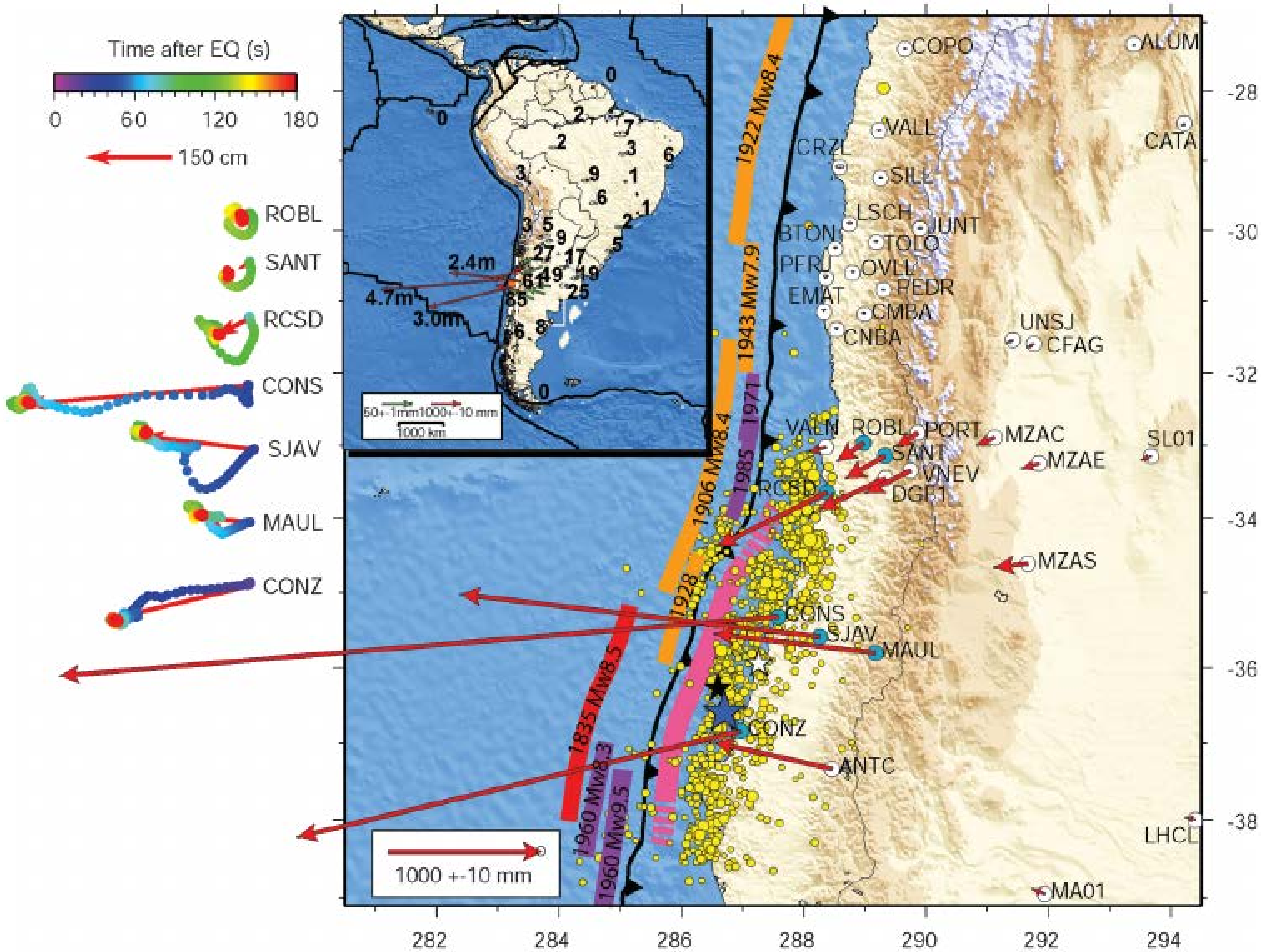


« We would then conclude that the southern part of the Concepción–Constitución
gap has accumulated a slip deficit that is large enough to produce a very large earthquake of about Mw= 8.0–8.5. »

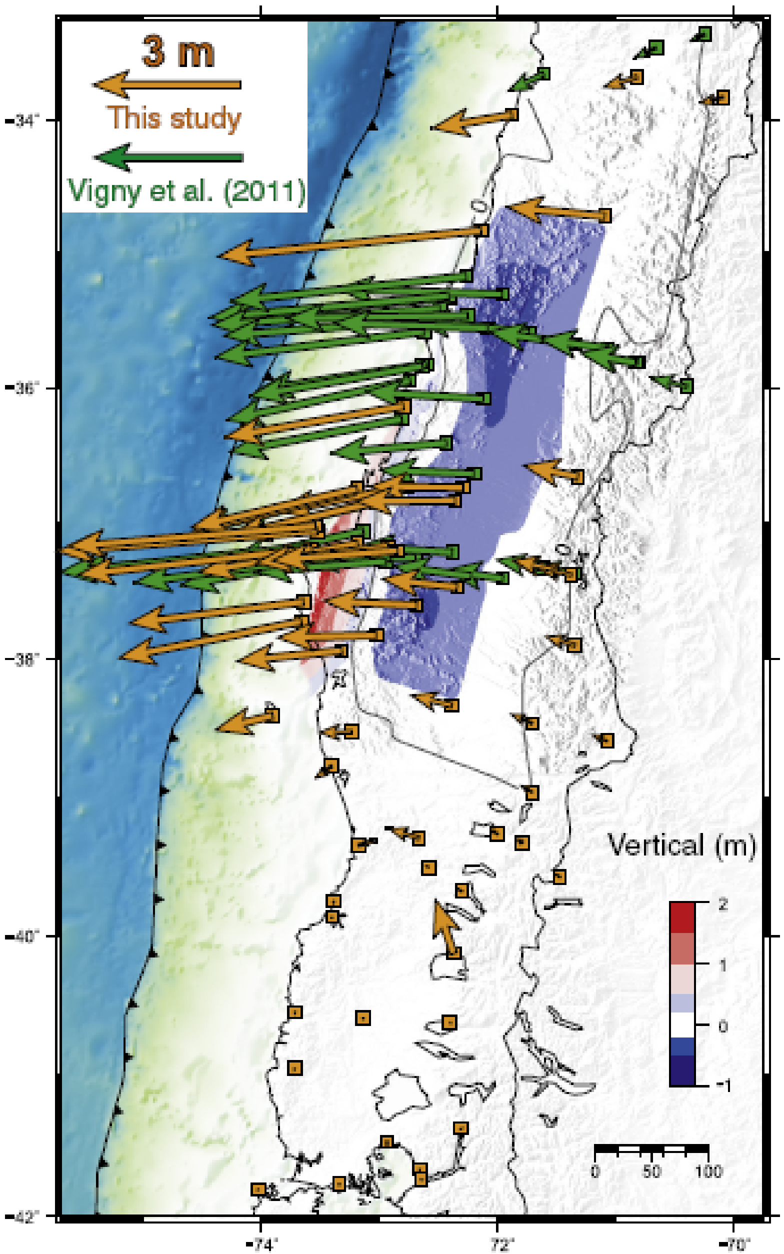
This is of course a worst case scenario that needs to be refined by additional work.

(Campos, Ruegg, Vigny, R.M. et al, 2002, 2003, 2009)

Ground displacement from GPS stations for theMaule earthquake of 2010



Static GPS observation of the Maule 2010 earthquake

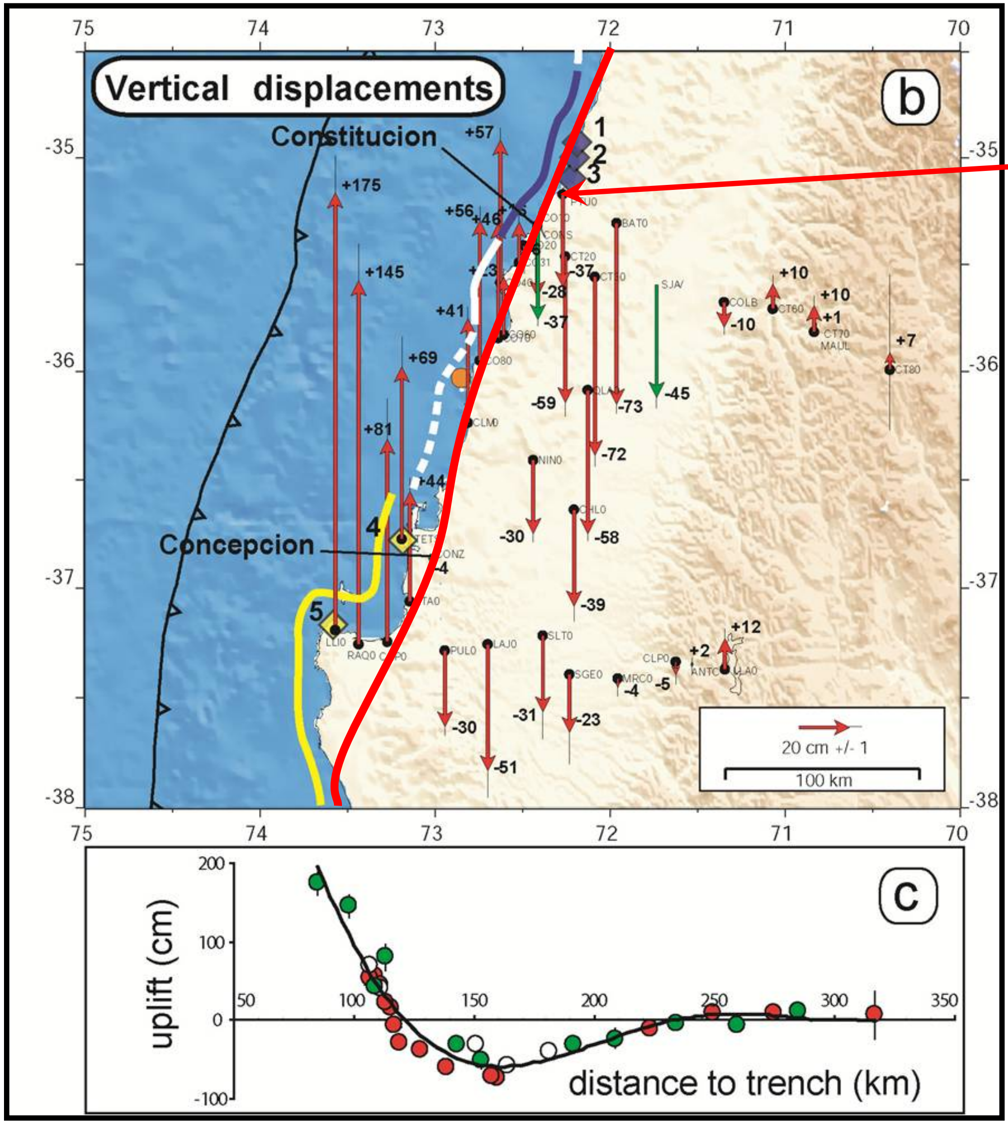


Rupture zone
400 km

Vigny et al, Science, 2011

Moreno et al, EPSL, 2012

Vertical displacements measured by GPS



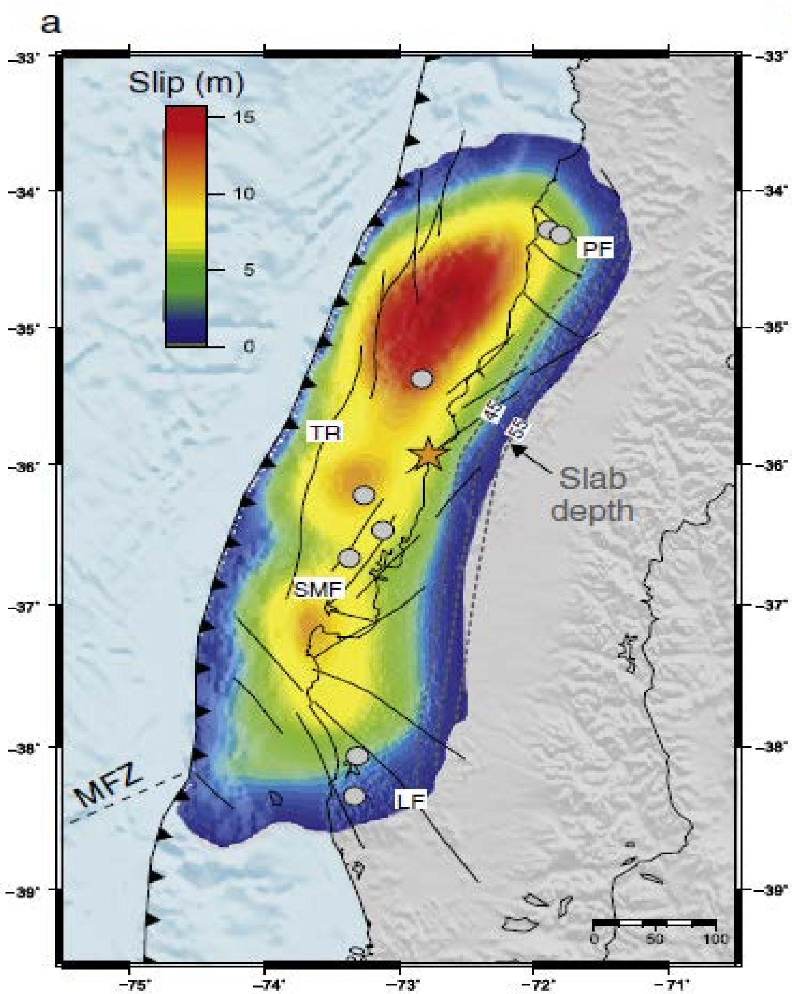
Hinge line

Color diamonds
Vertical displacement
of biological markers

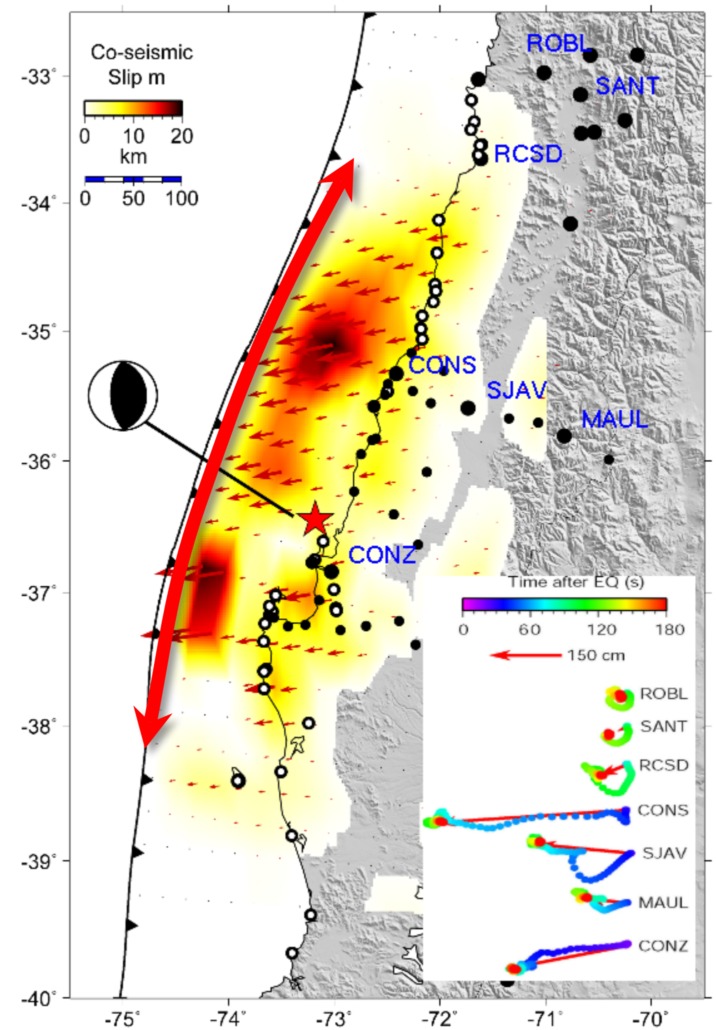
(Farias et al, 2010)

From Vigny et al, 2011

Inversion of Geodetic slip distribution

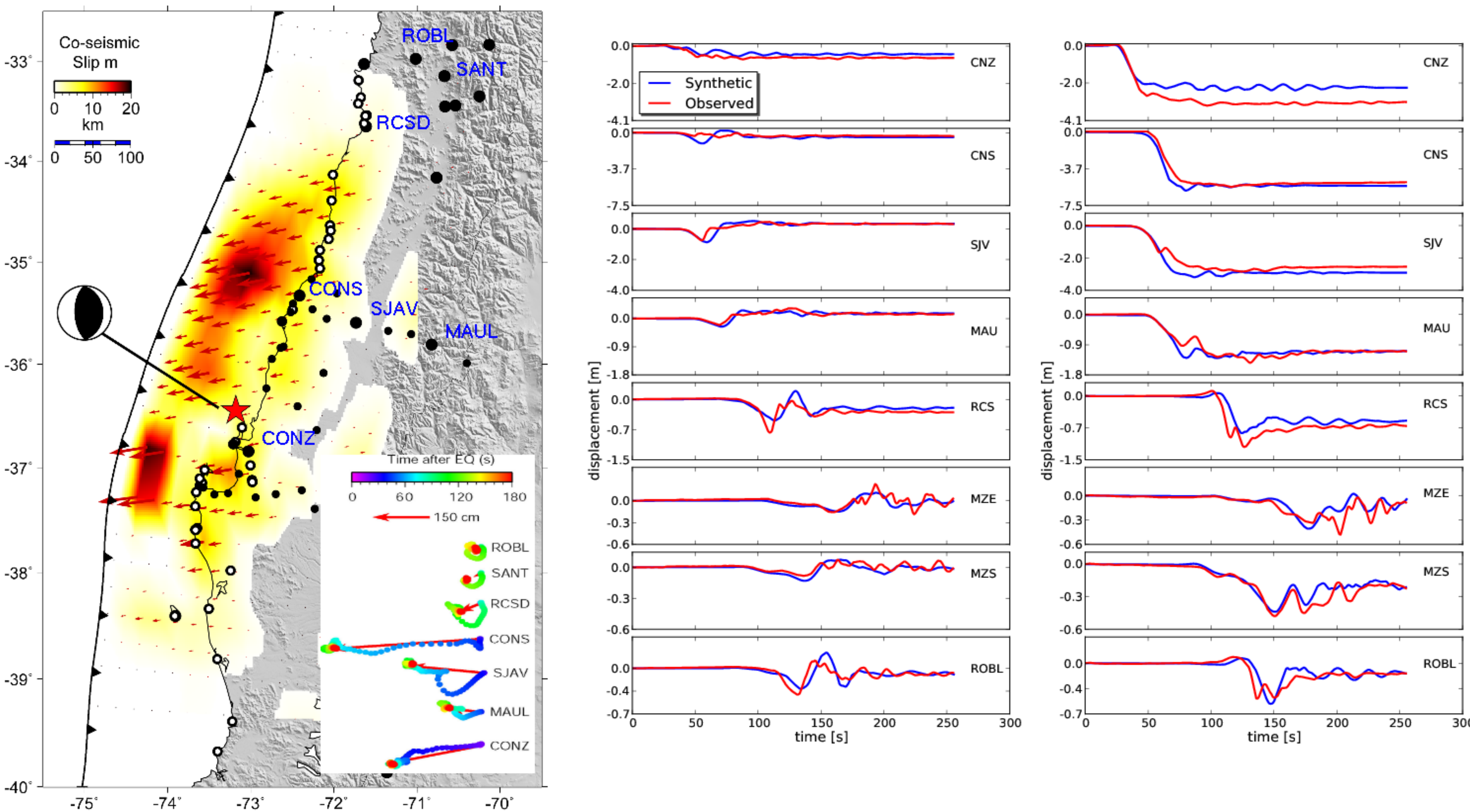


Moreno et al 2012



Vigny et al 2012

Modelling the near field GPS data for the Mw 8.8 Maule 2010 earthquake

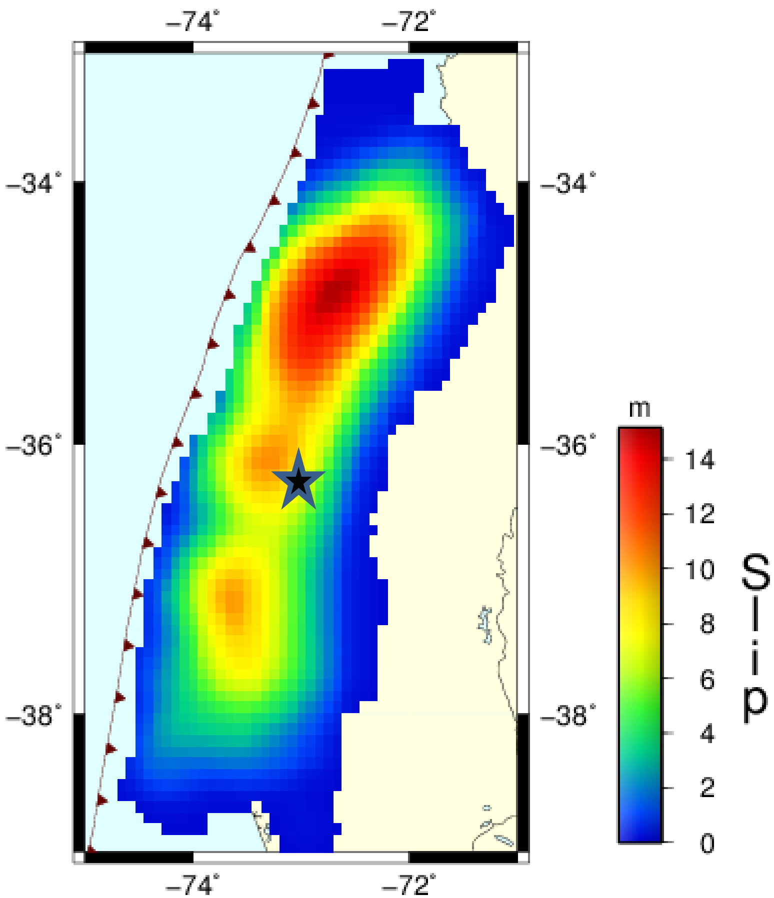


From Vigny et al Science (2011)

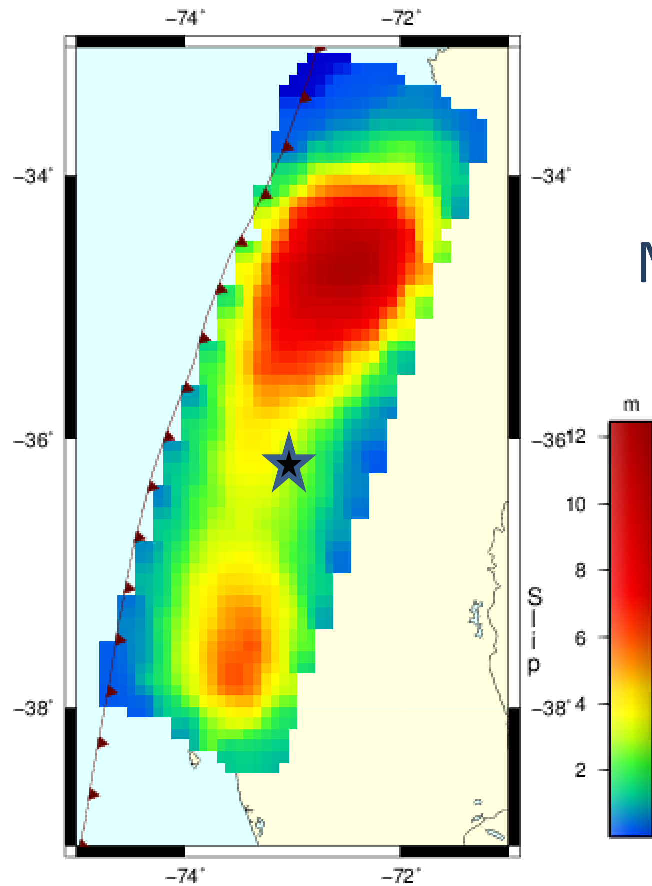
Maule 2010: geodetic versus Far field BW inversion

Slip inverted from GPS

Slip Inverted from Far field body waves



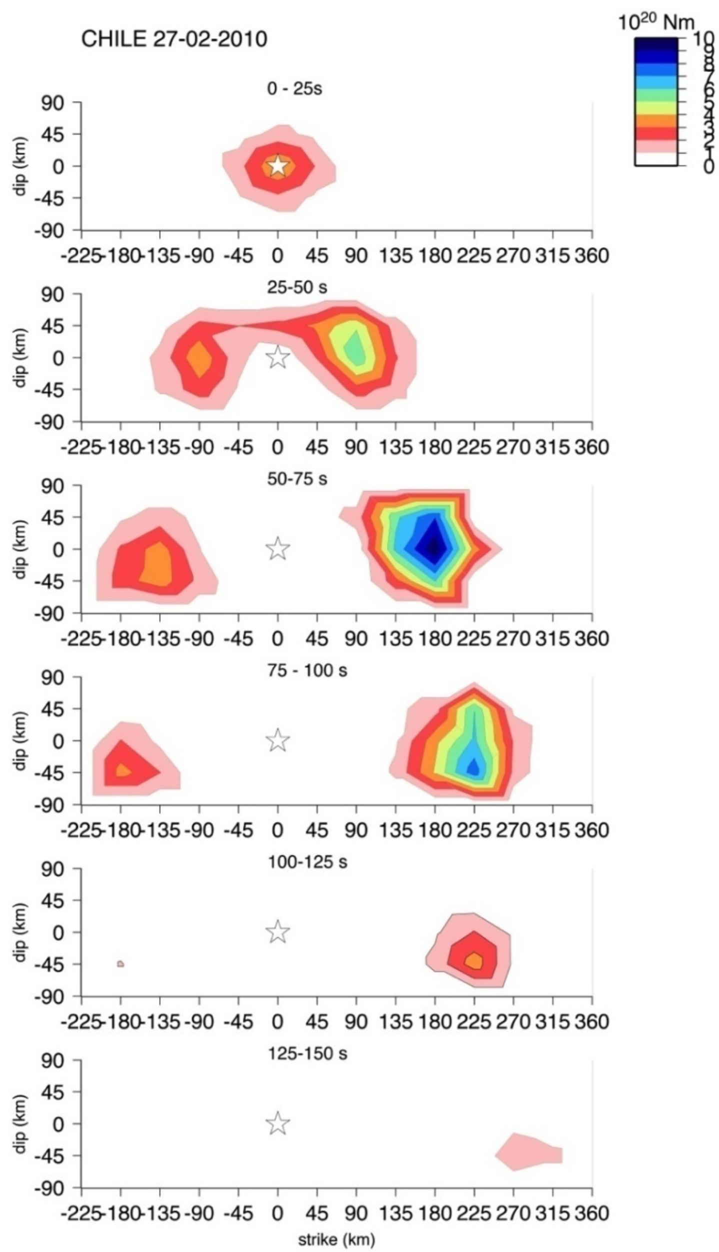
Moreno et al (EPSL, 2012)

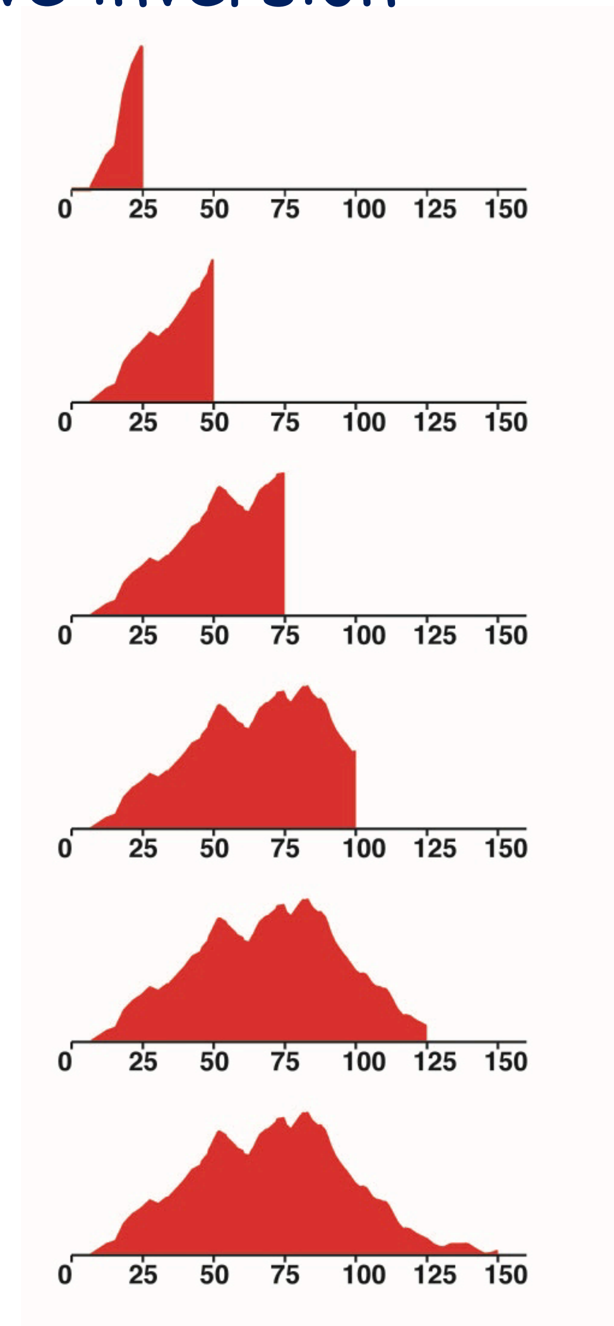


Mw = 8.8

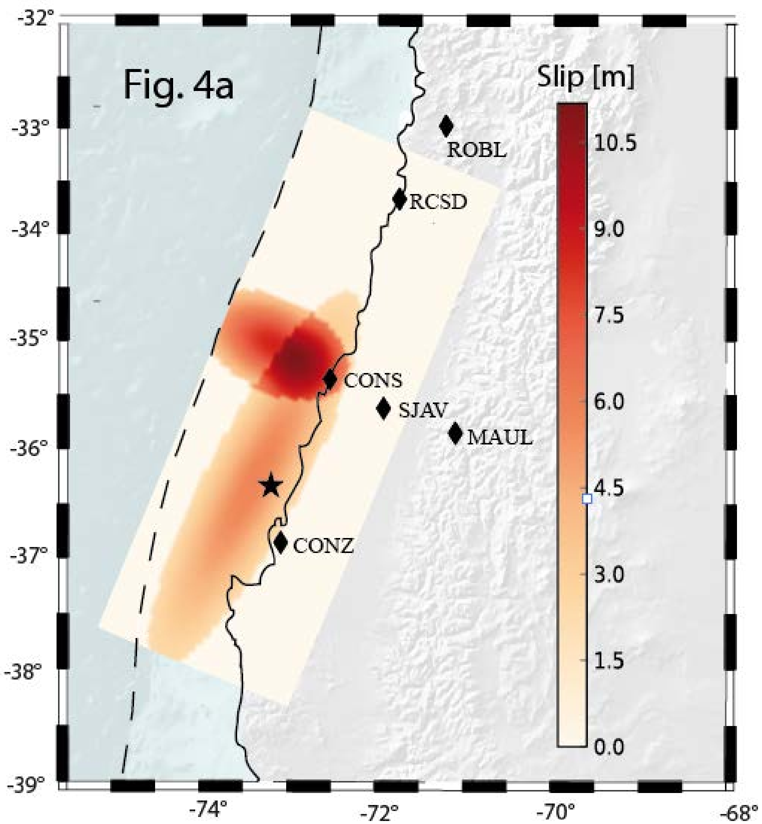
Pro, Buforn, Madariaga (EGU 2013)

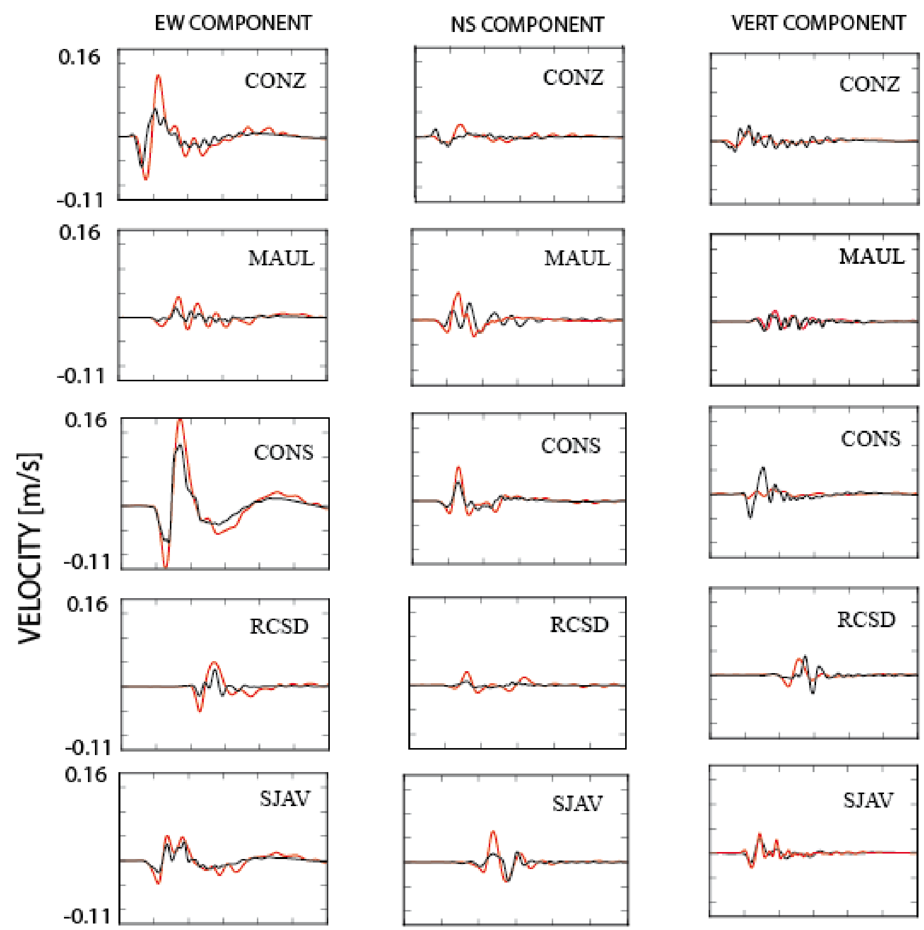
Maule 2010: Far field Body wave inversion





Ground velocity inversion from cGPS
Uses AXITRA for synthetics

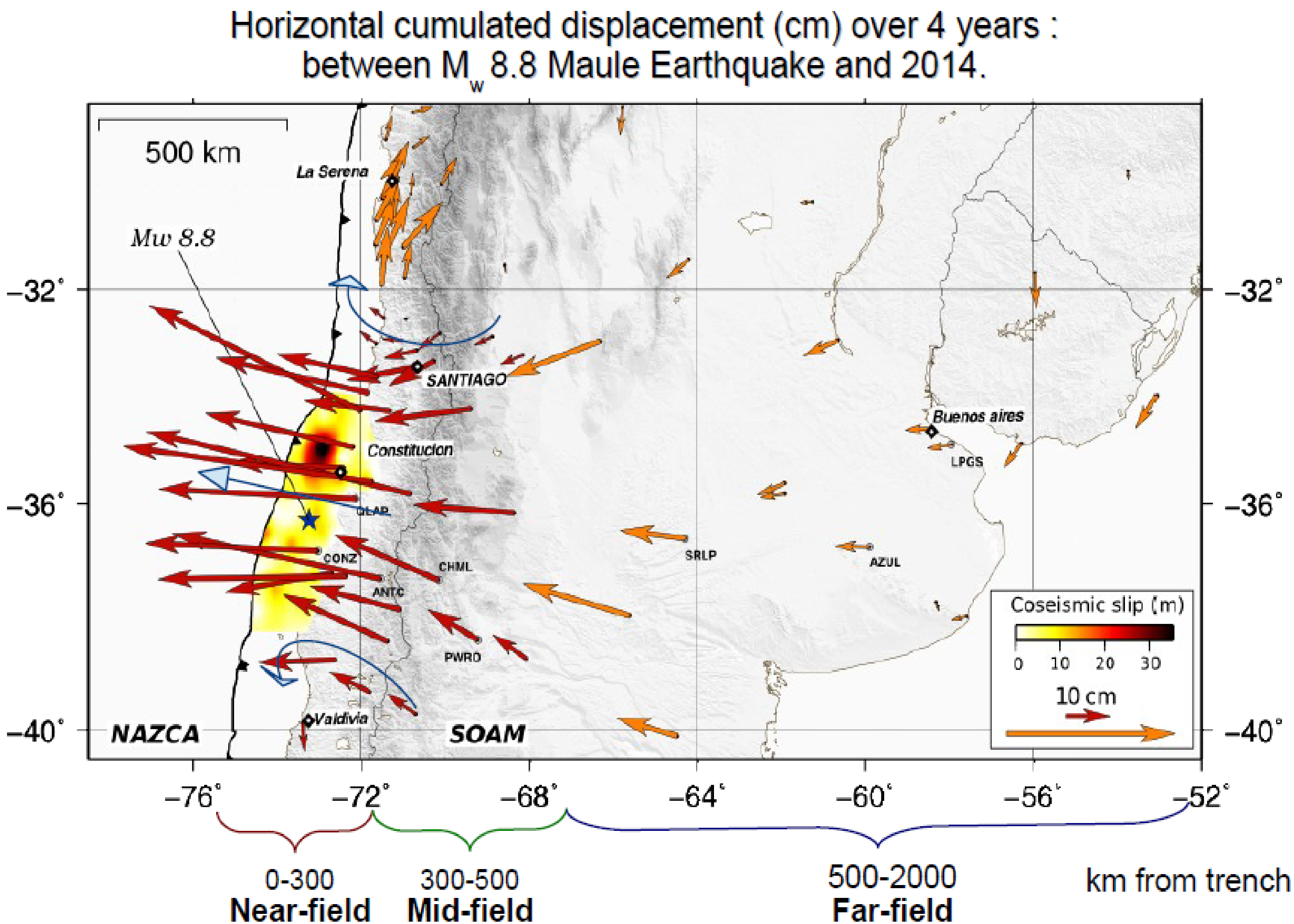




Ruiz Madariaga, unpublished

Ruiz et al, Earthquake Spectra, 2012

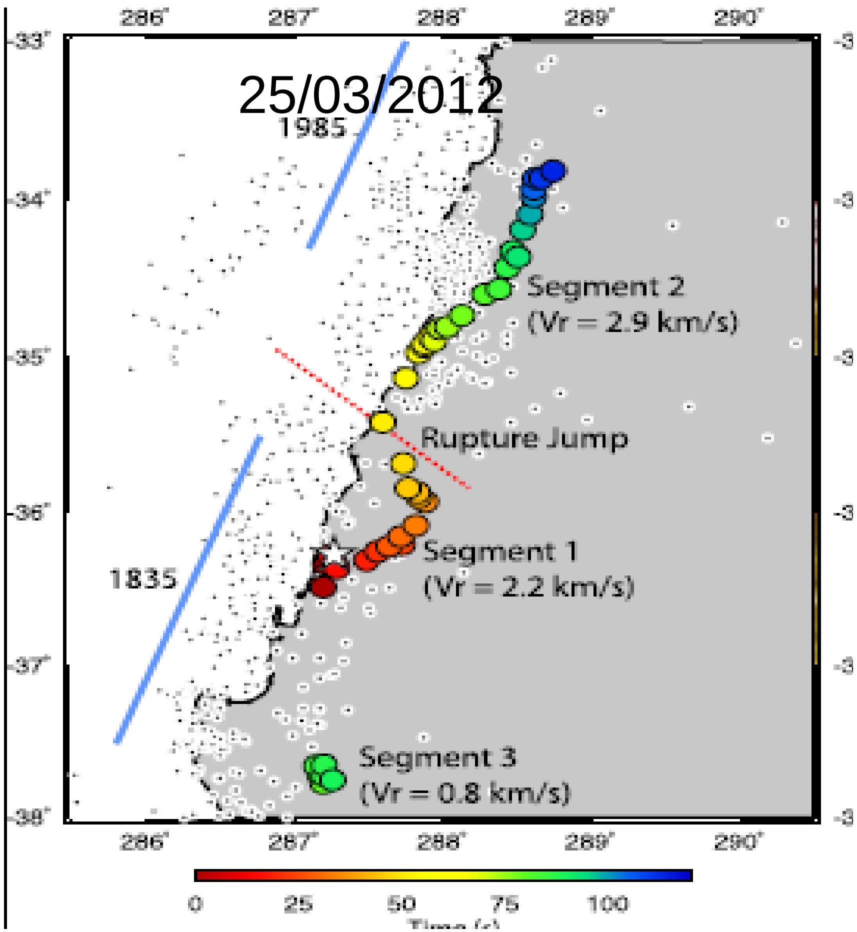
Postseismic deformation after Maule



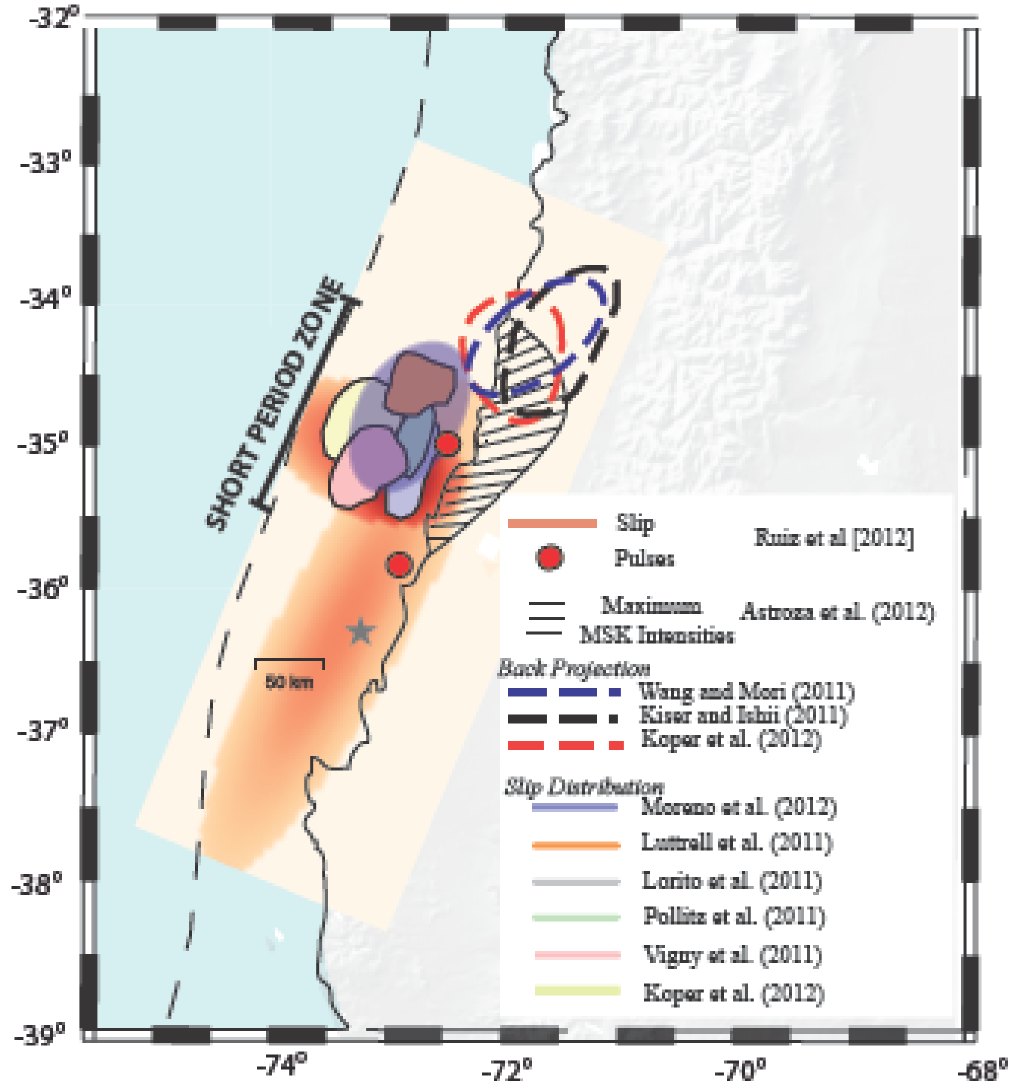
E. Klein et al, 2015, Ruiz et al, 2015

Use of stacking and backprojection for modelling High frequency features

Low and High Frequency features of Maule 2010
Uses Backprojection

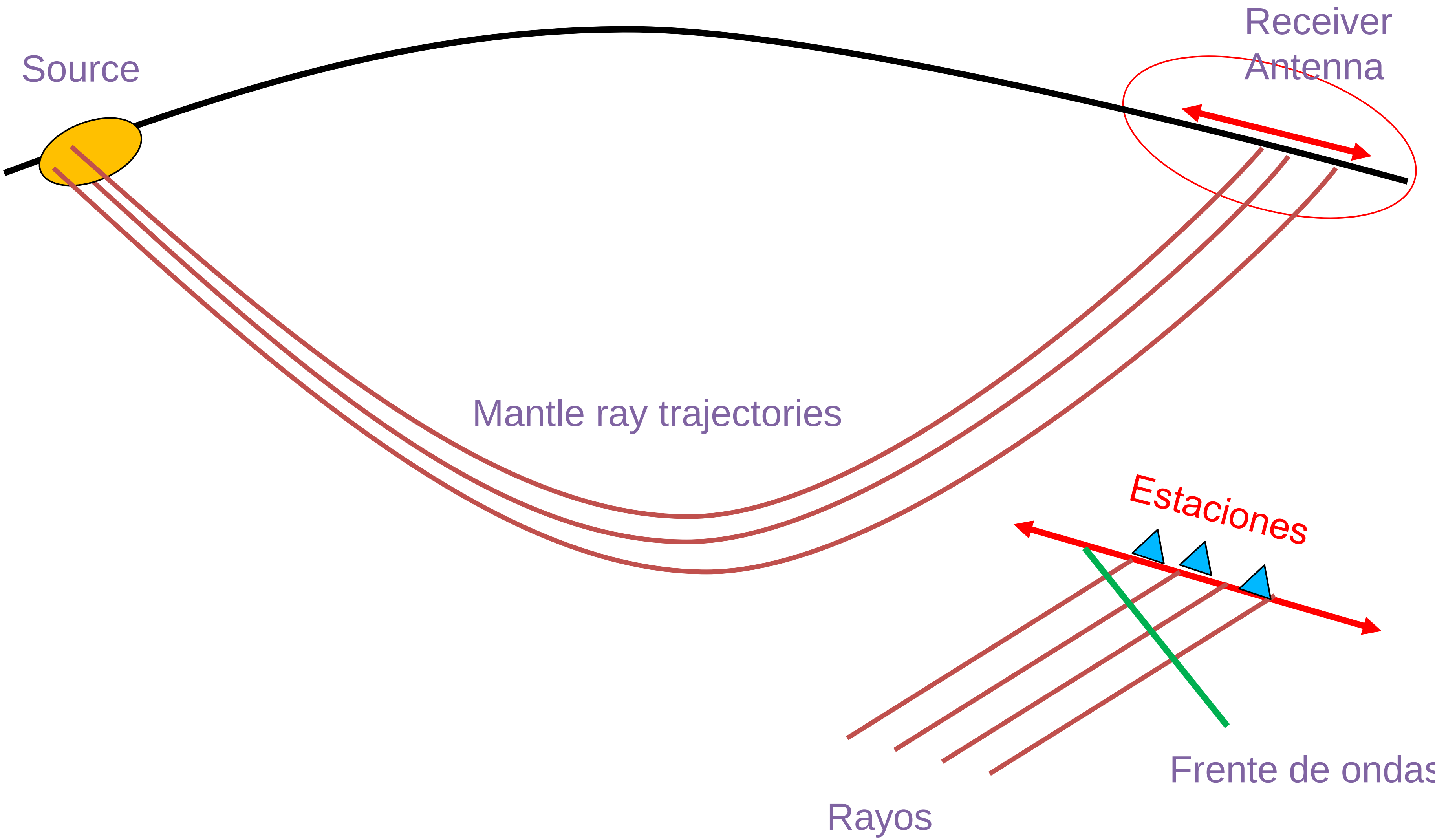


Kieser and Ishii, 2011



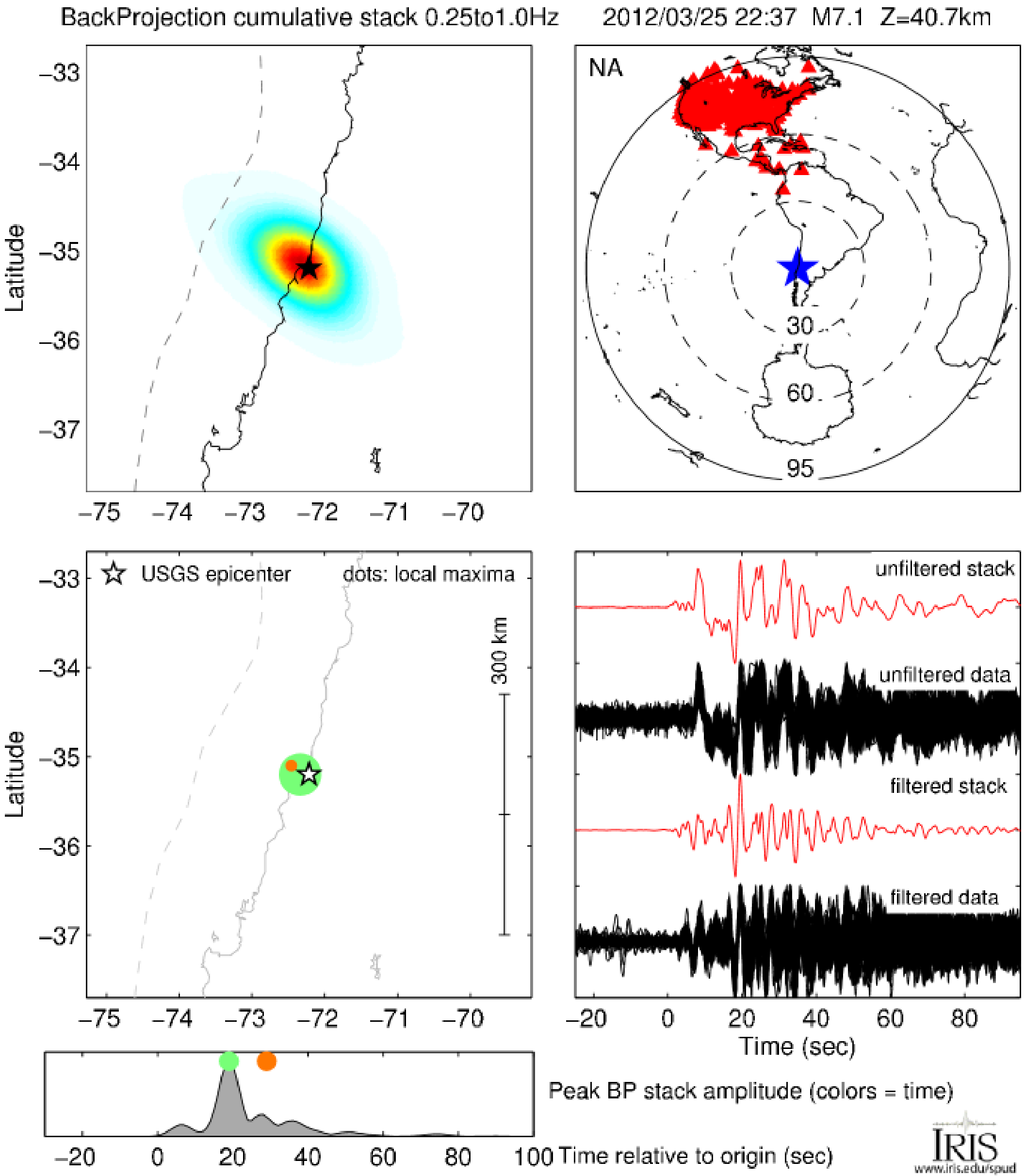
From Ruiz et al, 2012

Use of seismic antennaes for stacking



Use of a seismic receiver antenna

Example of Maule aftershock Mw 7.1 of 25/3/2012   near Constitucion

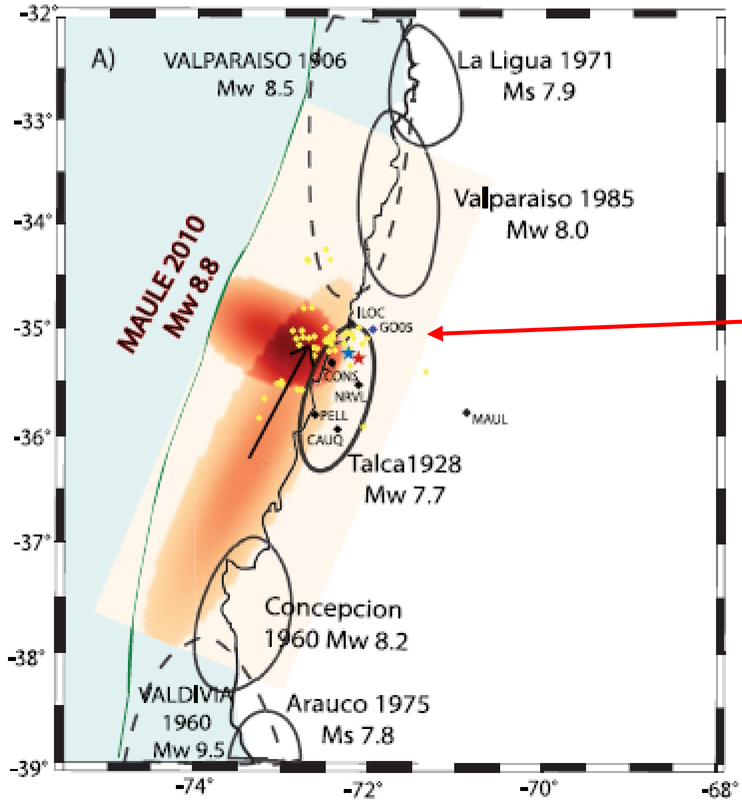


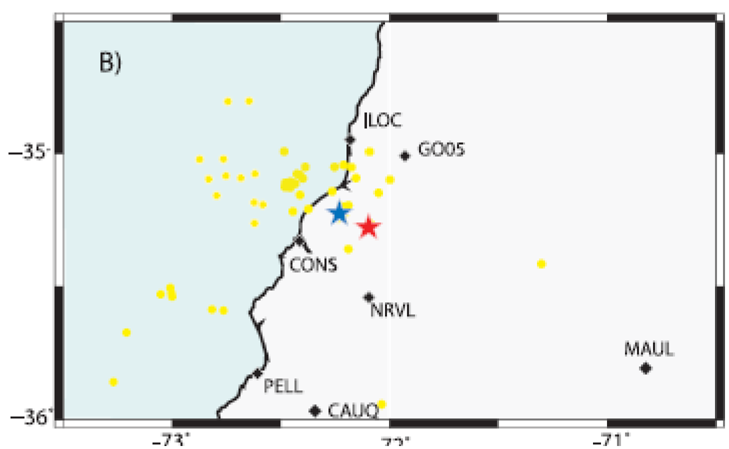
From SPUD in IRIS Data Center

http://ds.iris.edu/spudservice/data/1586357

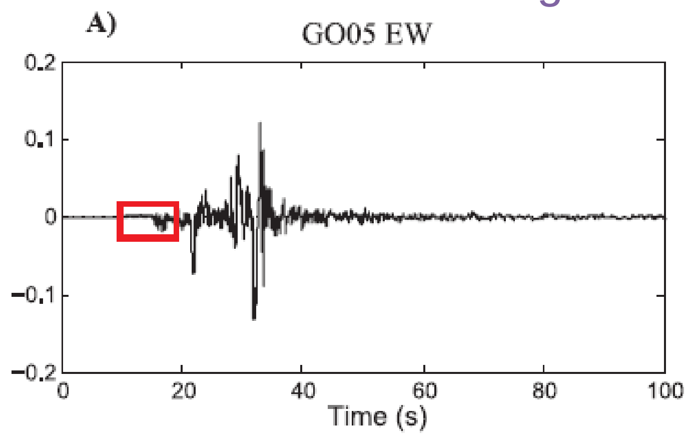
Ruiz et al, EPSL 2013

Example of Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion

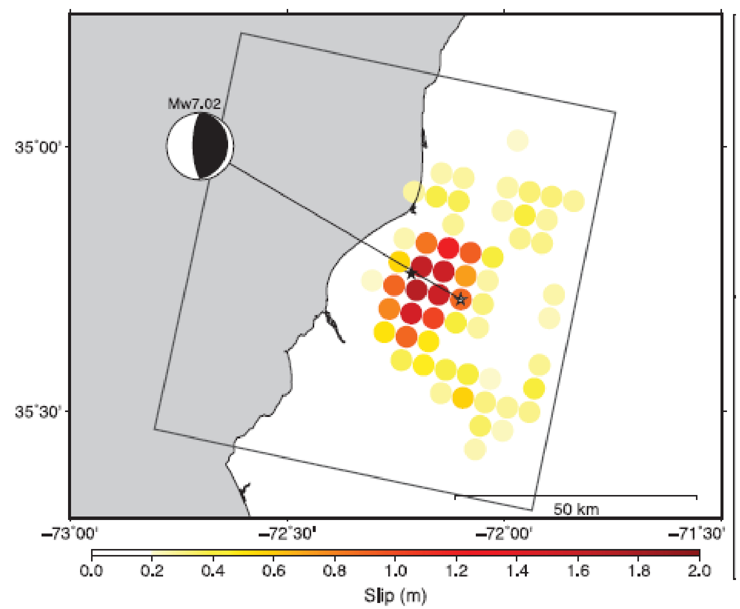




Near field Accelerogram

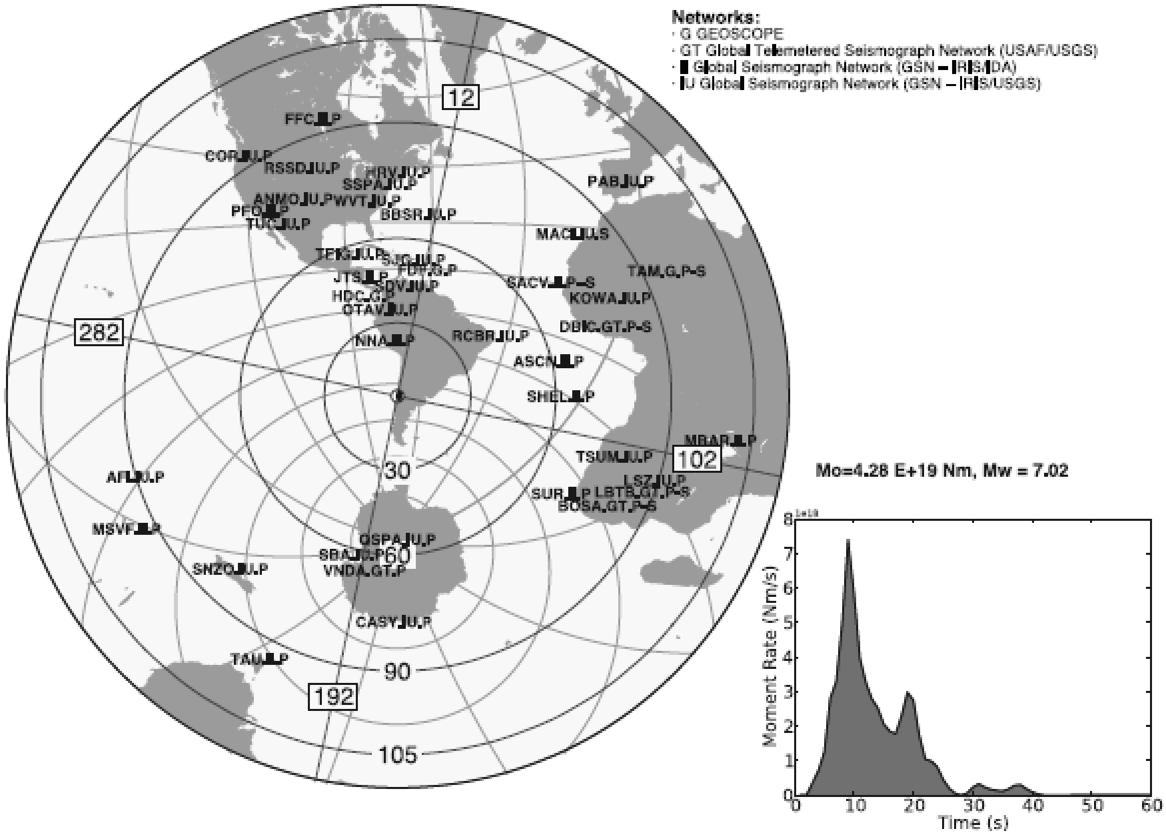


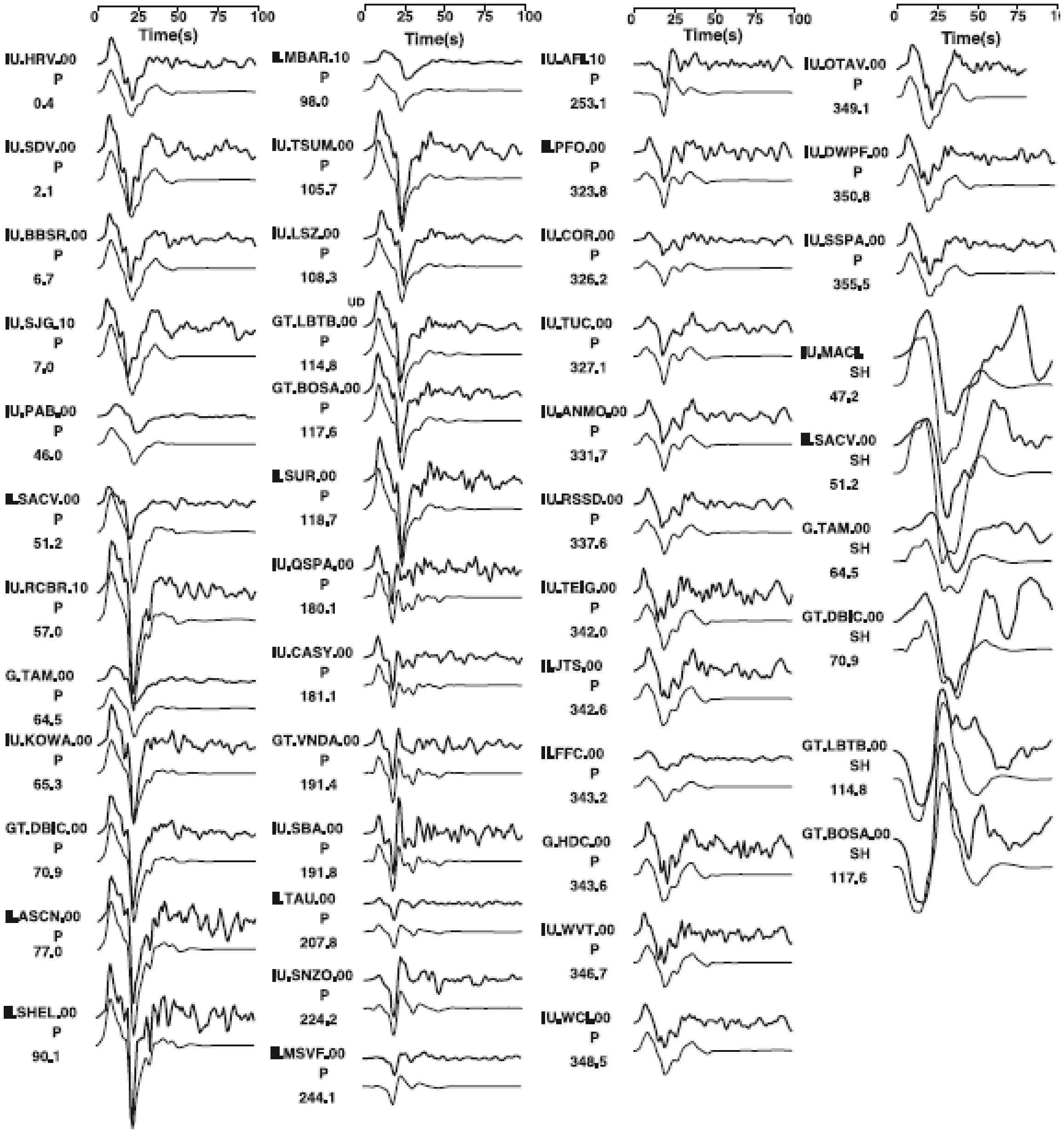
Seismic source



Example of Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion

Far field body wave modellig



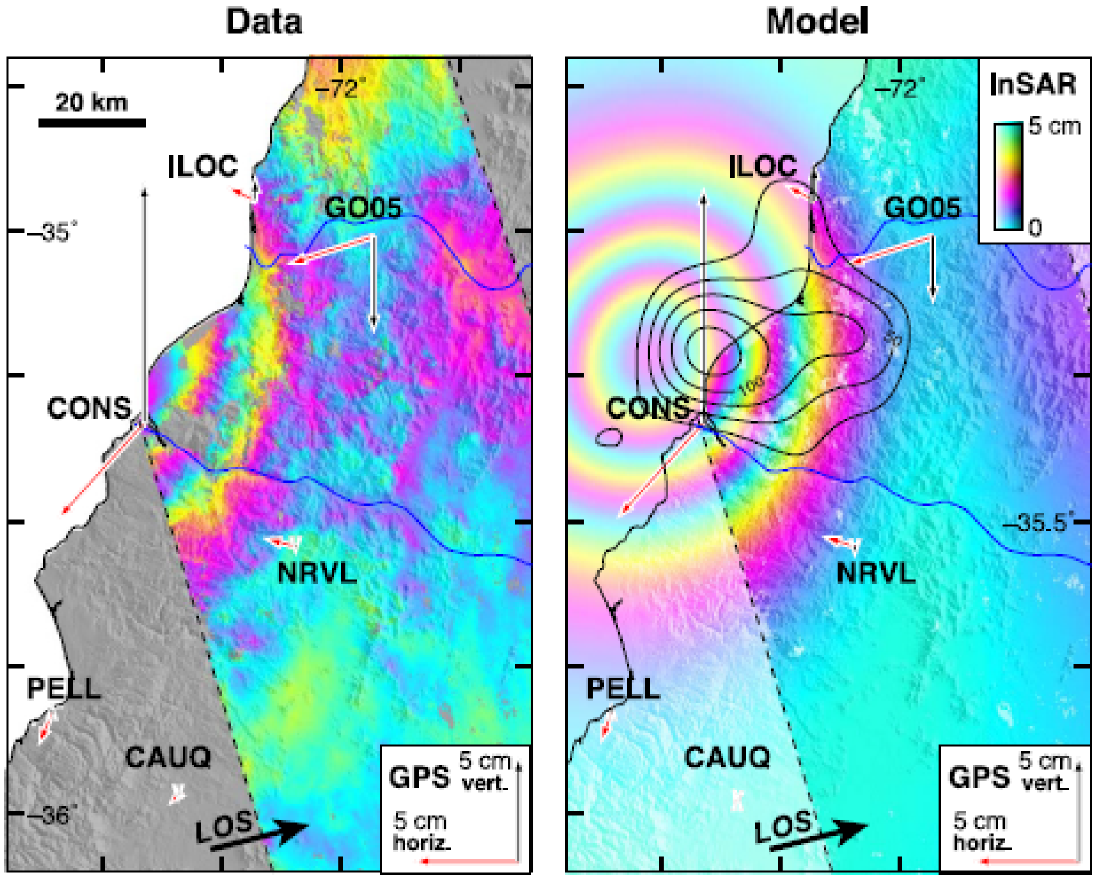


0 25 50 75 100
Time(s)
IU.HRV.00 P 0.4
IU.SDV.00 P 2.1
IU.BBSR.00 P 6.7
IU.SJG.10 P 7.0
IU.PAB.00 P 46.0
SACV.00 P 51.2
IU.RCBR.10 P 57.0
G.TAM.00 P 64.5
IU.KOWA.00 P 65.3
GT.DBIC.00 P 70.9
ASCN.00 P 77.0
SHEL.00 P 90.1
MBAR.10 P 98.0
IU.TSUM.00 P 105.7
IU.LSZ.00 P 108.3
UD
GT.LBTB.00 P 114.8
GT.BOSA.00 P 117.6
SUR.00 P 118.7
IU.QSPA.00 P 180.1
IU.CASY.00 P 181.1
GT.VNDA.00 P 191.4
IU.SBA.00 P 191.8
TAU.00 P 207.8
IU.SNZO.00 P 224.2
MSVF.00 P 244.1
P 253.1
PFO.00 P 323.8
IU.COR.00 P 326.2
IU.TUC.00 P 327.1
IU.ANMO.00 P 331.7
IU.RSSD.00 P 337.6
P 342.0
P 342.6
FFC.00 P 343.2
G.HDC.00 P 343.6
IU.WVT.00 P 346.7
P 348.5
IU.OTAV.00 P 349.1
IU.DWPF.00 P 350.8
IU.SSPA.00 P 355.5
SH 47.2
SACV.00 SH 51.2
G.TAM.00 SH 64.5
GT.DBIC.00 SH 70.9
GT.LBTB.00 SH 114.8
GT.BOSA.00 SH 117.6

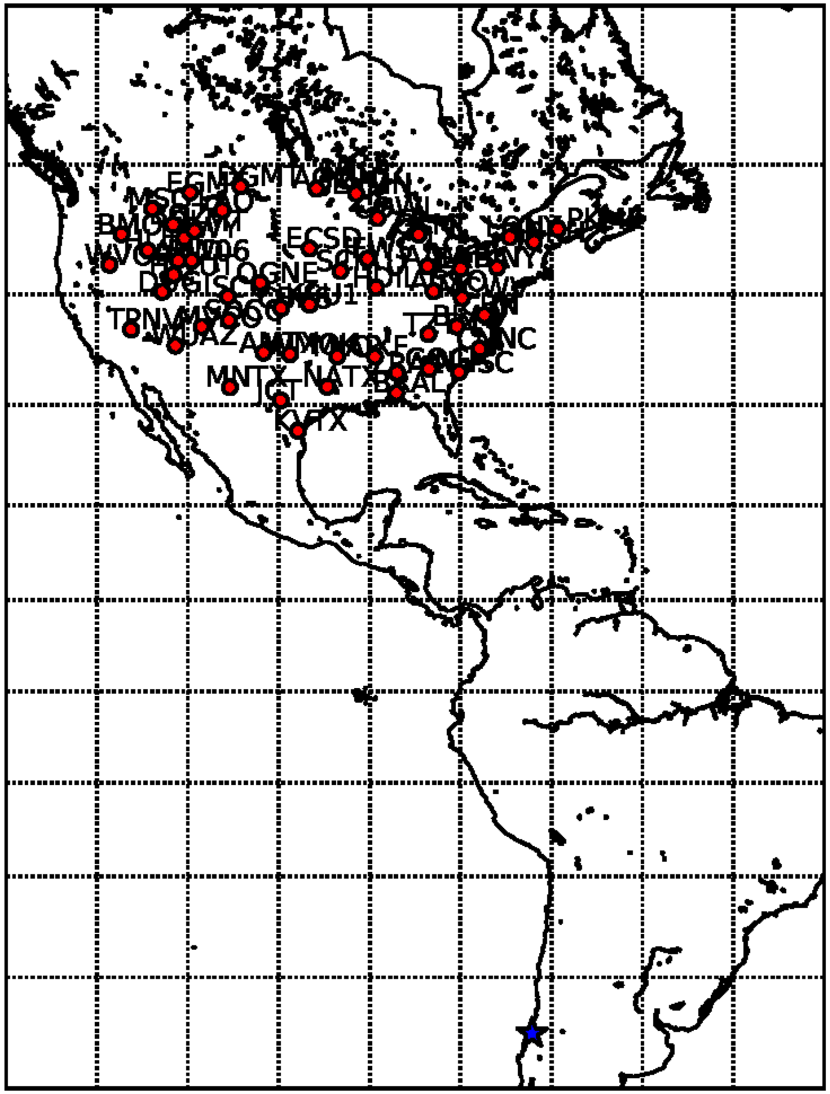
SH

Example of Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion

Observed and synthetic interferogram

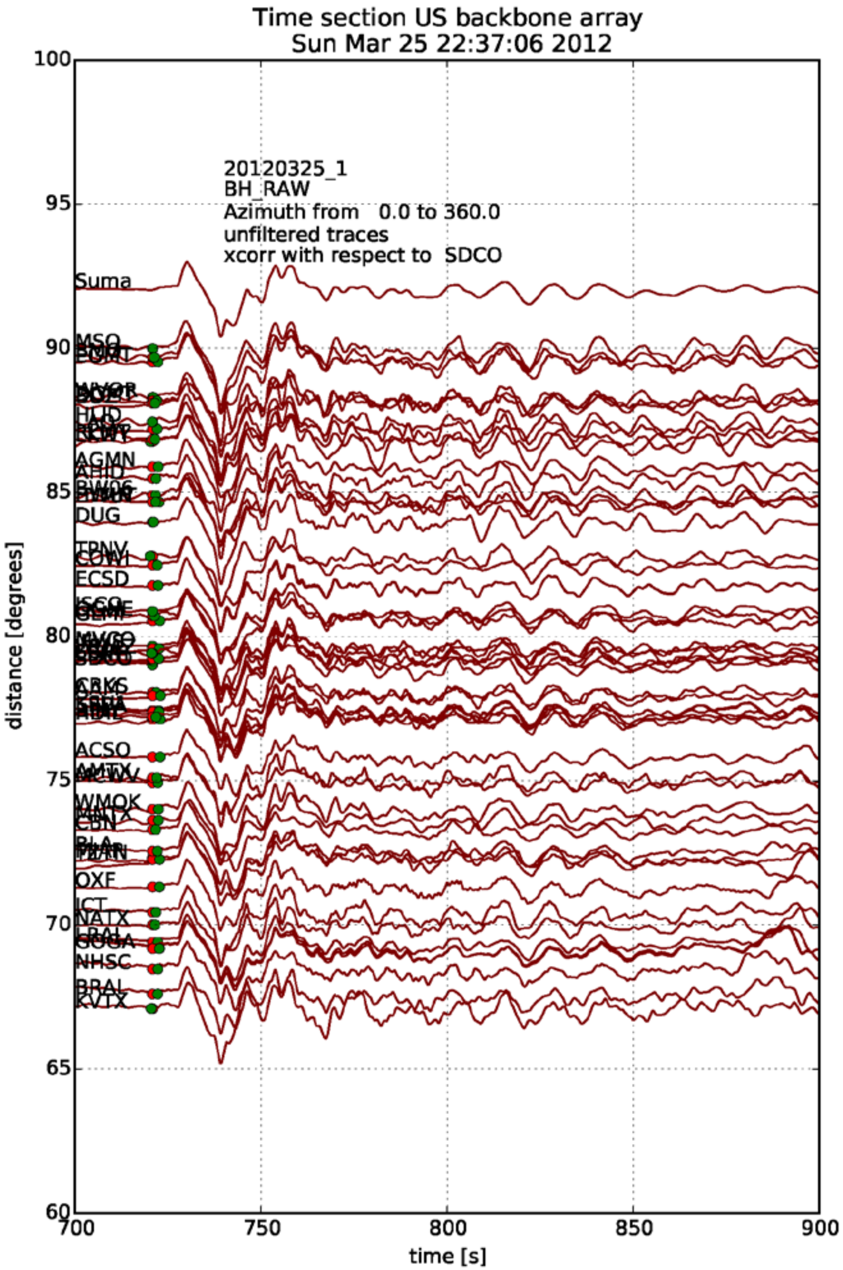


Available data from the IRIS data center Wilber III applicat



Red US array

25 Marzo 2012 Constitucion EQ



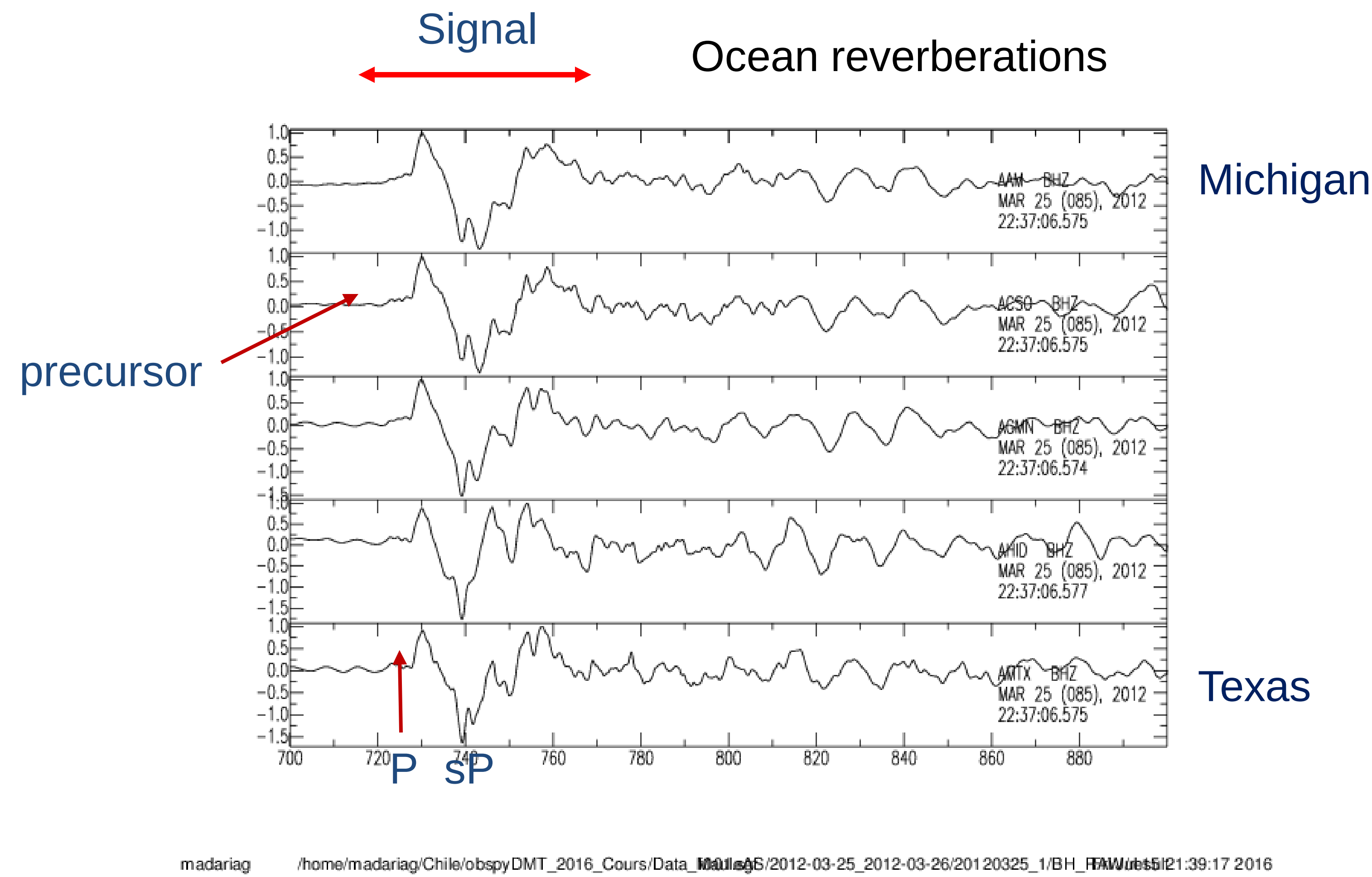
Displacement record « section »

Maule aftershock Mw 7.1 of 25/3/2012
near Constitucion

Traces were aligned by
Cross correlation

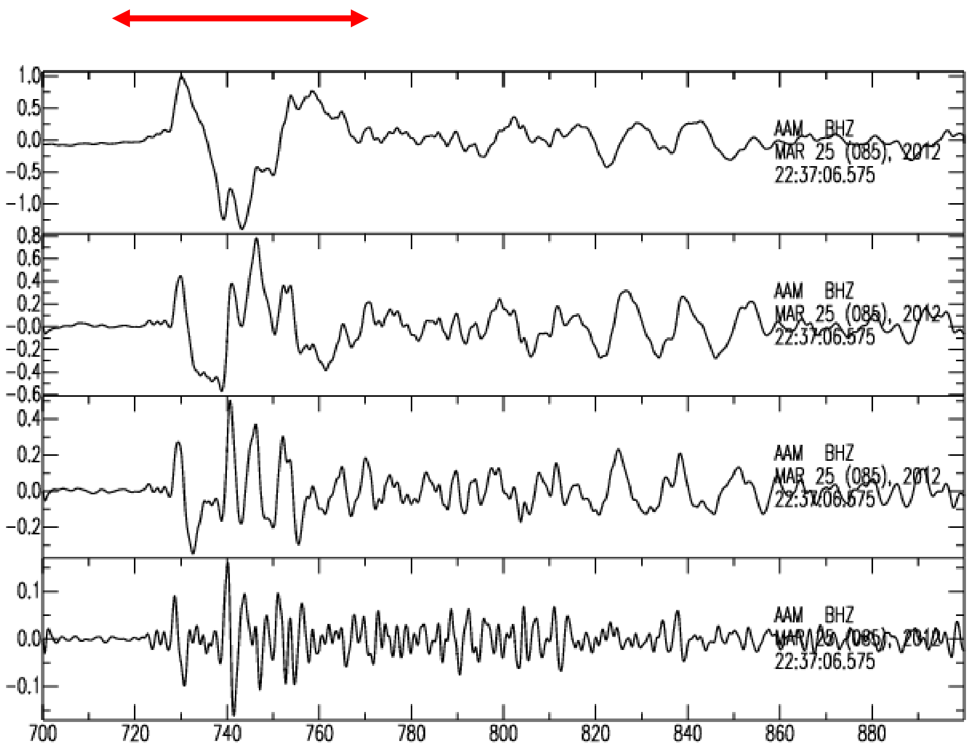
Displacement record « section »

Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion



Displacement record « filter » AAM (Michigan)

Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion



Original BB

Band pass 0.1-1 Hz

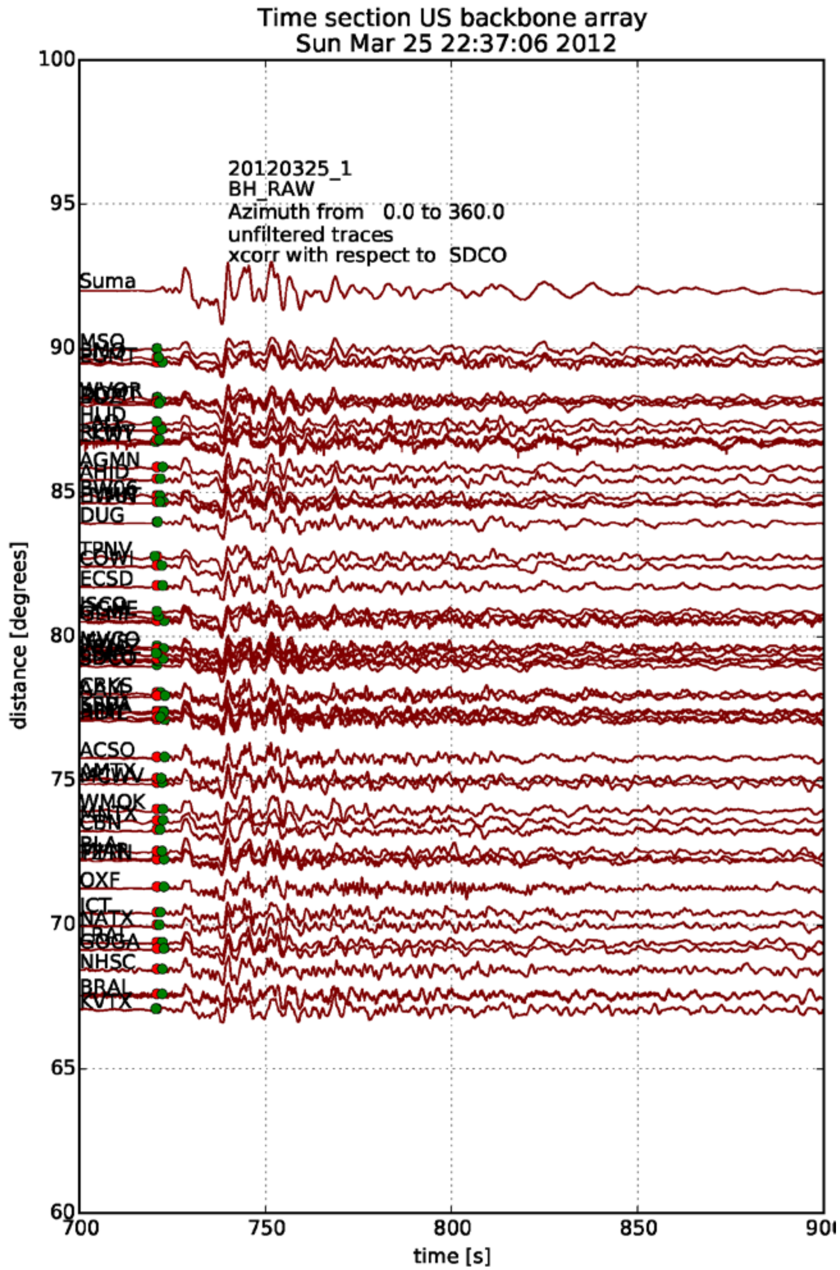
0.2-1 Hz

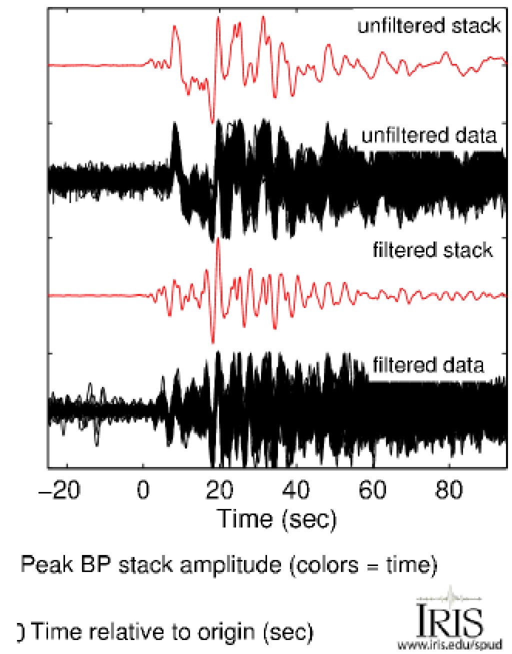
0.3-1 Hz

madariag /home/madariag/Chile/obspyDMT_2016_Cours/Data_Maule/AS/2012-03-25_2012-03-26/20120325_1/BH_RAW 2016

Velocity record « section »

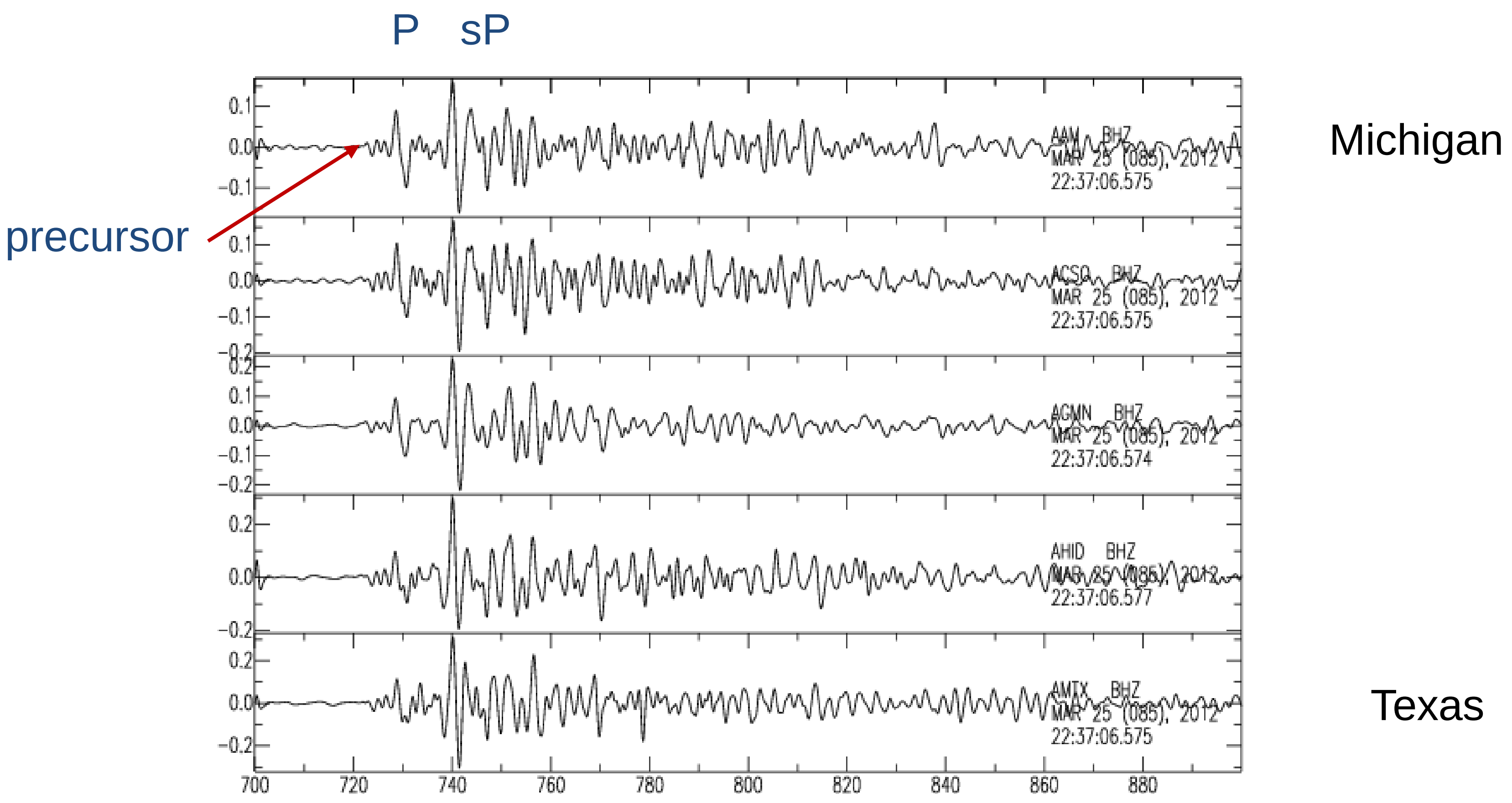
Maule aftershock Mw 7.1 of 25/3/2012
near Constitucion





Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion

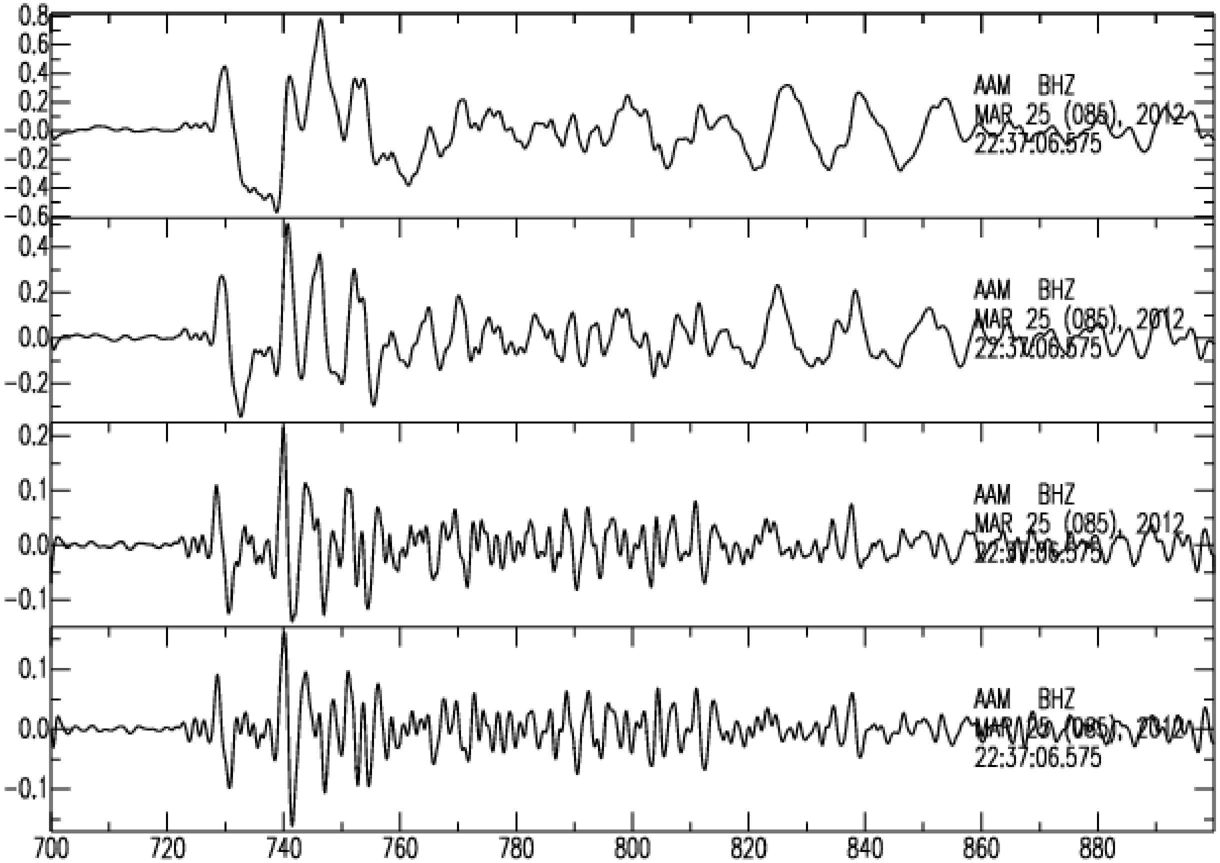
5 velocity seismograms of the US array



madariag /home/madariag/Chile/obspyDMT_2016_Cours/Data_Maule_AS/2012-03-25_2012-03-26/20120325_1/BH_RAW 21:58:09 2016

Velocity record « filter » AAM (Michigan)

Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion



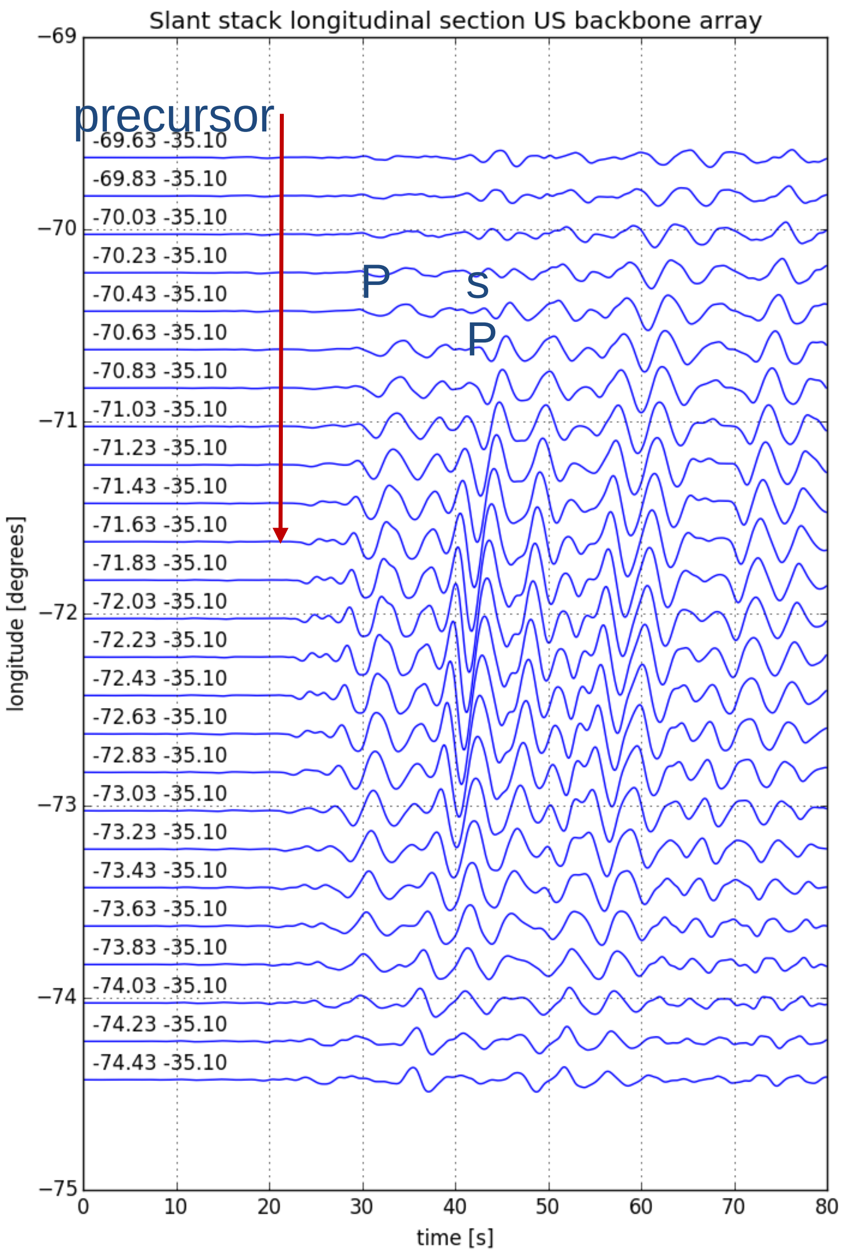
Original BB

Band pass
0.1-1 Hz

0.2-1 Hz

0.3-1 Hz

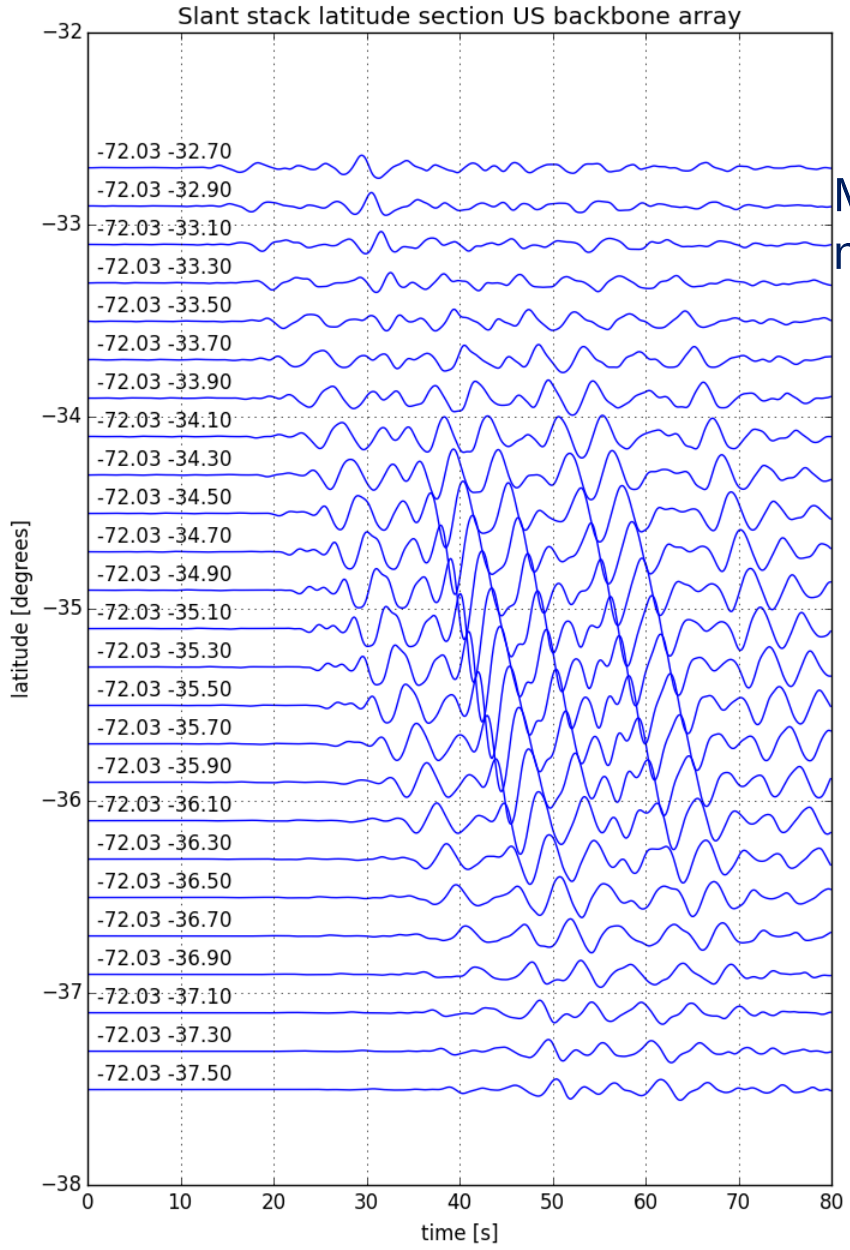
madariag /home/madariag/Chile/obspyDMT_2016_Cours/Data_Maule_AS/2012-03-25_2012-03-26/20120325_1/BH_RAW/test.1 02:57:52 2016



Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion

Sum the stack at different points on the source area

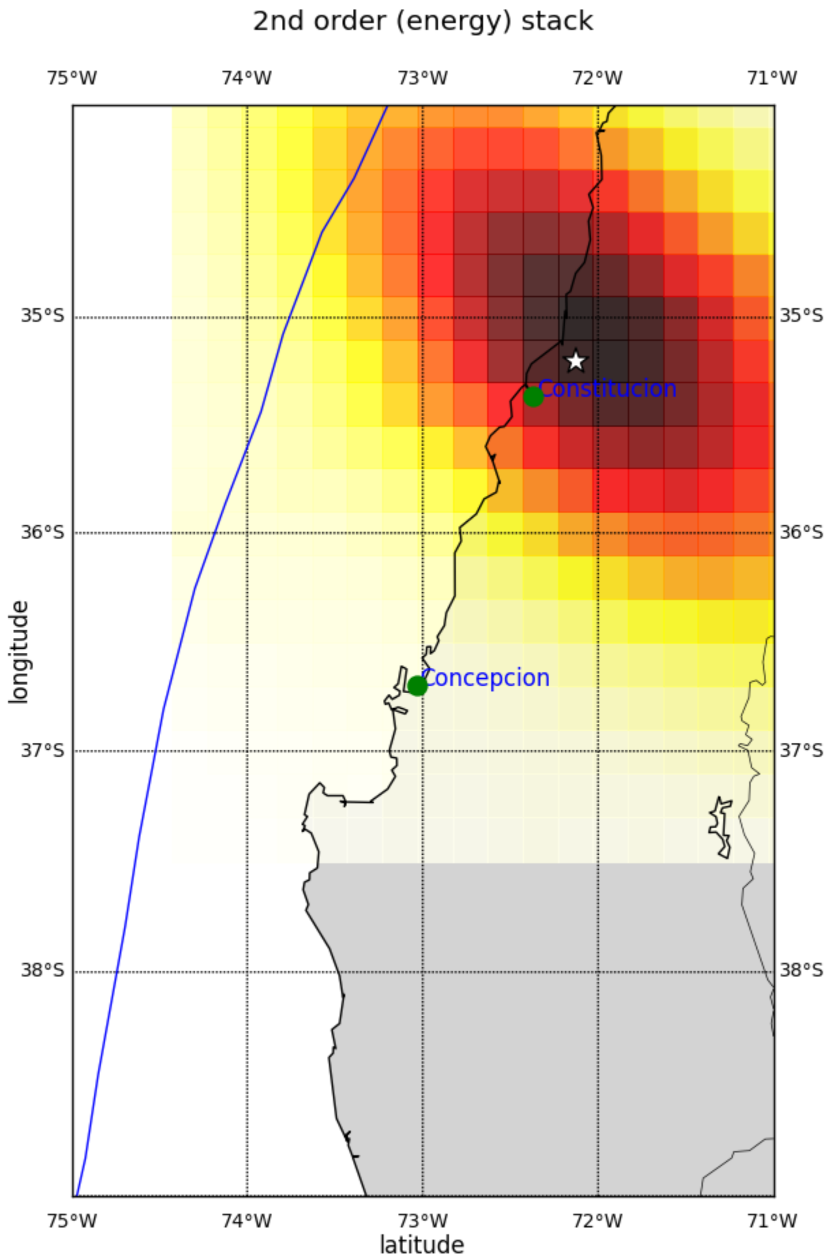
This is a constant latitude (-35.1) section



Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion

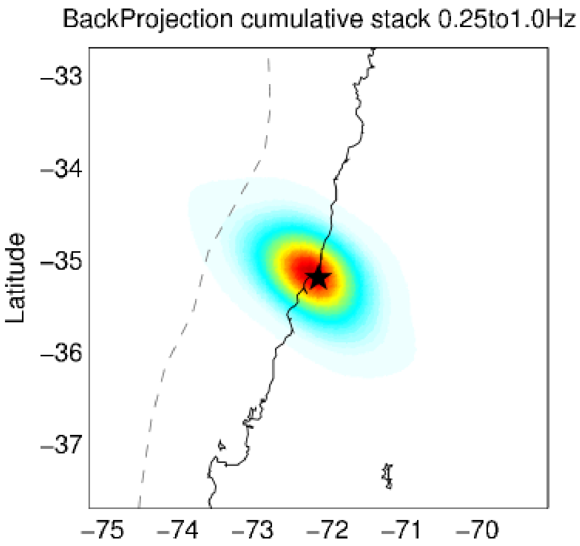
Sum the stack at different points on the source area

This is a constant longitude (-72.03) section



Maule aftershock Mw 7.1 of 25/3/2012 near Constitucion

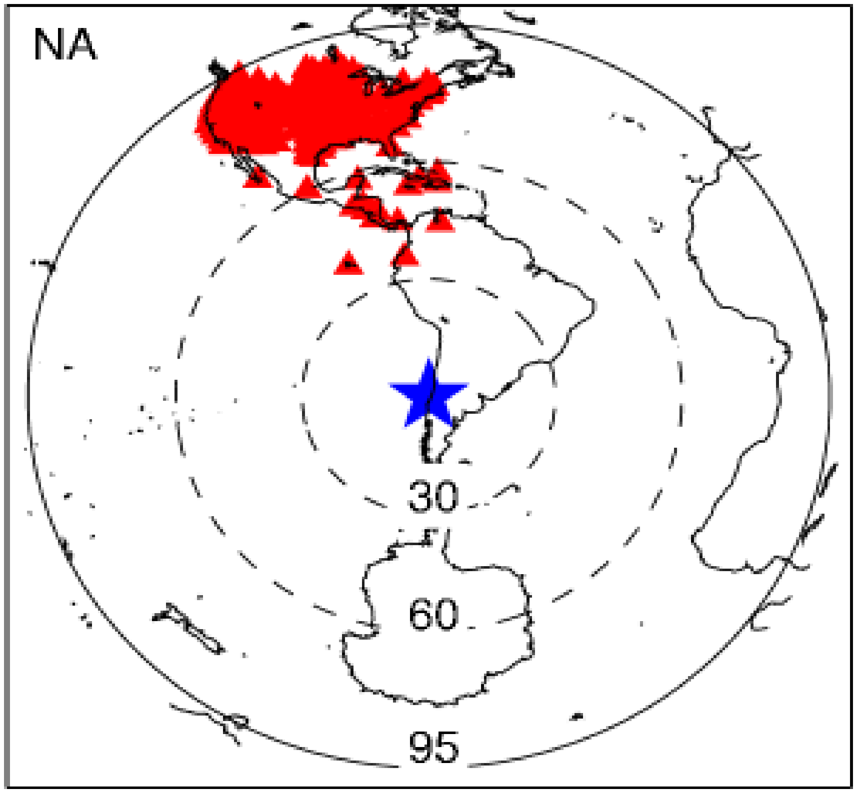
This figure shows the projection (energy sum)
Of the stacked seismograms



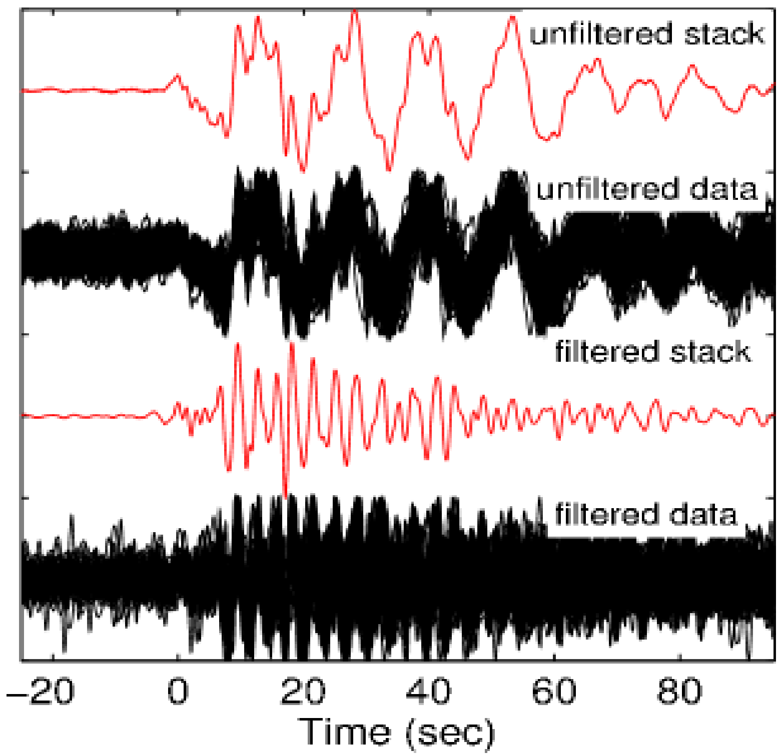
Use of a receiver antenna

Example of Maule aftershock Mw 6.7 of 14/2/2011   near Constitucion

2011/02/14 03:40 M6.7 Z=17km



Example of stack at different frequencies

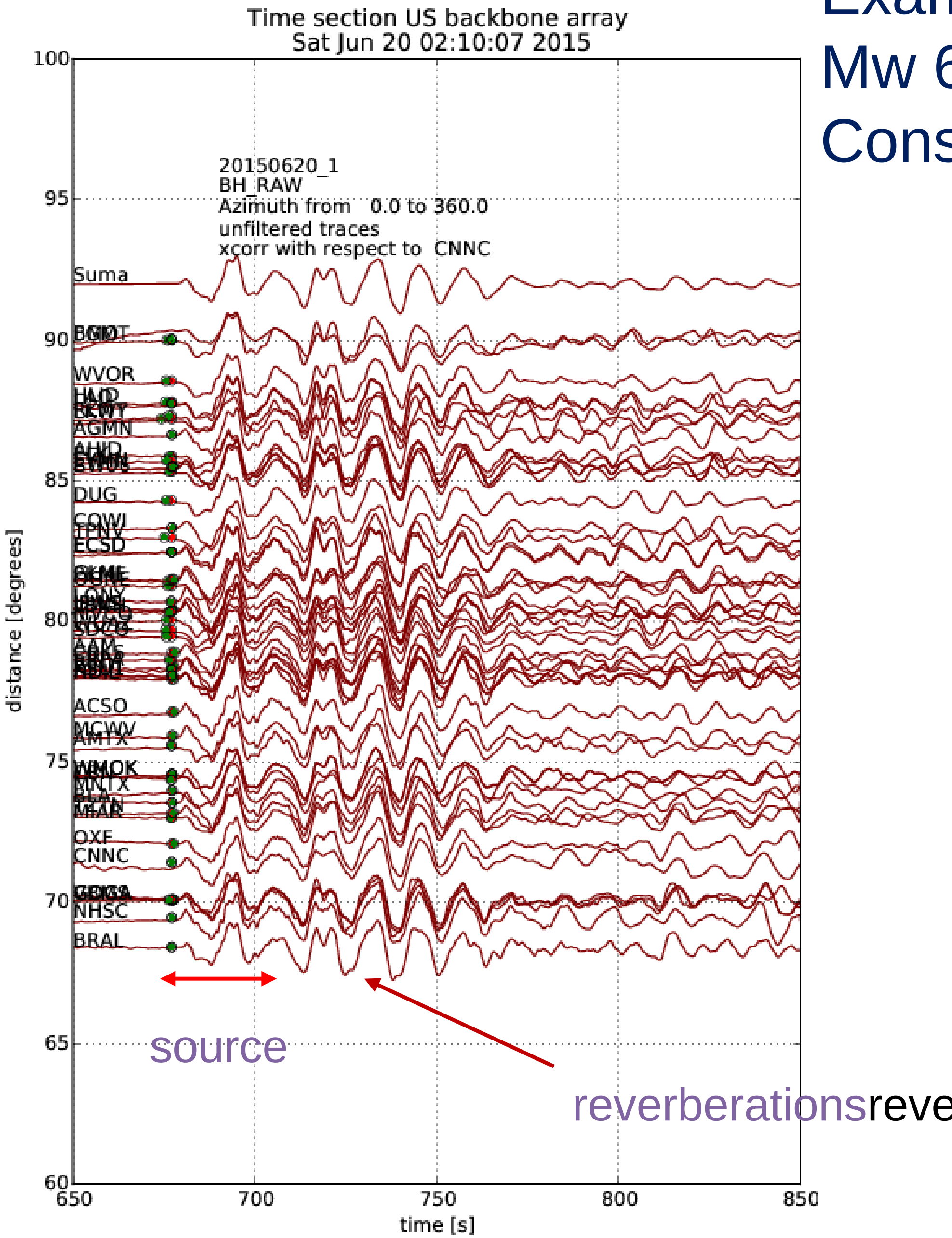


Peak BP stack amplitude (colors = time)

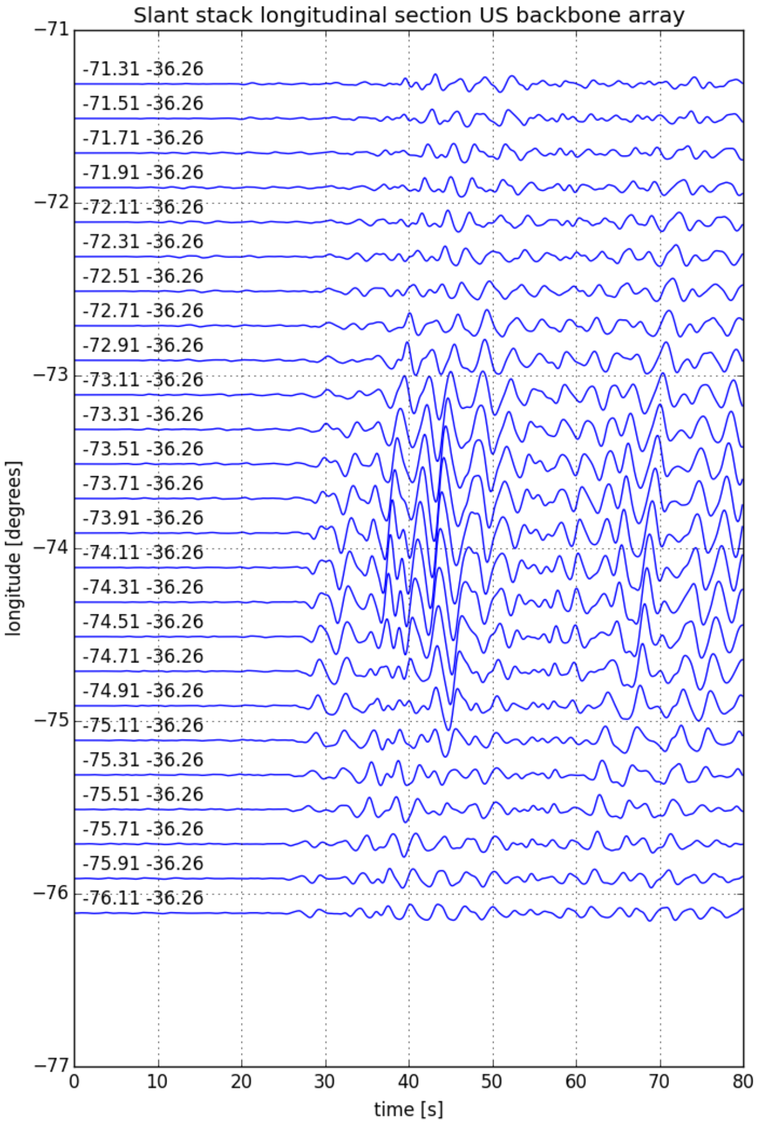
Time relative to origin (sec)

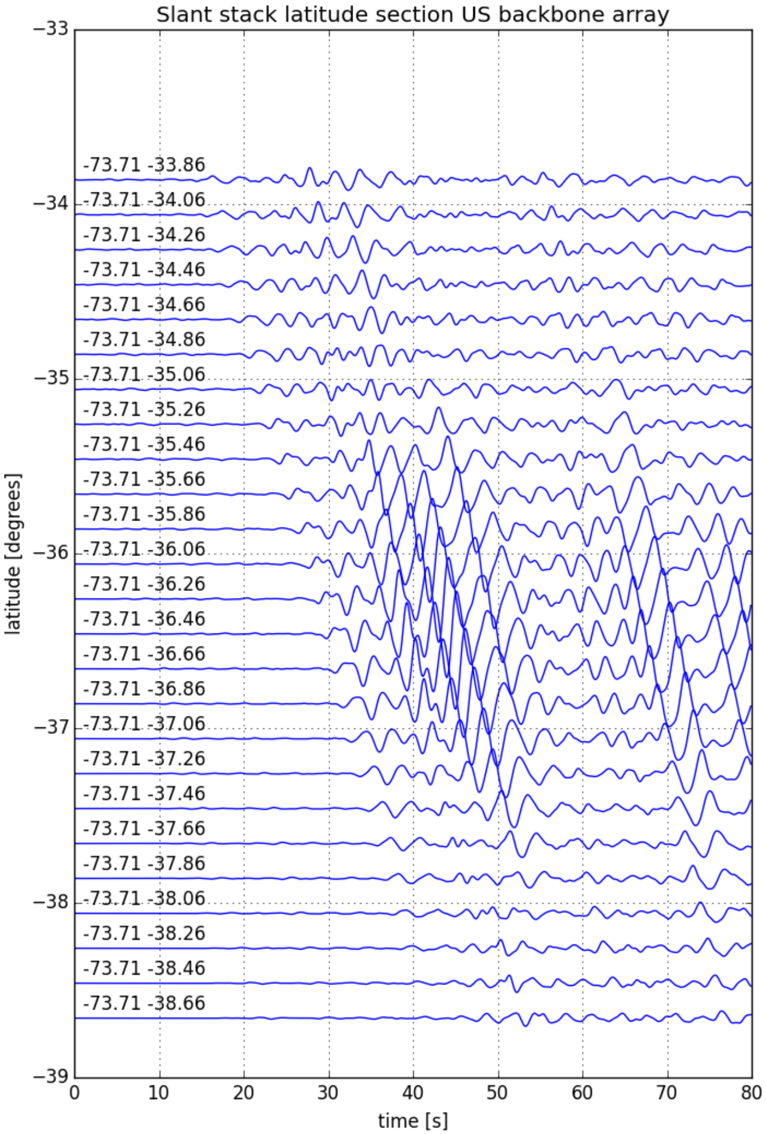
IRIS www.iris.edu/spud

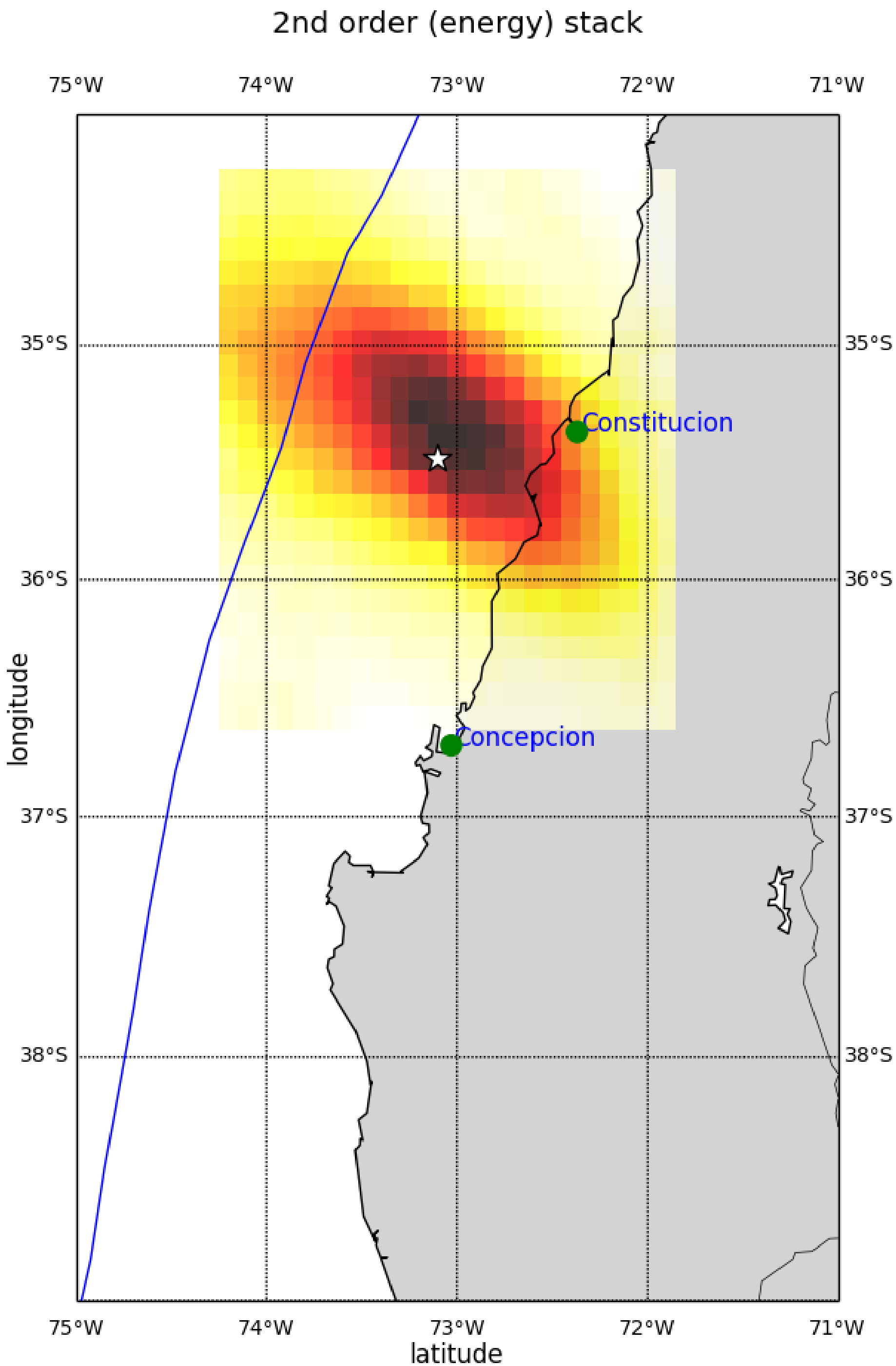
Example of Maule aftershock Mw 6.7 of 14/2/2011 near Constitucion



Example of Maule aftershock Mw 6.7 of 14/2/2011 near Constitucion





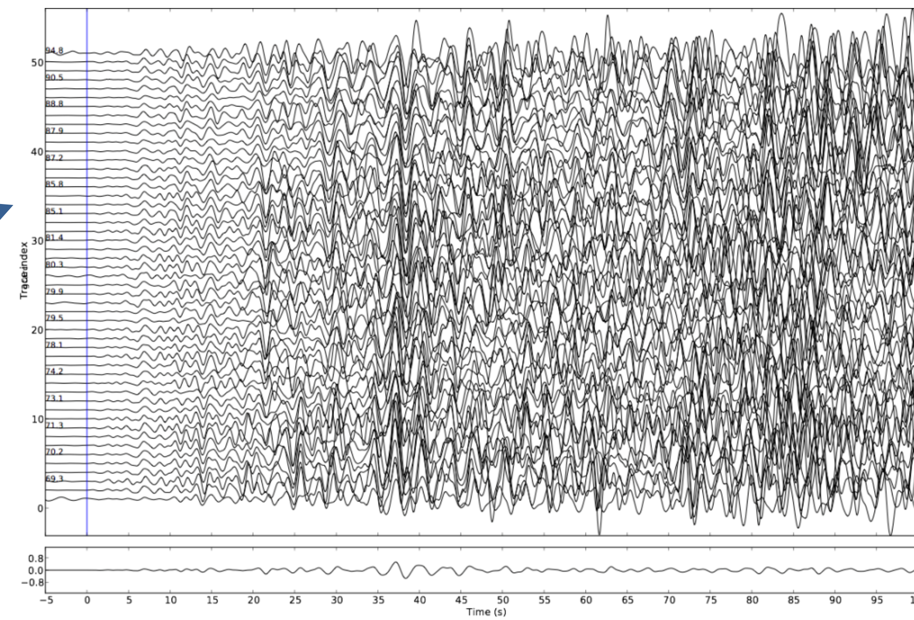


There are several ways to obtain
The stacked source area.

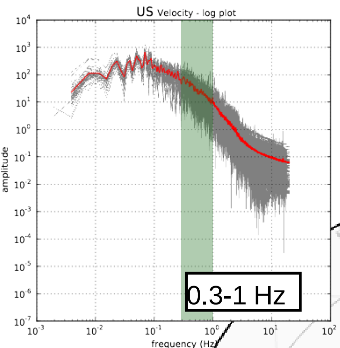
Most of them are cosmetic
Because at high frequency
signals are coherent

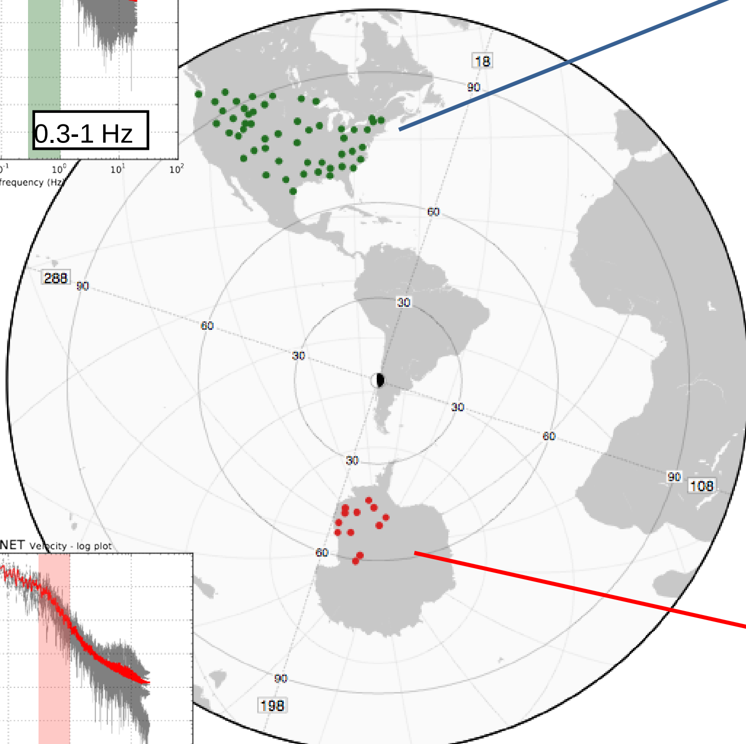
Back Projection of Maule earthquake : Data

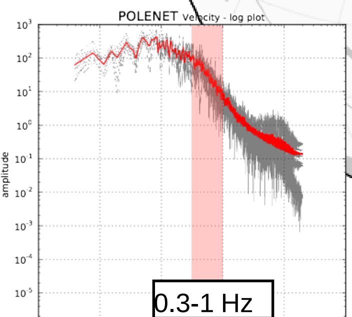
US Array

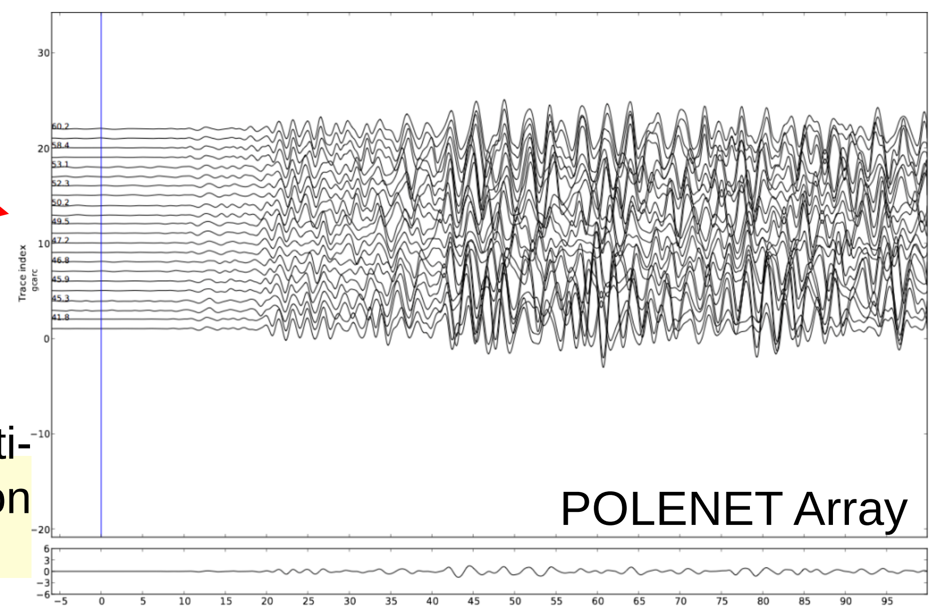


Satriano et al., in progress



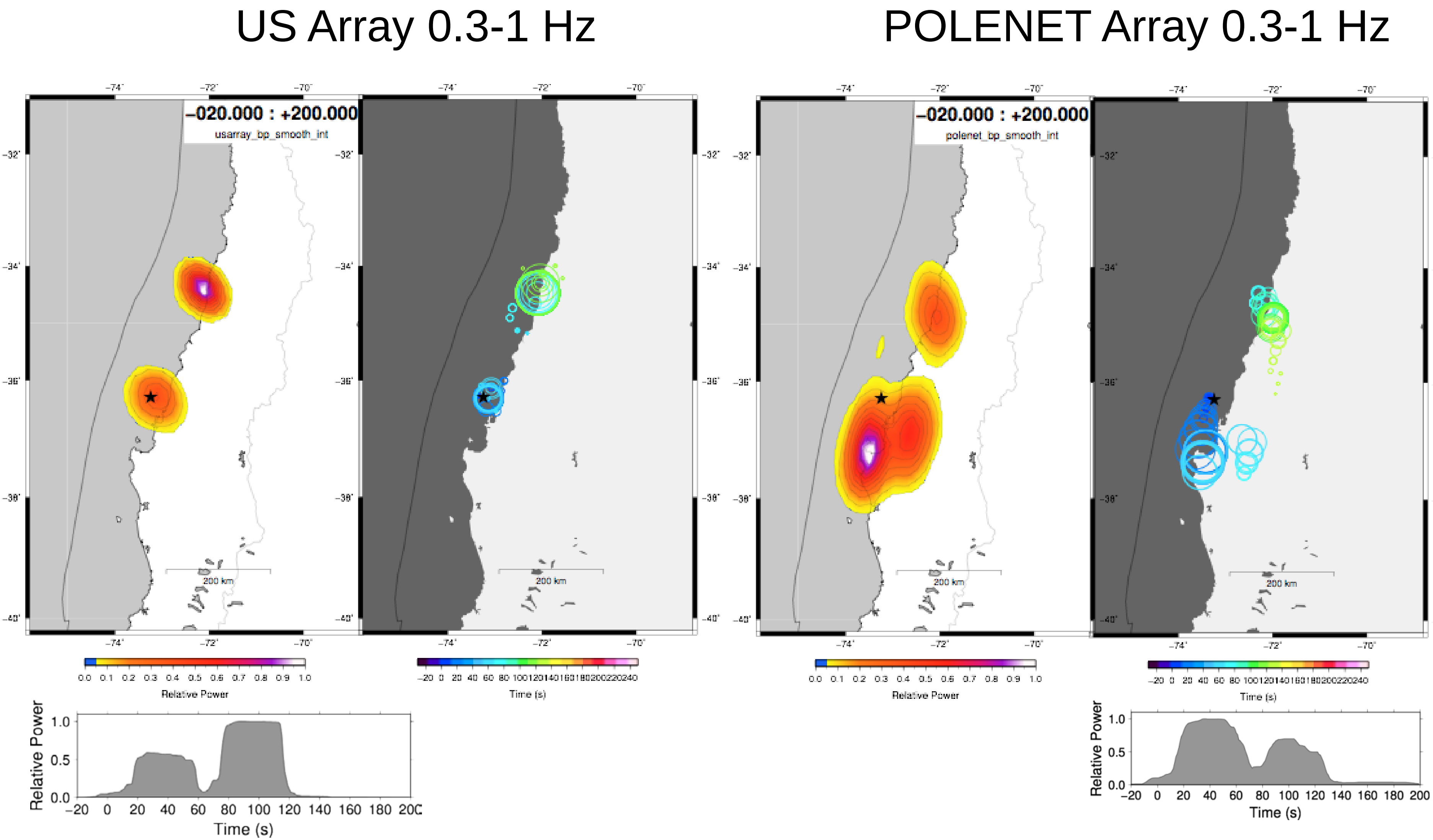






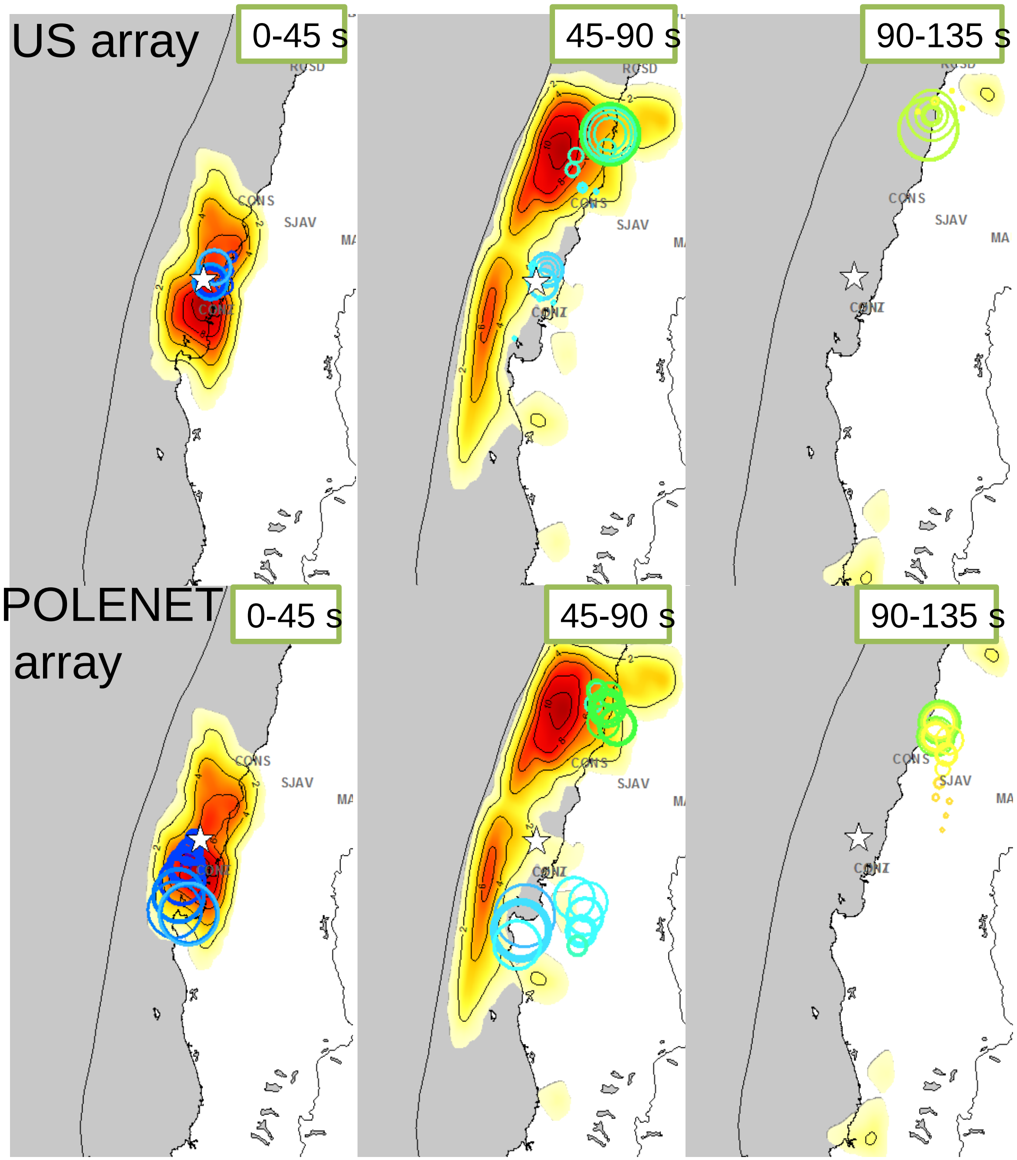
Travel time residuals corrected by multi-channel cross correlation --> station corrections

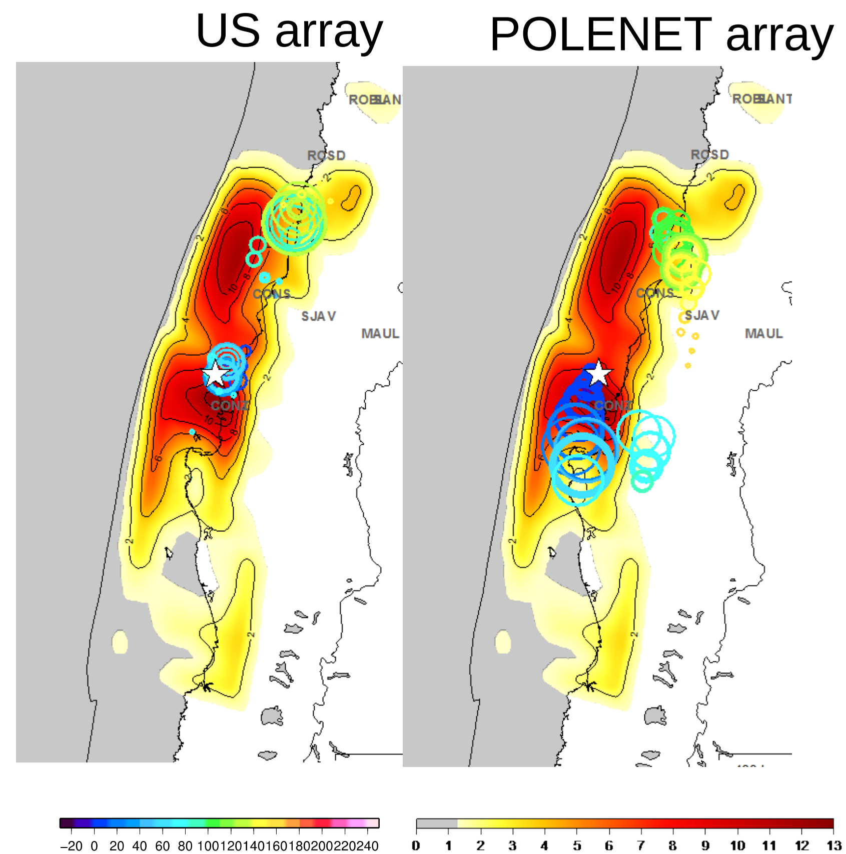
Back Projection: results



Satriano et al., in progress

Teleseismic Kinematic Inversion and Back Projection





Satriano, Donicio et al, in preparation


The end