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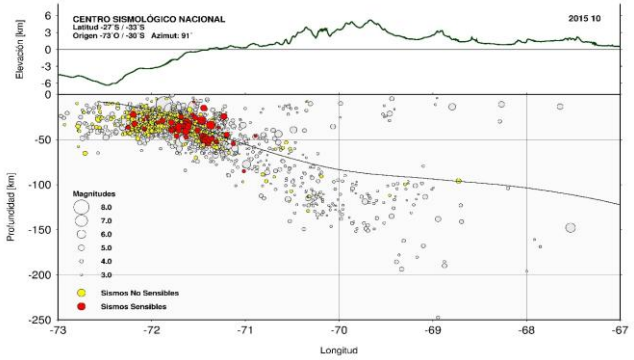
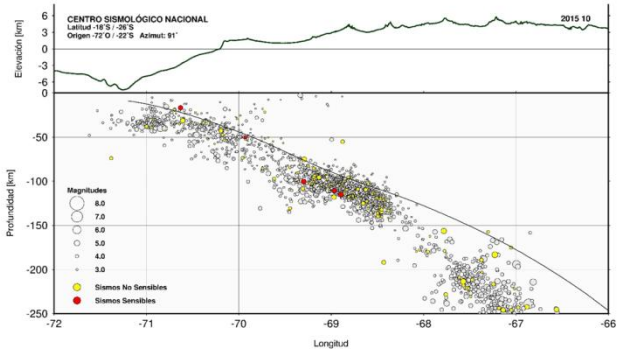
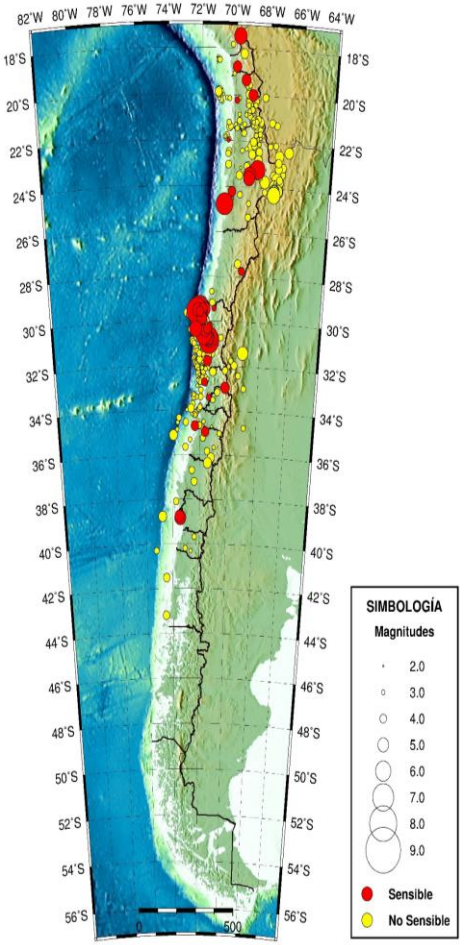
Technology Trends in Chilean Research on Earthquakes and Seismology







26 August 2016
CONICYT
Santiago

Sergio Barrientos
National Seismological Center
Universidad de Chile

Seismicity of Chile

Feb 2010 – Apr 2016

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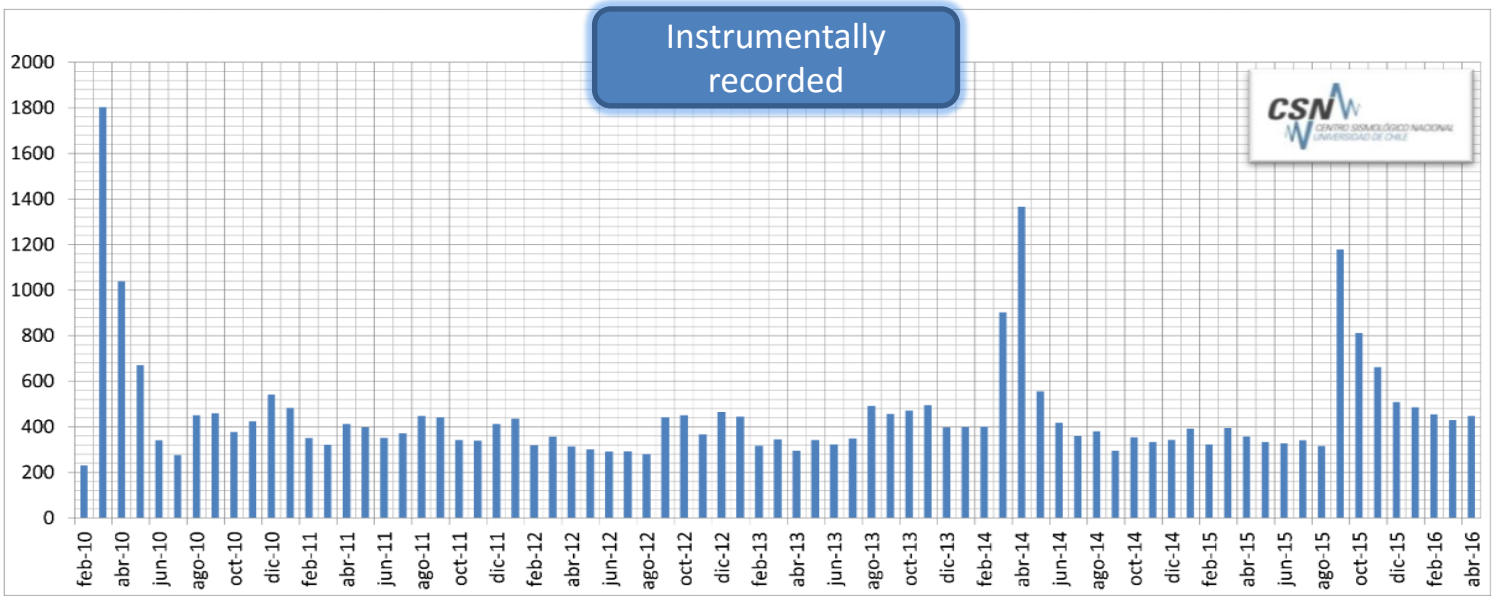
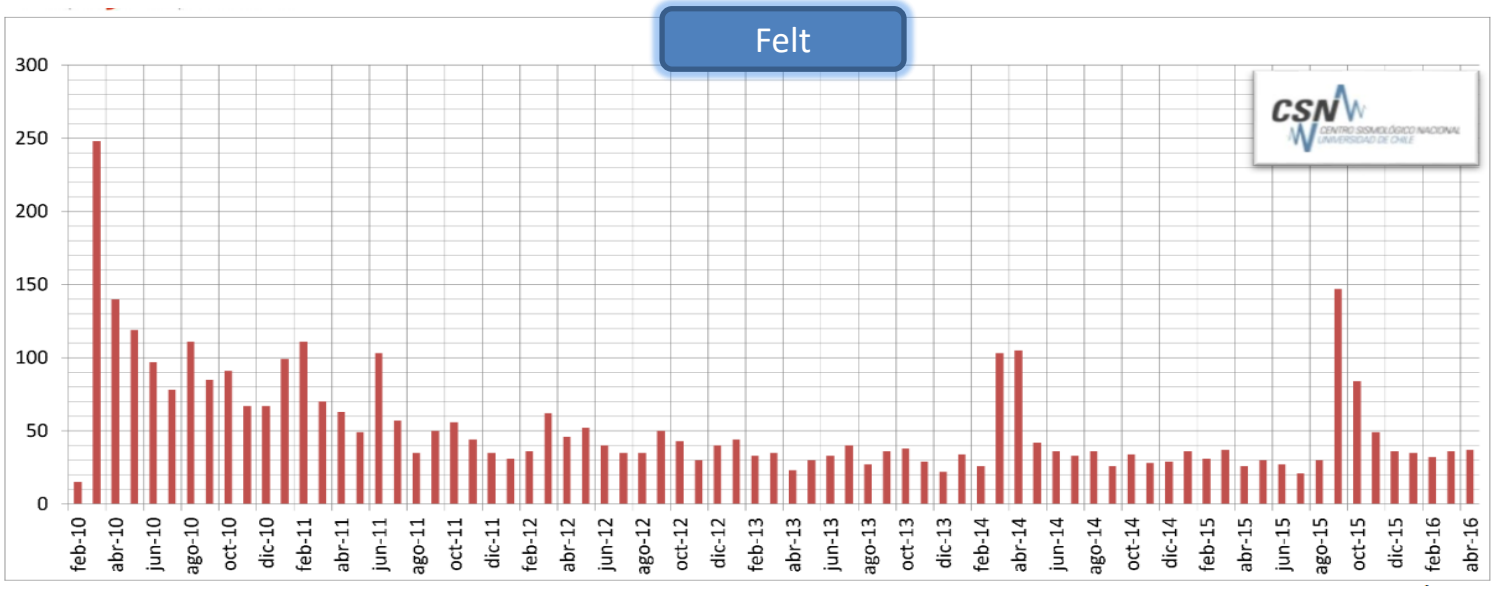
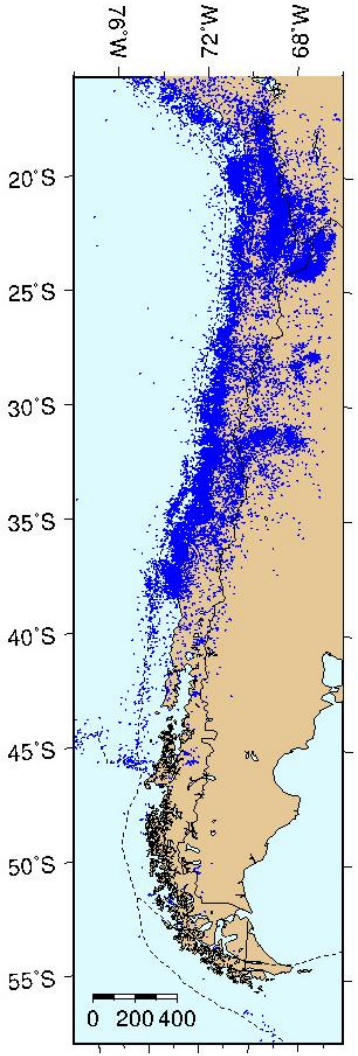
Instrumentally recorded



Felt





Sismicidad de Chile

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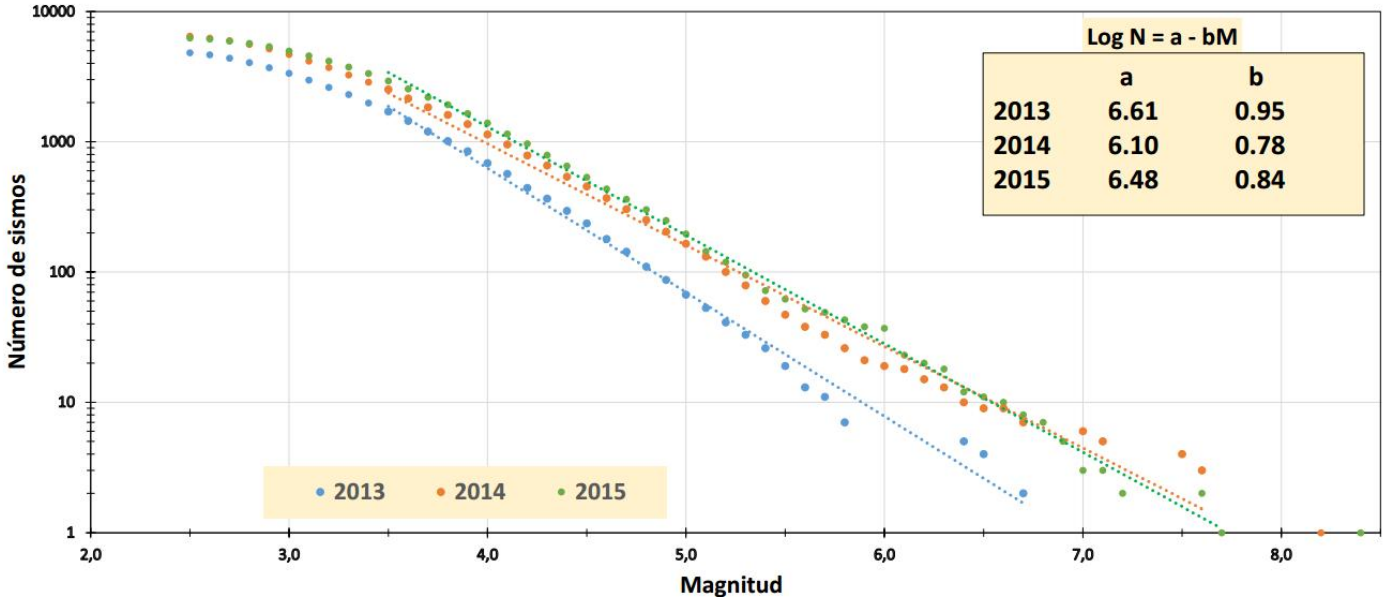
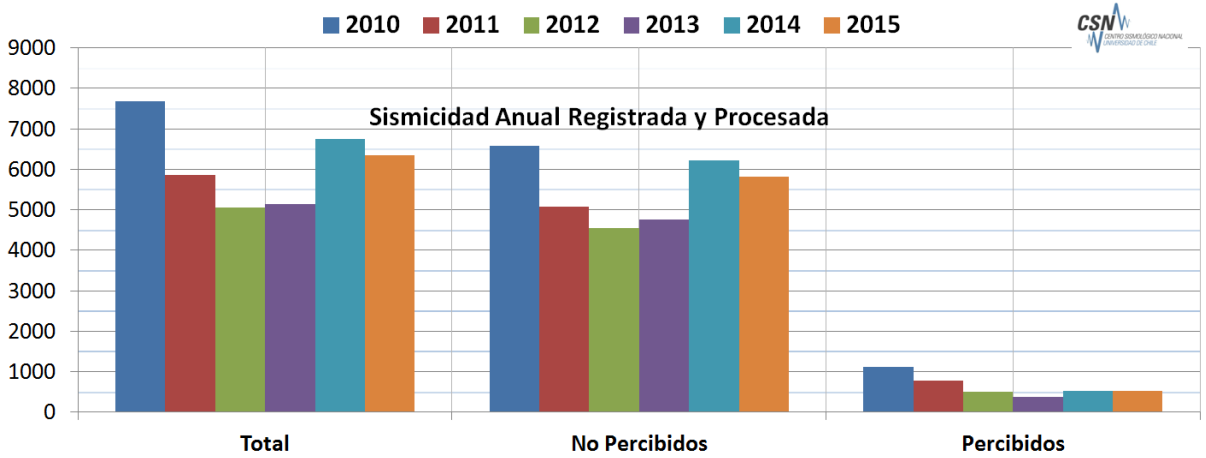
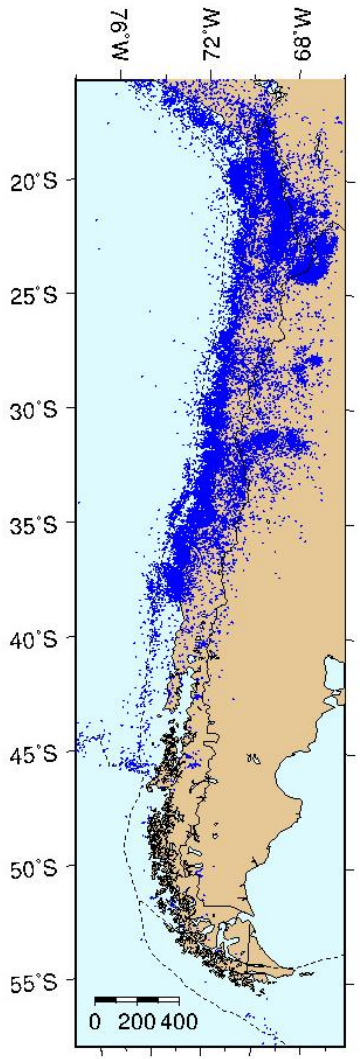
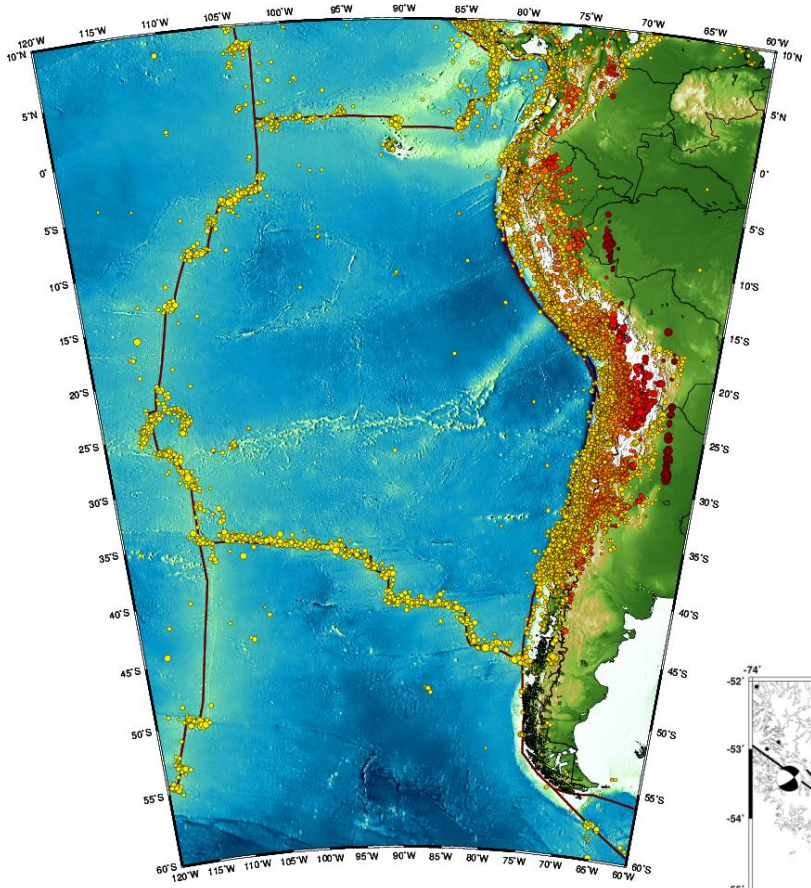


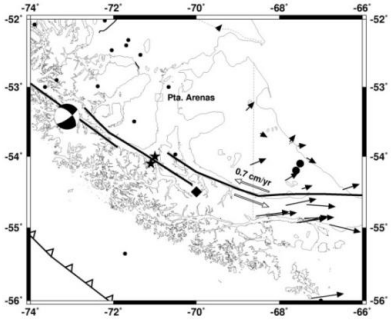


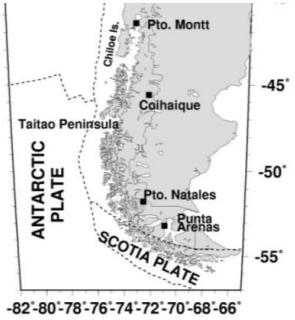


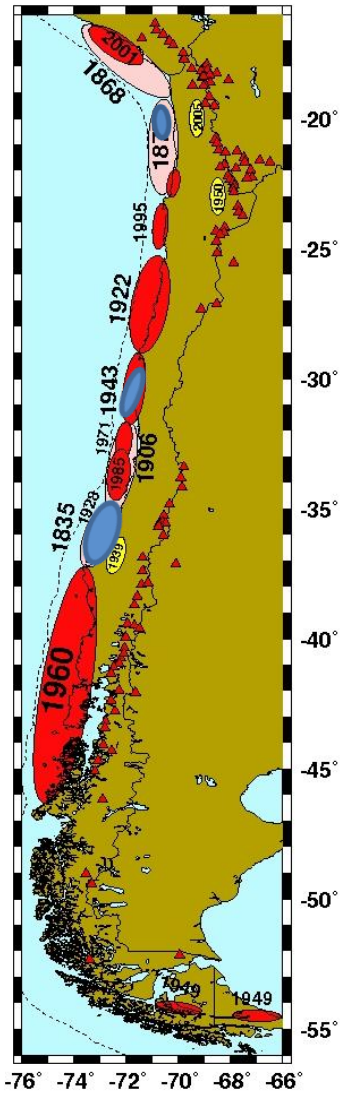
Seismicity of Chile



- *High rates of seismic prouctivity*
  - *Number of events per unit time*
  - *Giant earthquakes*
- *Approx. one magnitude 8 earthquake every decade*
- *Different types of faults and seismogenic regions*
- *Significant number of events followed by tsunamis*
- *Shallow seismicity*
- *Active tectonics close to urban centers and infrastructure*



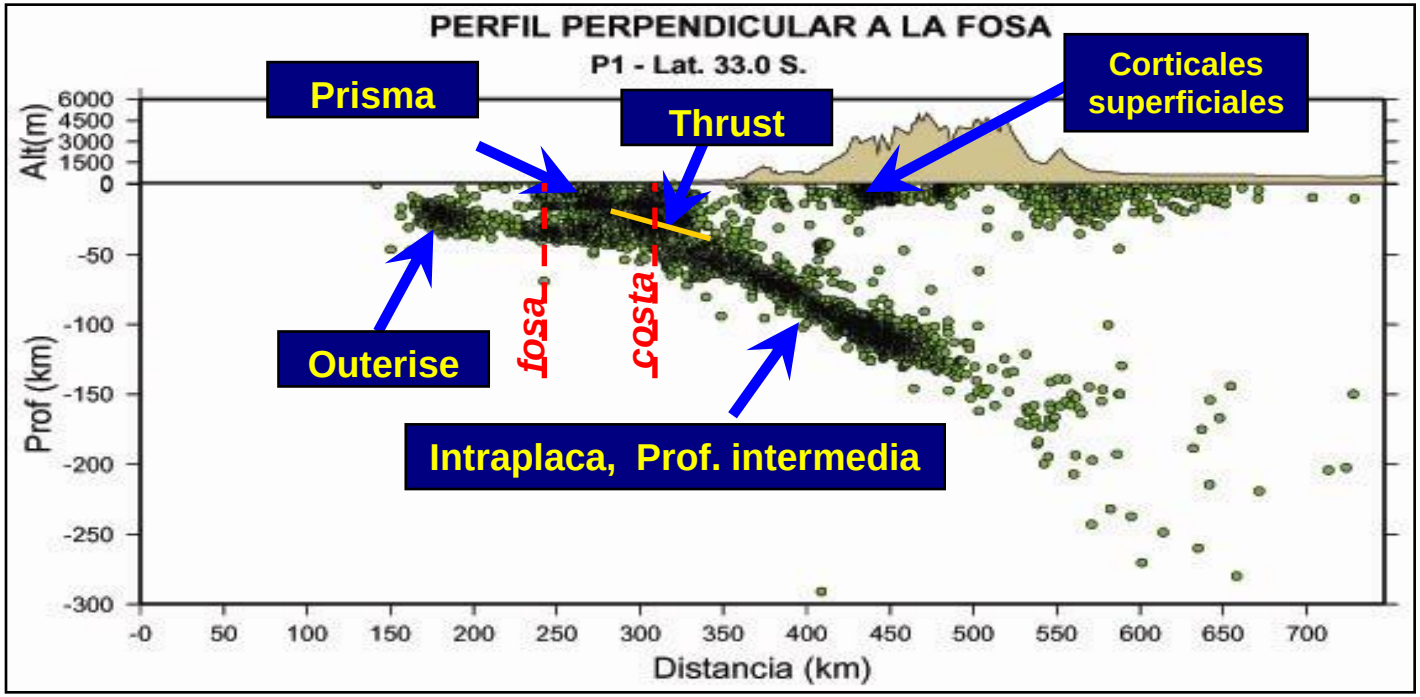


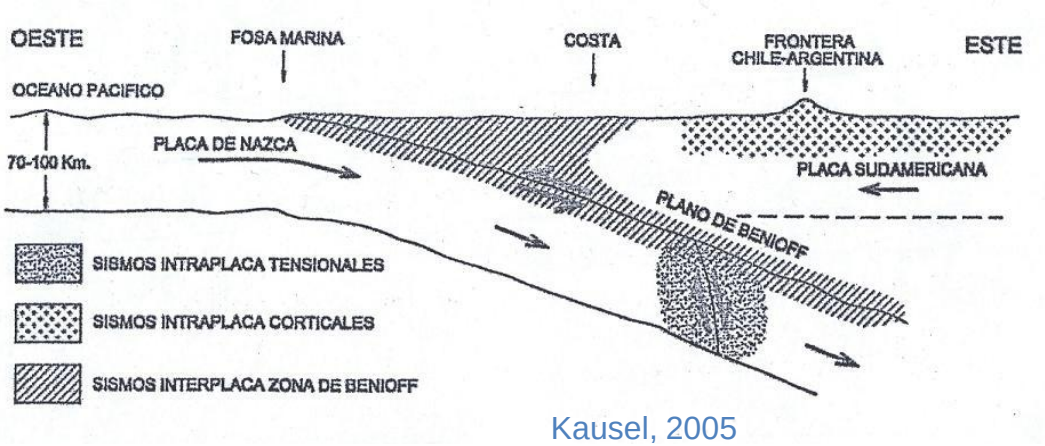


In Chile, since 1900, in terms of Disasters of Natural Origin:

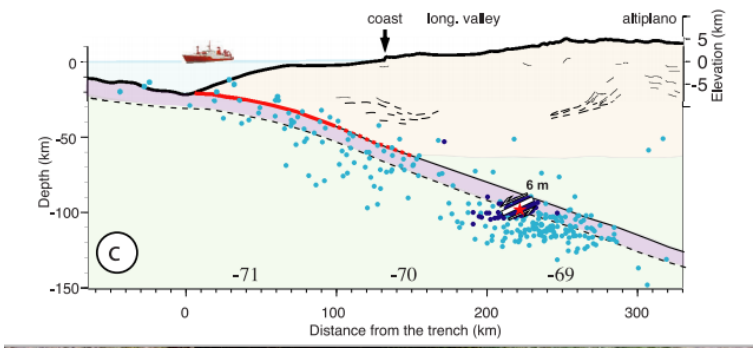
- *99% fatalities due to earthquakes and tsunamis*
- *98% economic loss due to earthquakes and tsunamis*

Subduction



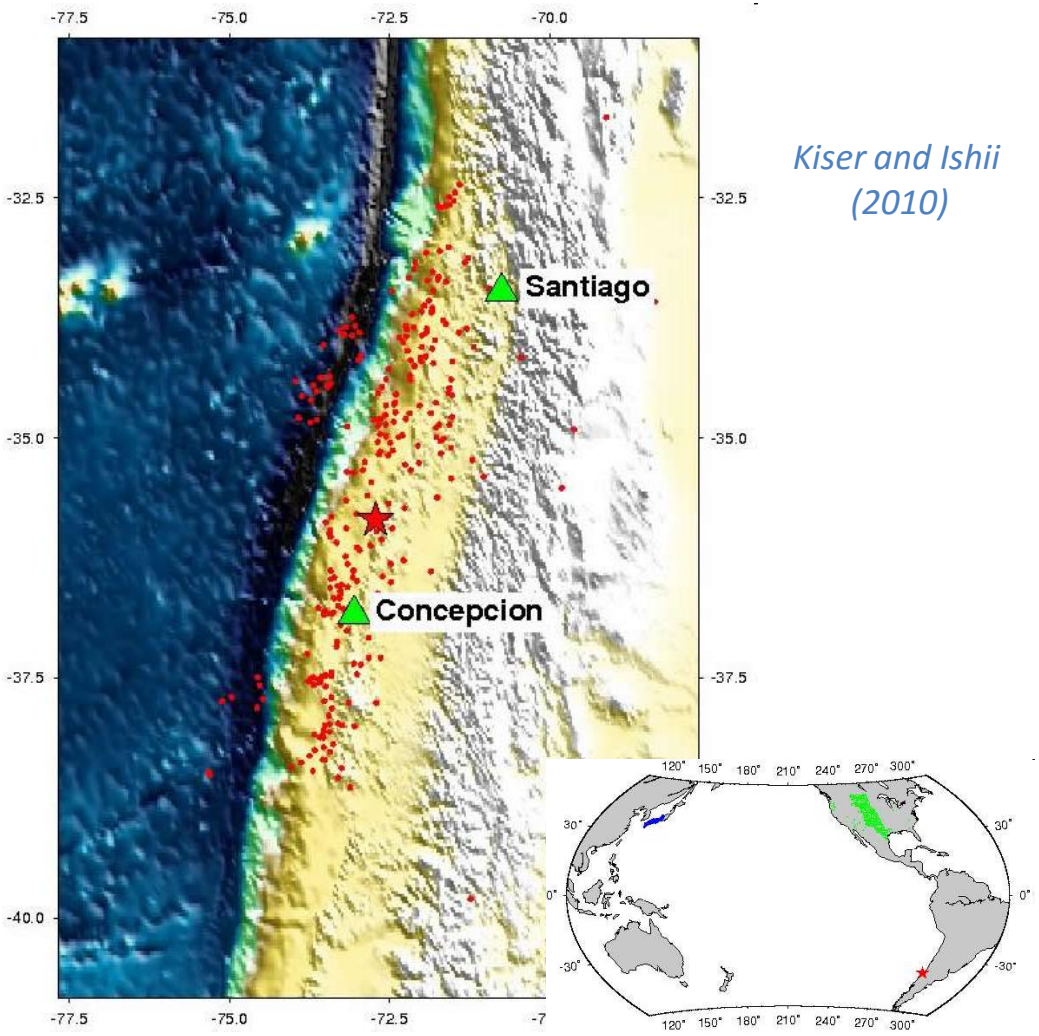


Kausel, 2005

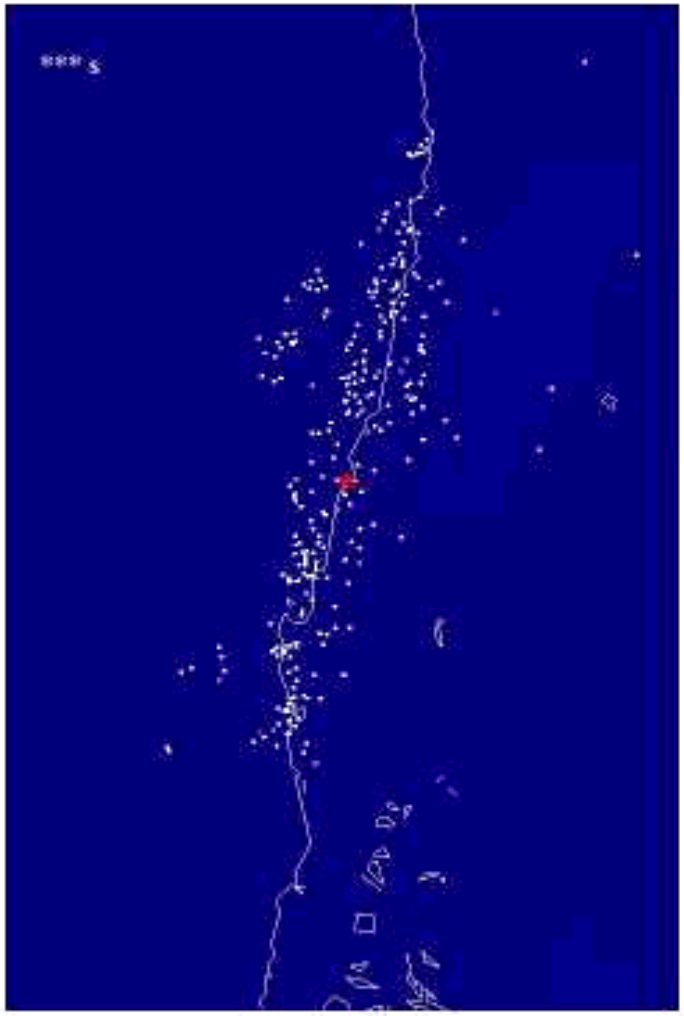


Peyrat, 2006

Maule Earthquake 2010



Kiser and Ishii (2010)



Maule Earthquake (2010)

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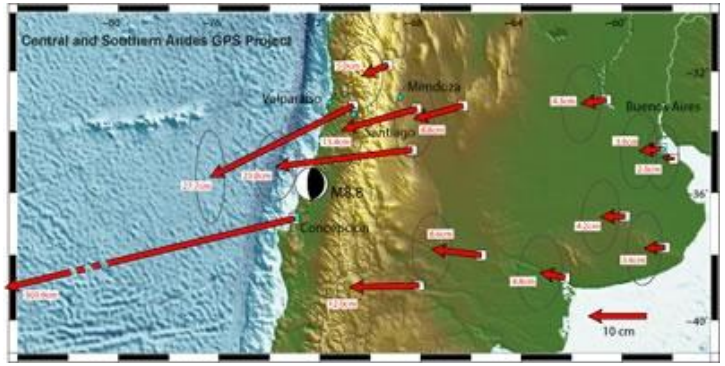
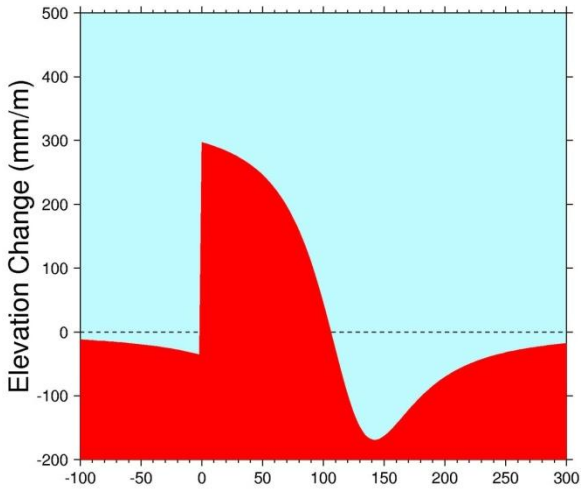
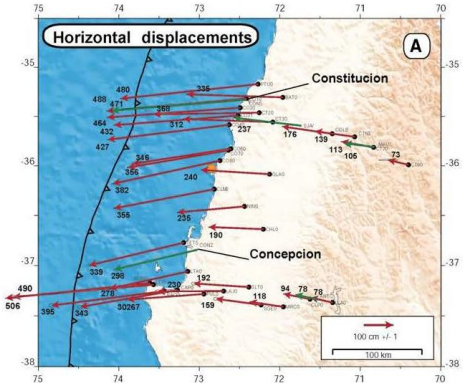
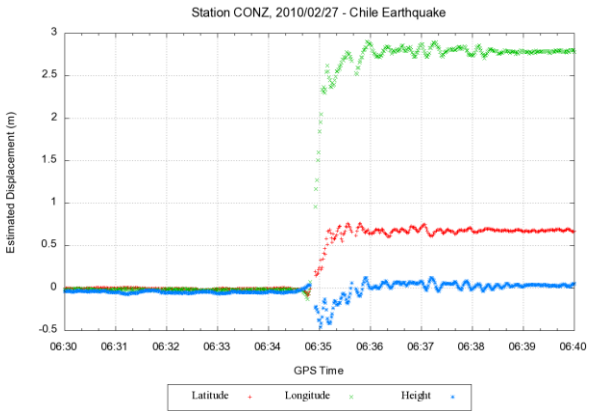
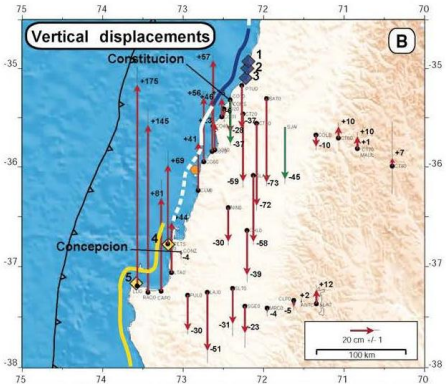


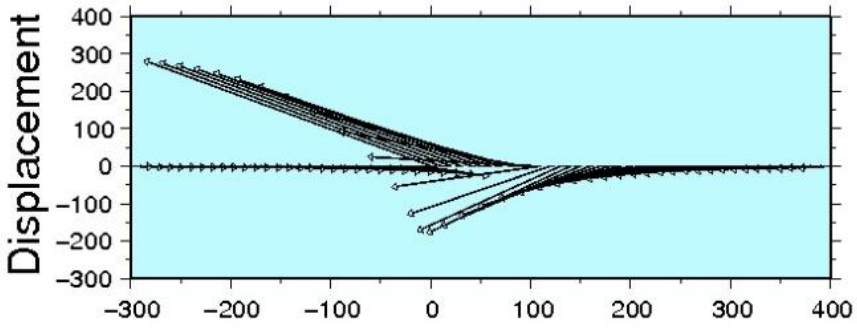


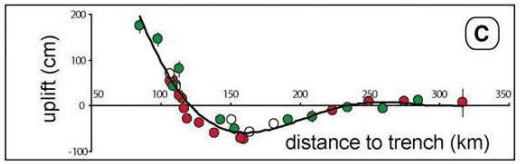


CAP



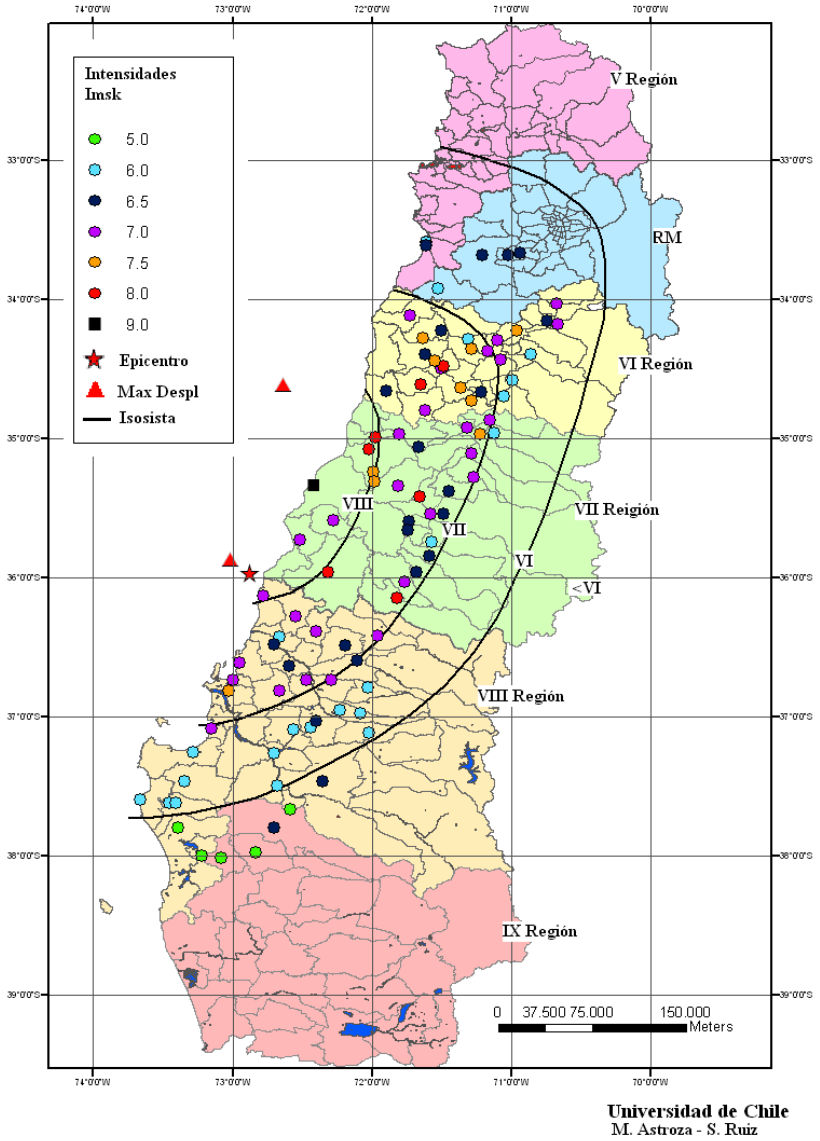






C Vigny et al.

M.M. Intensities, Aftershocks



Astroza et al., 2010

Horizontal displacements (GPS)

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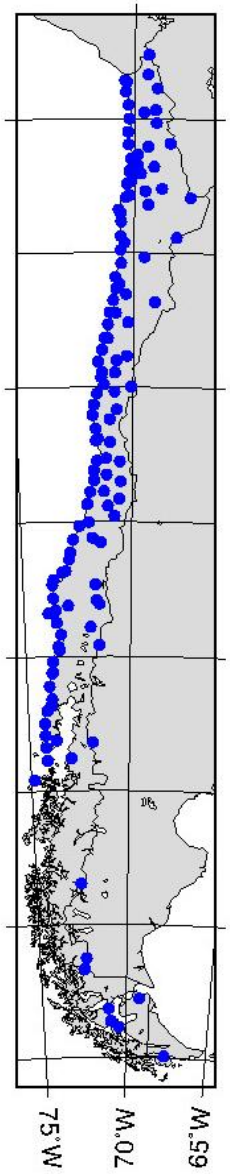

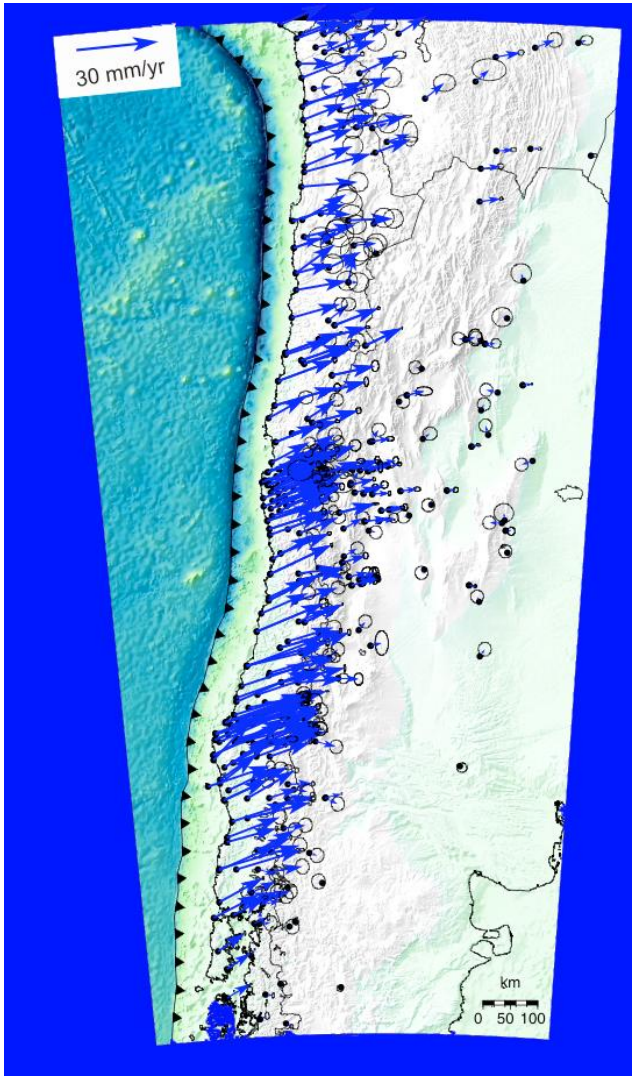

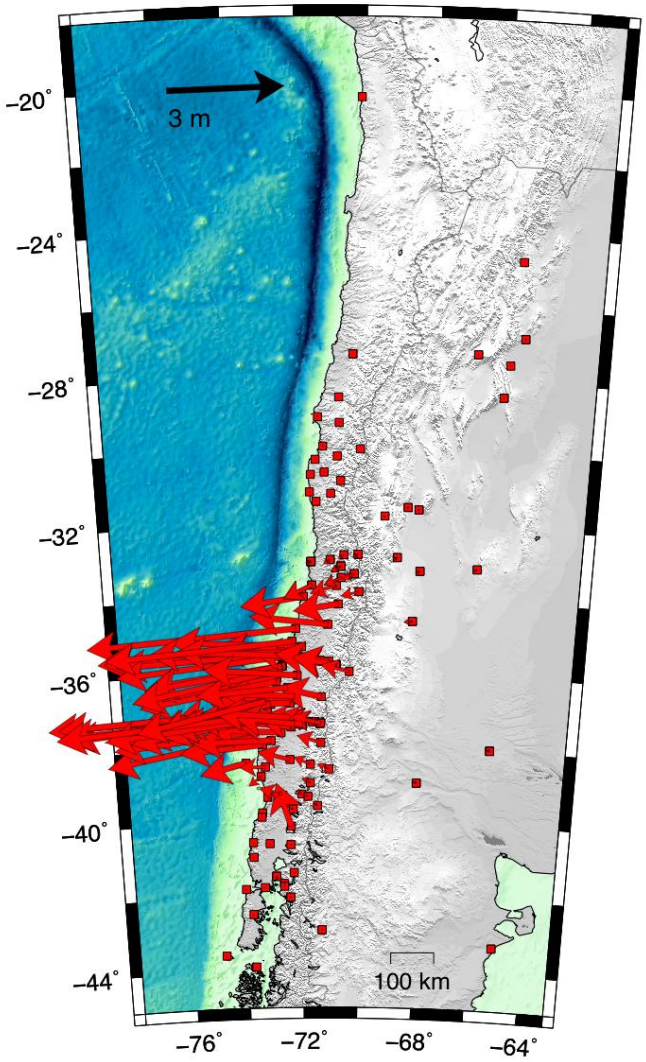

Interferometric Synthetic Aperture Radar

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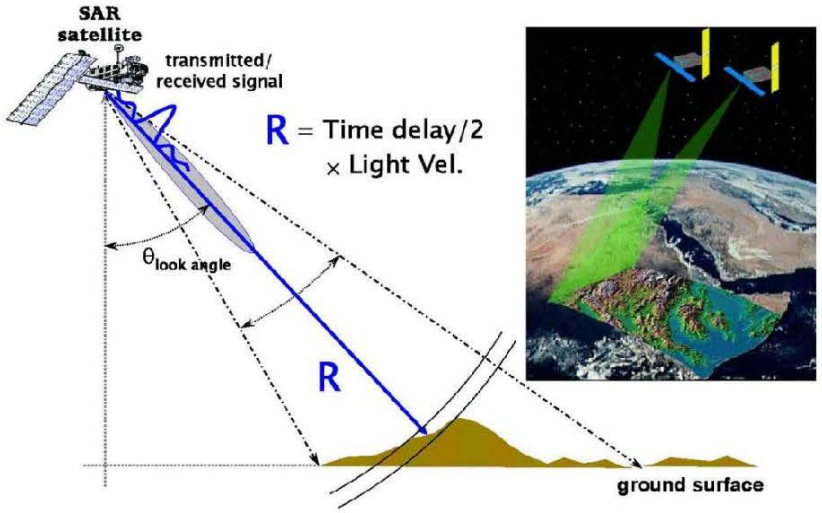
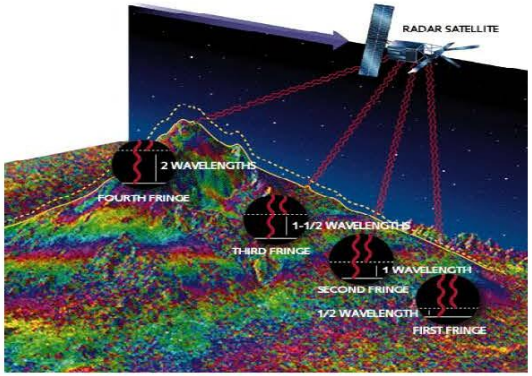
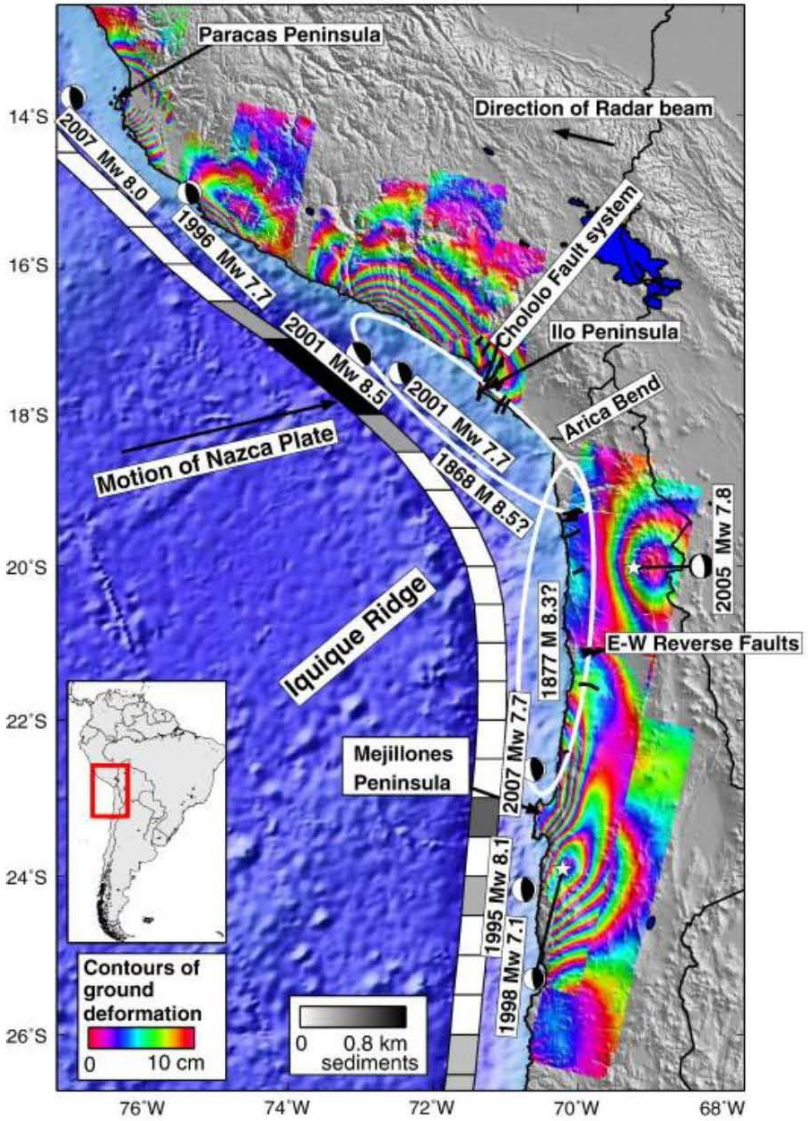




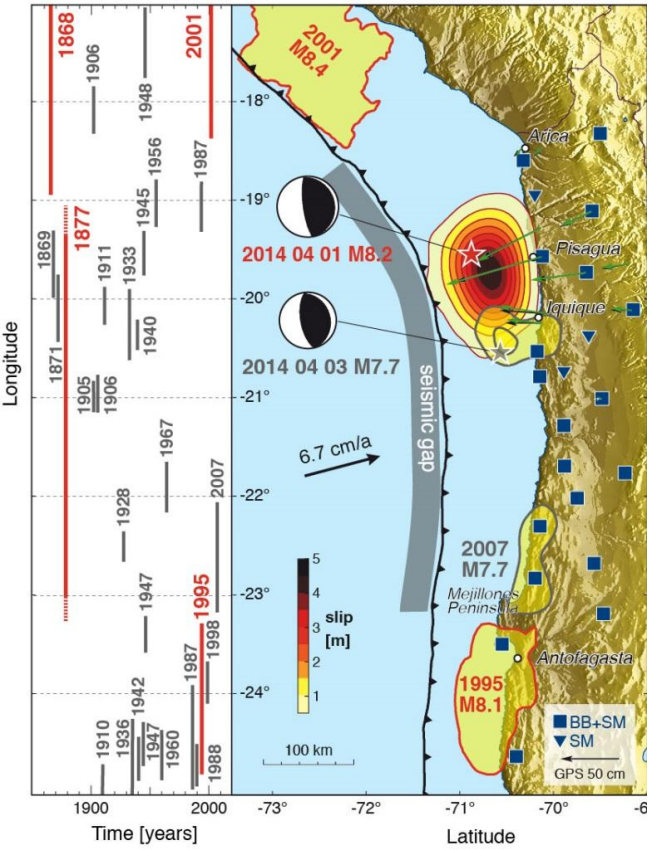
$$\triangle\rho = \frac{4\pi r B_{\perp t}}{\lambda R tan\theta} + \frac{4\pi h B_{\perp t}}{\lambda R sin\theta} + \frac{4\pi\delta\rho}{\lambda} + \triangle\Theta$$

Franges Orbitales — Topographie — Déformation — Bruit

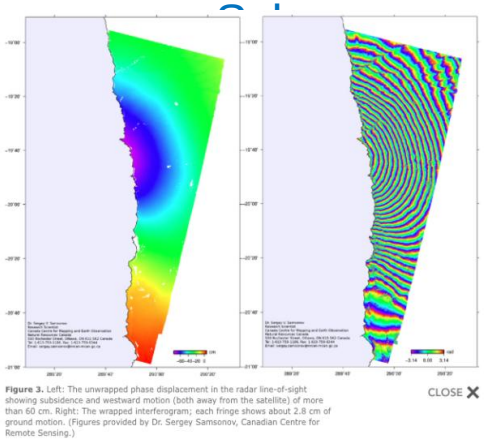


Loveless et al, 2010

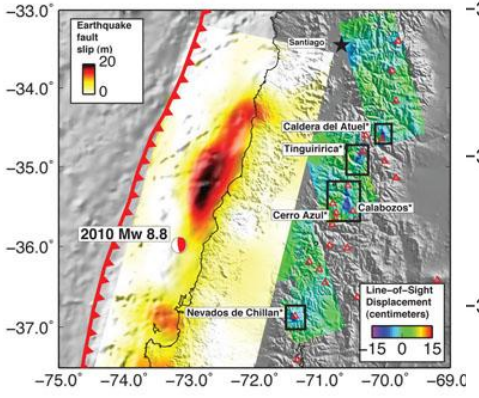
Recent Earthquakes



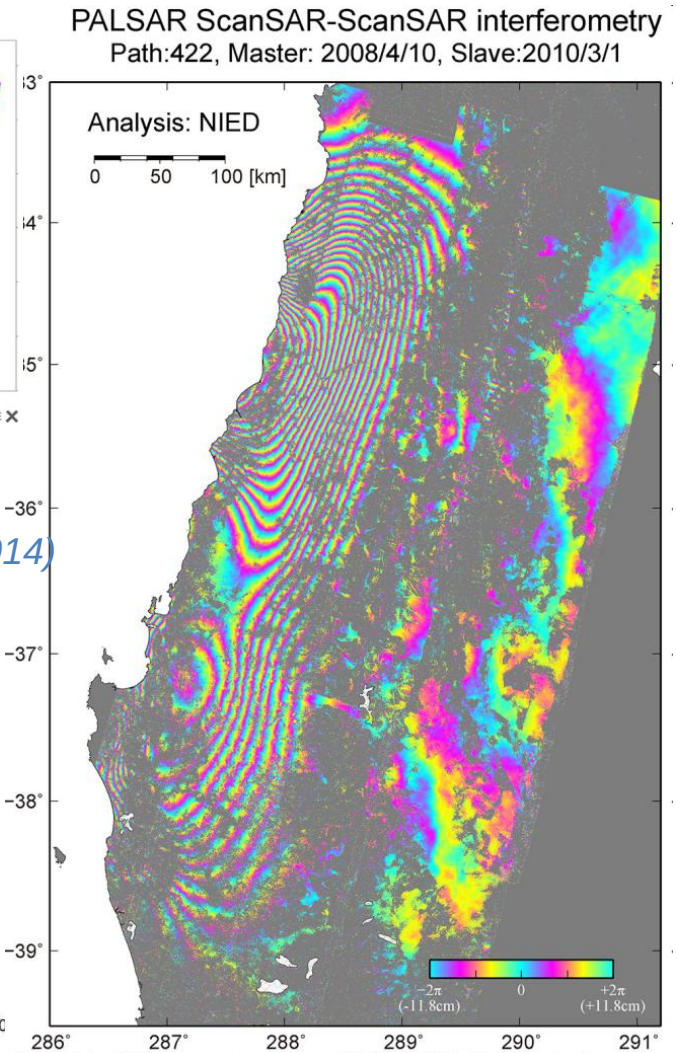
Schurr et al. (2014)



Samsonov (2014)



Pritchard *et al.* 2013



Ando, 2010

Large Tsunamis in Chile

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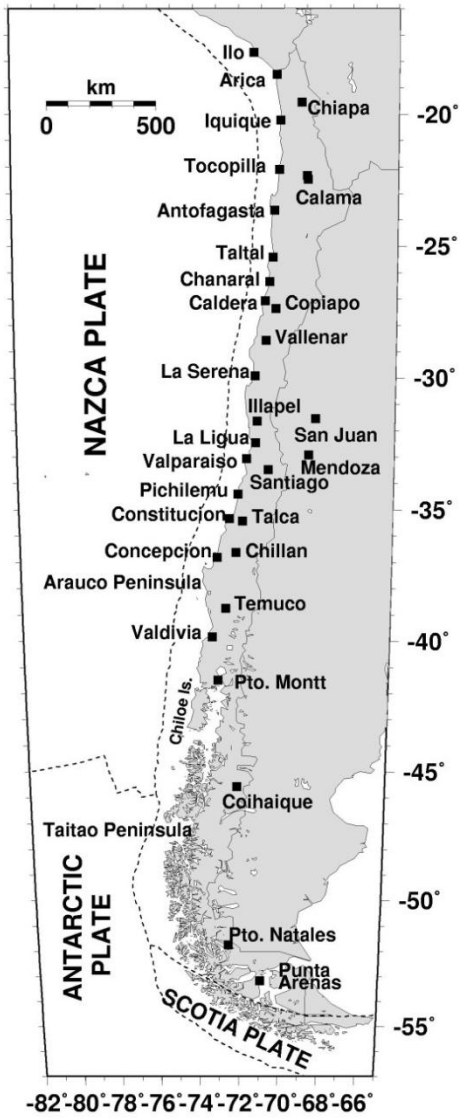
Place	*year*	*Run-up*
Arauco - Concepción	1562	
Concepción	1570	4 m Concepción
Valdivia	1575	4m Corral
Sur de Perú	**1604**	**16 m en Arica**
Concepción	1657	4 m
Chile Central	**1730**	**16 m Concepción**
Concepción	**1751**	**3.5 m Concepción, _ > Is. Juan Fernández**
Atacama	1819	4 m Caldera
Valparaíso	1822	3.5 m
Concepción	**1835**	**13 m Isla Quiriquina**
Valdivia	1837	2 m Ancud
Coquimbo - La Serena	1849	5 m Coquimbo
Atacama	1851	3 m Huasco
Atacama	1859	6 m Caldera
Sur de Perú	**1868**	**20 m Arica**
Norte de Chile	**1877**	**21 m Mejillones**
Valparaíso	1906	1.5 m
Atacama	1918	5 m Caldera
Atacama-Vallenar	**1922**	**9 m Chañaral**
Región del Maule	1928	1.5 m Constitución
Illapel	1943	1 m Los Vilos
Sur de Chile	**1960**	**25 m Is. Mocha, 15 Mehuín, 10 m Corral, Ancud**
Tal-Tal	1966	0.8 m Caldera
Valparaíso	1985	1.5 m
Antofagasta	1995	2.8 m
Tocopilla	2007	25.5 cm Antof., 19.3 cm Iquique, 19.5 cm en Arica
Centro-Sur de Chile	**2010**	**27 m Constitución**



Tsunamis

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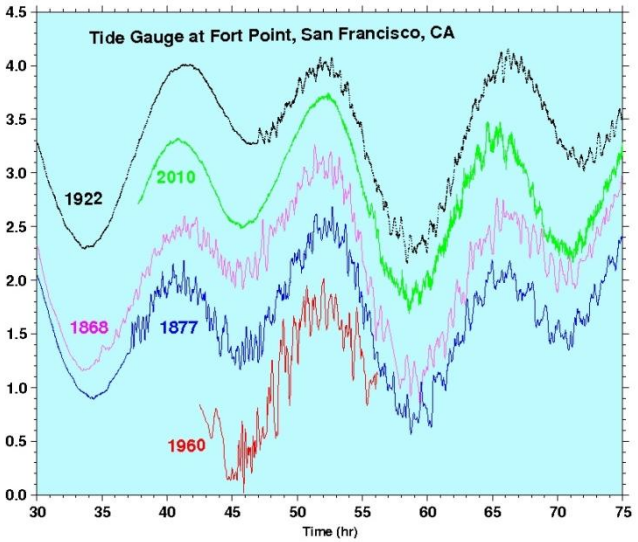
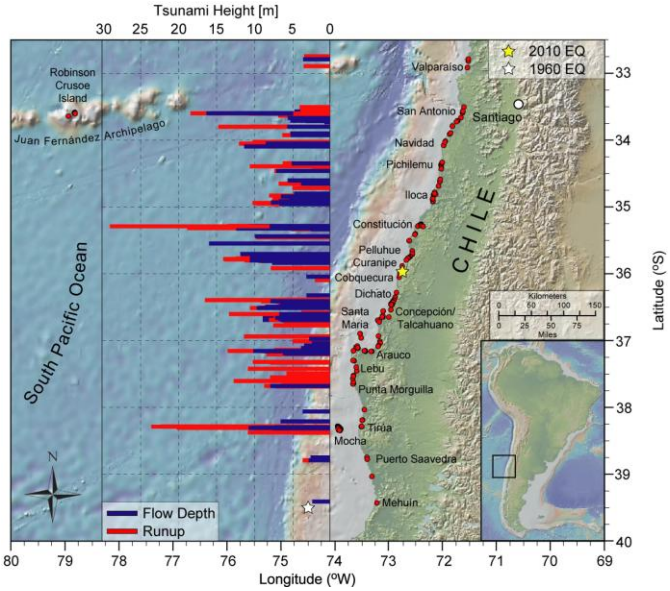
In Chile, due to disasters of natural origin, since 1900 earthquakes and tsunamis have produced :

- *99 % of fatalities*
- *98% economic damage*





Fritz et al (2011)

Runups 4 m or more:

1570,
1575, 5
1604, 29
1657, 53
1730, 73
1751, 21
1819, 68
1835, 16
1837, 2
1849, 12
1859, 10
1868, 9
1877, 9
1918, 41
1922, 4
1960, 38
2010, 50
2014, 4
2015 1

T = 24.7 years

Runups 10 m or more:

1604,
1730, 126
1751, 21
1835, 84
1837. 2
1868, *31*
1877, 9
1922, 45
1960, 38
2010, 50

T = 45 - 50 years

Large Tsunamis in Chile

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10 m or more:

1604, 1730, 1835, 1868, 1877, 1922, 1960, 2010

Intervals 126, 105, 33, 9 45, 38, 50;

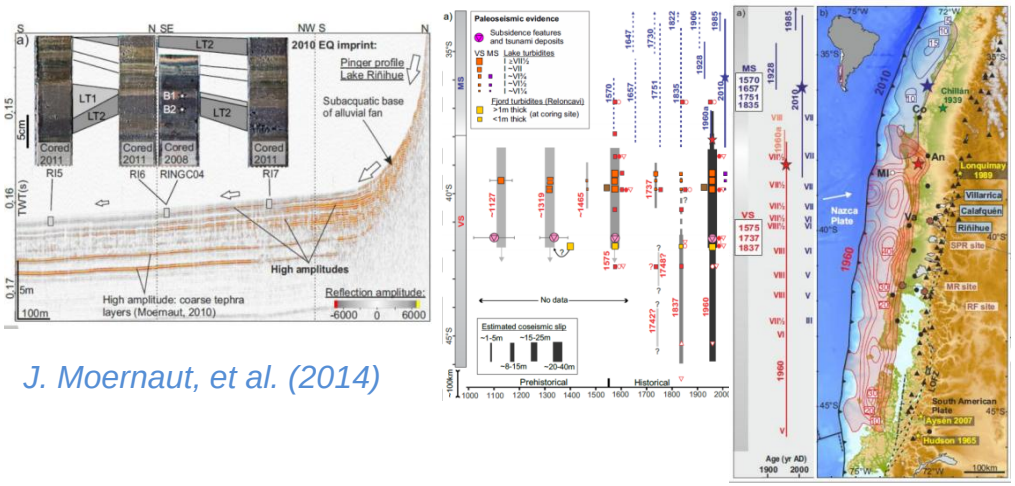
Average = 58 yr

4 m or more:

1570, 1575, 1604, 1657, 1730, 1751, 1819, 1835, 1849, 1859, 1868, 1877, 1918, 1922, 1960, 2010

Intervals: 5, 29, 53, 73, 21, 68, 16, 2, 12, 10, 9, 9, 41, 4, 38, 50, 4, 1;

Average = 24.7 yr



J. Moernaut, et al. (2014)

Photo # NH 496 Peruvian warship America, wrecked by tidal wave at Arica, Chile, August 1868

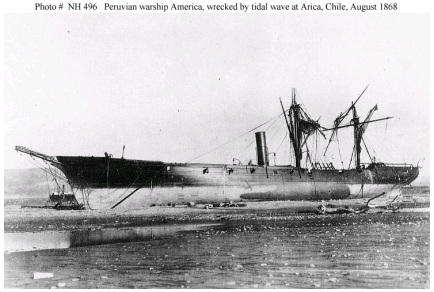
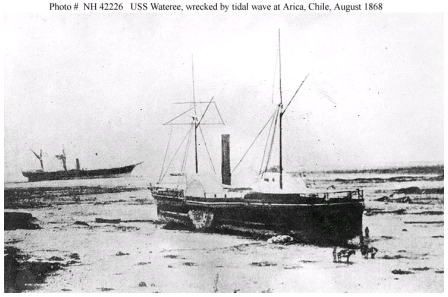
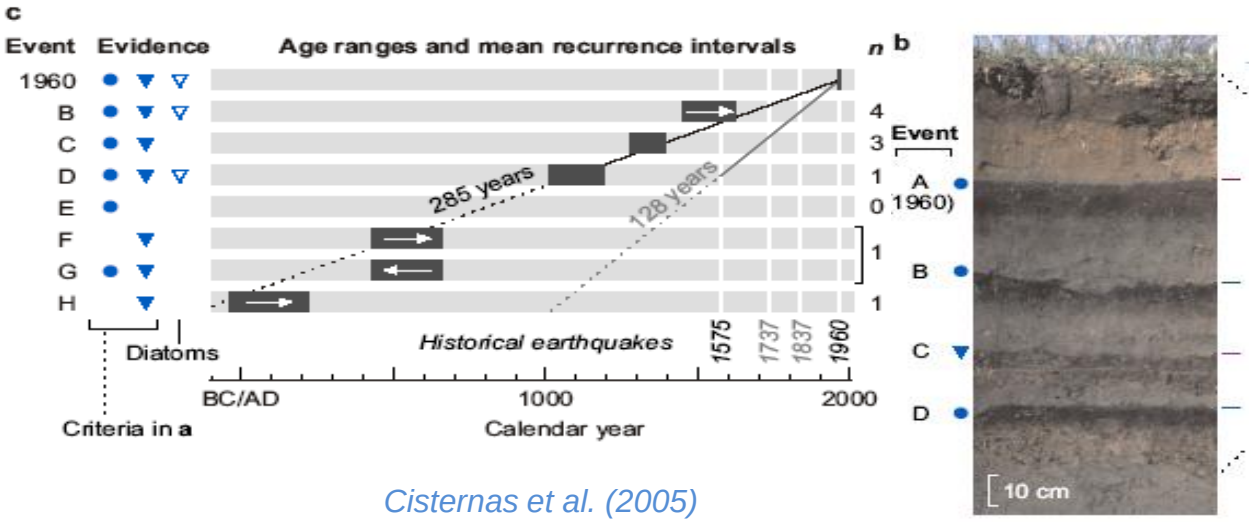


Photo # NH 42226 USS Wateree, wrecked by tidal wave at Arica, Chile, August 1868





Cisternas et al. (2005)

Large earthquakes in Chile

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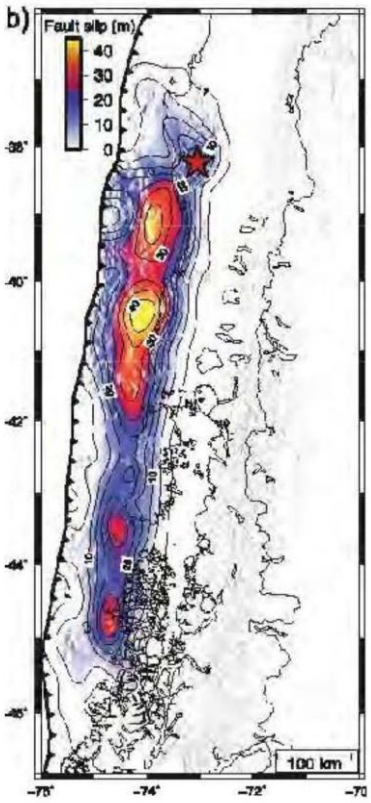
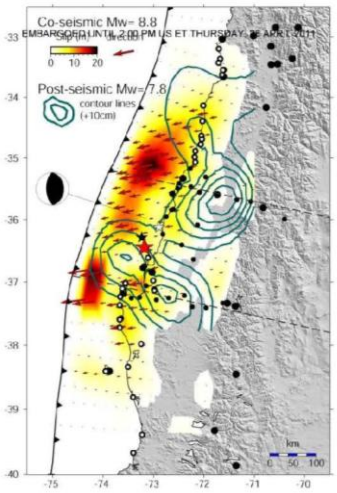
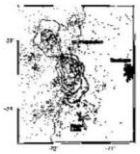


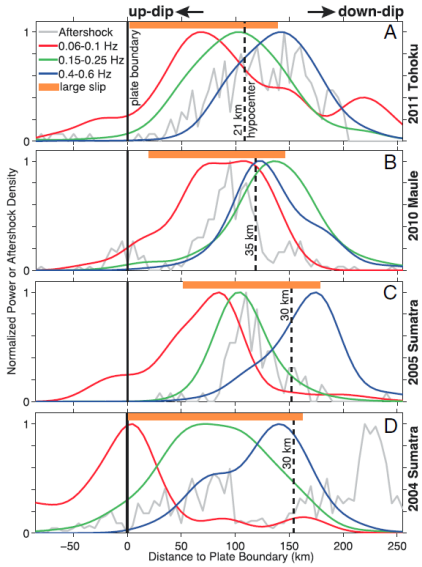
Moreno (2010)

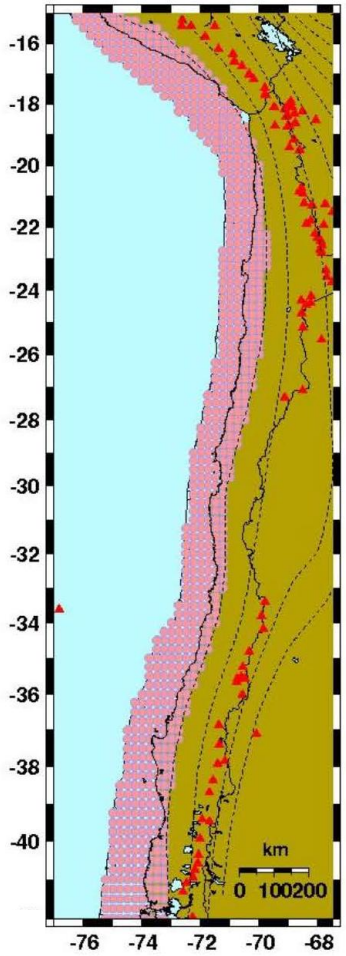


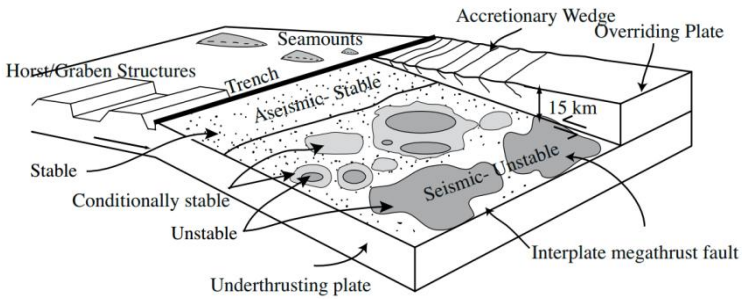
Vigny et al. (2011)



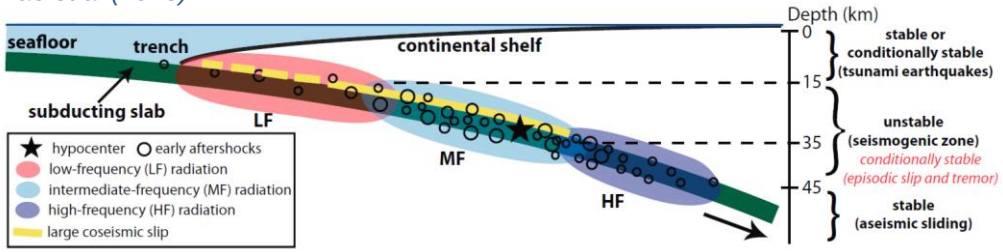
Barrientos (1997)







Yao et al (2013)



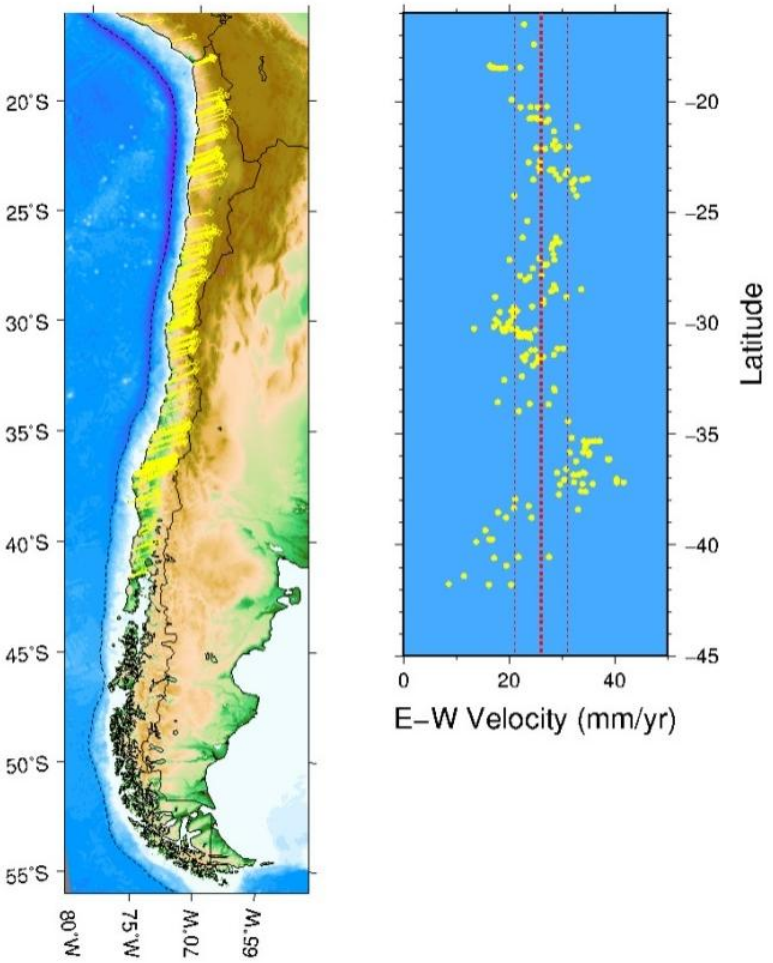
Compararison (Mw)

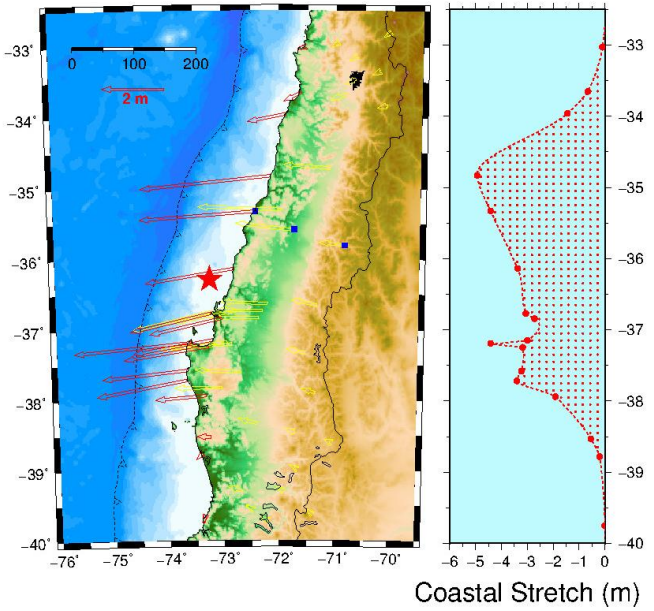
M = 9.5

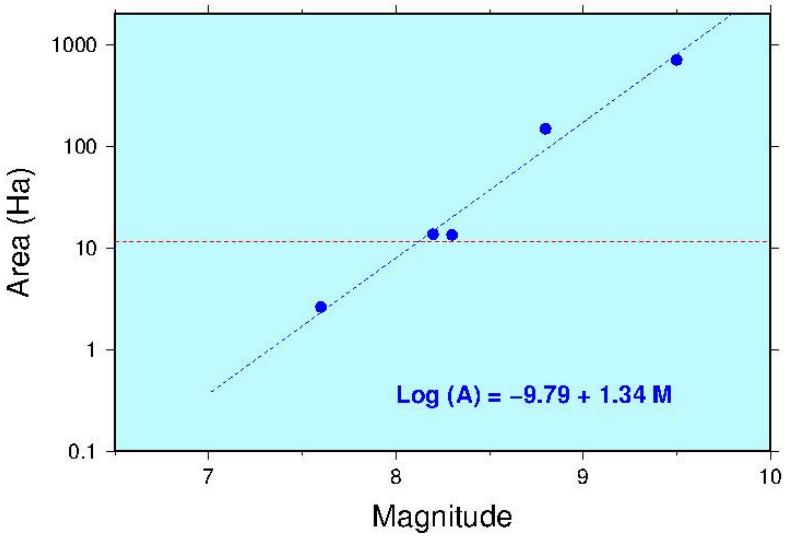
M = 8.8

M = 8.0

Area Change

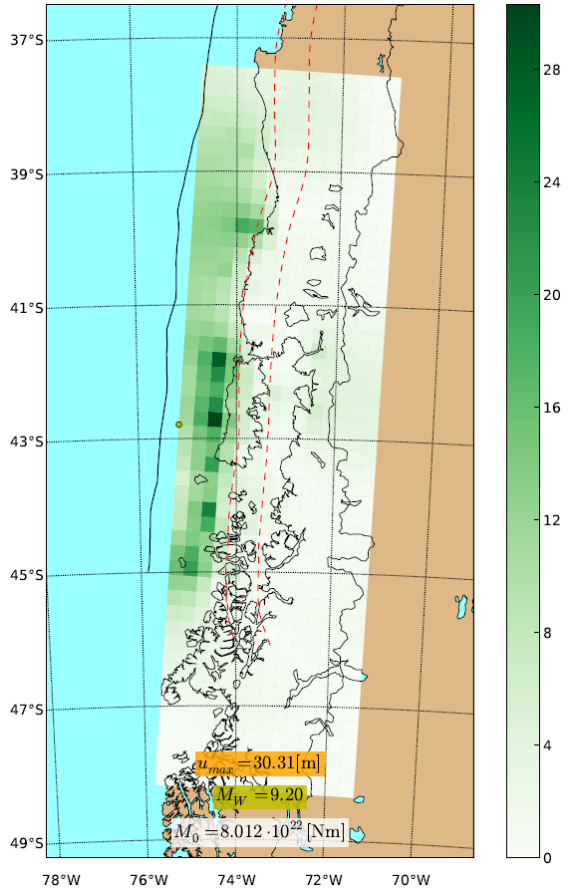




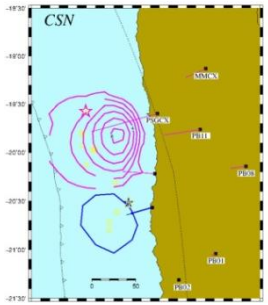


1 Ha = 100 m x 100 m

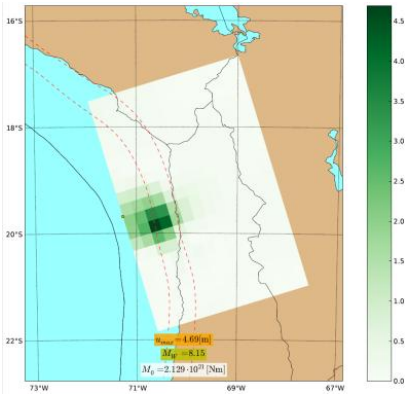
GNSS and horizontal displacements



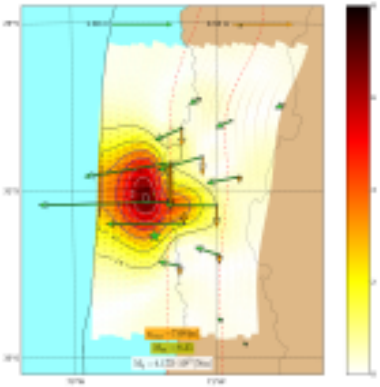
1960 M=9.5



2014 M=7.6



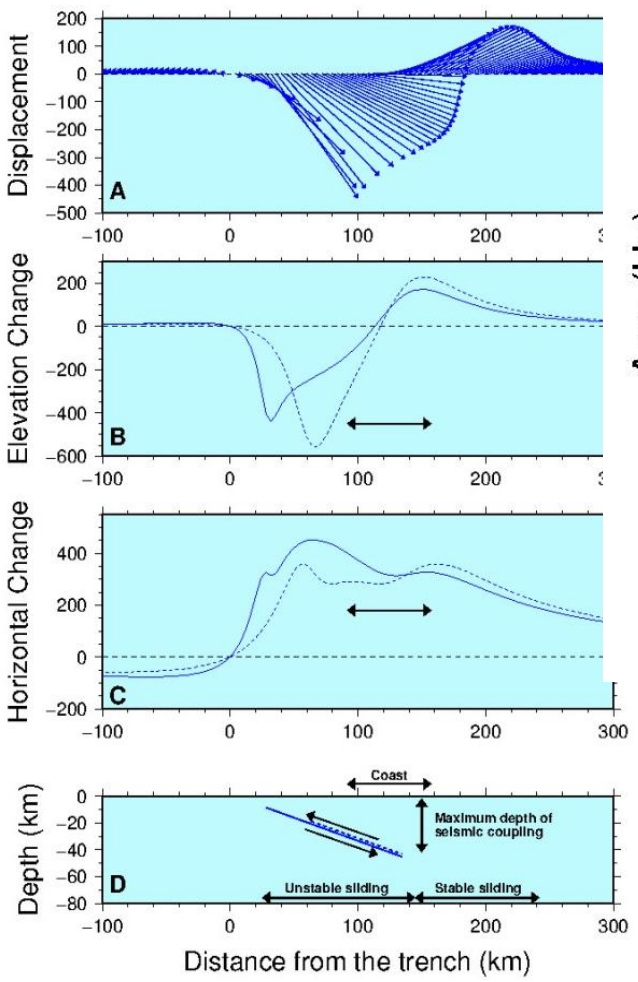
2014 M=8.1

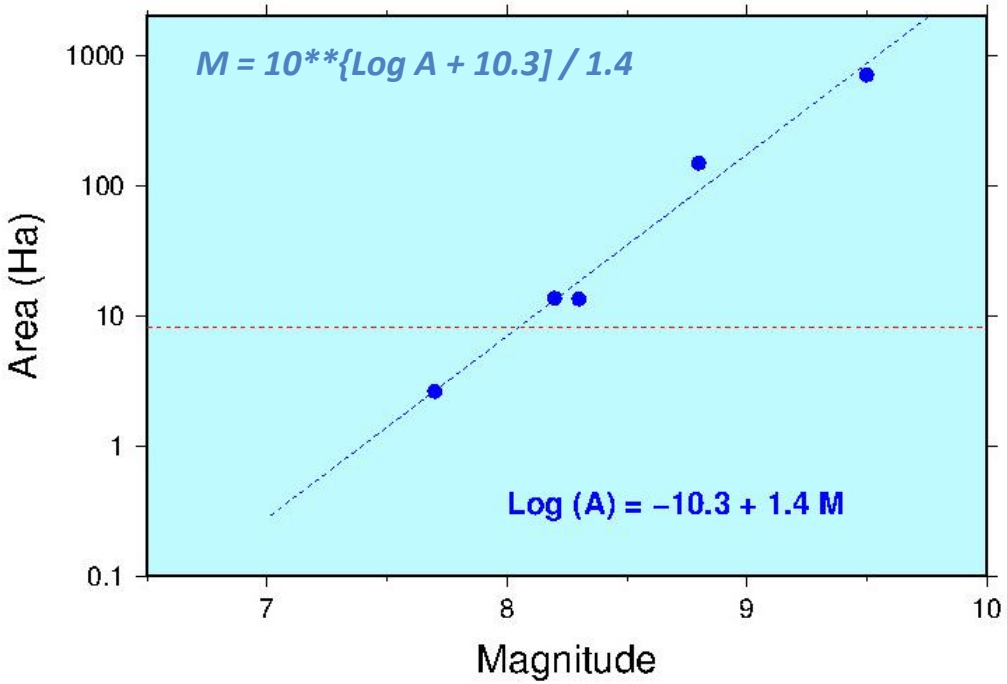


2015 M=8.3

Year	Magnitude Mw	Area (Ha)	Observations
1960	9.5	800	Estimated
2010	8.8	140	Observed
2015	8.3	12.1	Estimated
2014	8.1	11.8	Estimated
2014	7.6	1.5	Estimated

GNSS and horizontal displacements





Year	Magnitude Mw	Area (Ha)	Observations
1960	9.5	800	Estimated
2010	8.8	140	Observed
2015	8.3	12.1	Estimated
2014	8.1	11.8	Estimated
2014	7.6	1.5	Estimated

Coastal elevation change

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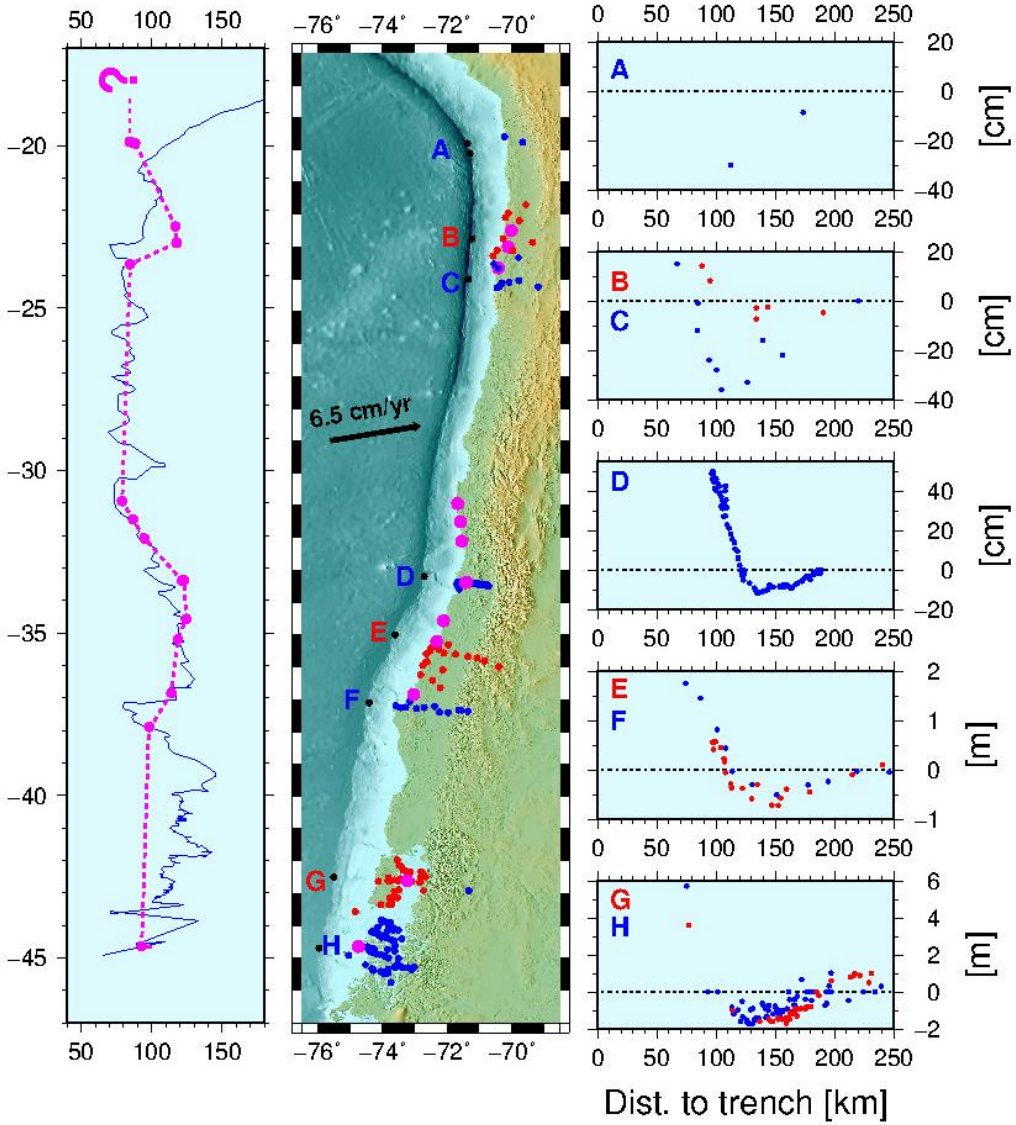
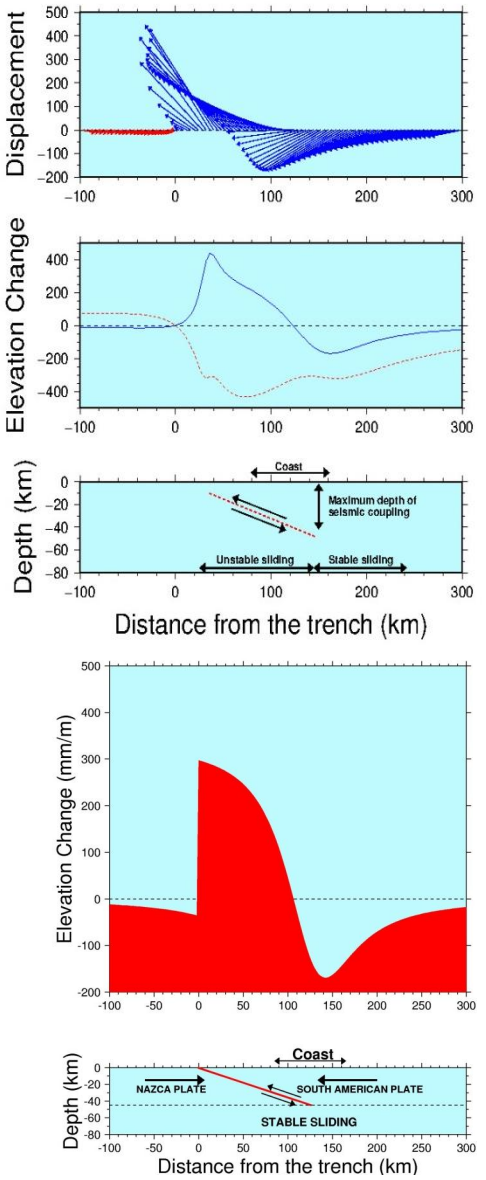
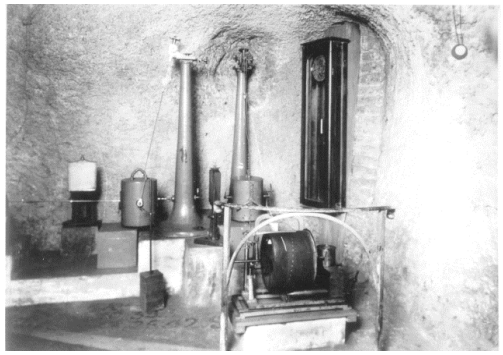


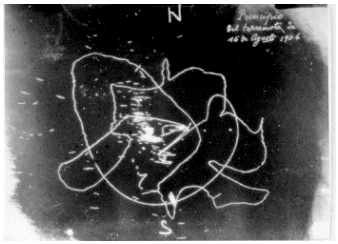


Seismic Network in 1911



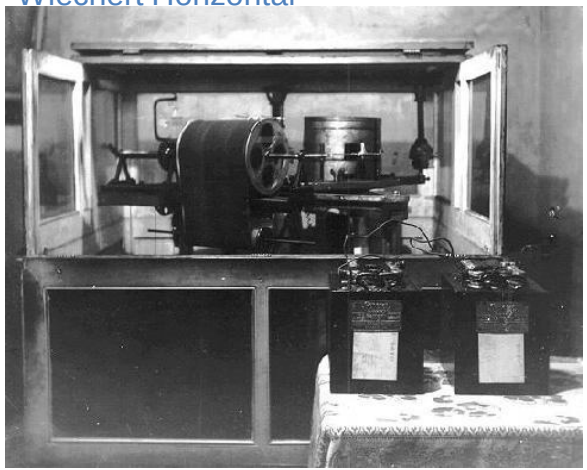
Bosch-Omori

1er Order Santiago, Santa Lucía:
Wiechert, 180 kg, 2 horizontals
Wiechert ,160 kg, vertical
Bosch Omori 100 kg, 2 horiz
Staitessi 950, kg 2 horizontals
wall clock,
Sismoscope

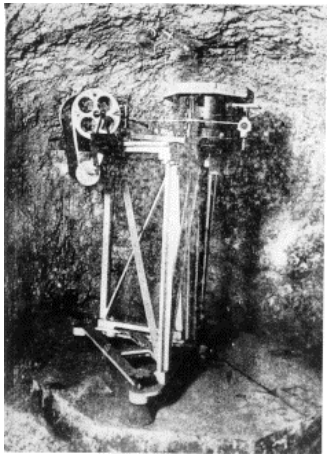


2º Order:
Tacna,
Copiapó,
Osorno
Punta Arenas
Wiechert de 180 kg 2 horizontals , clock

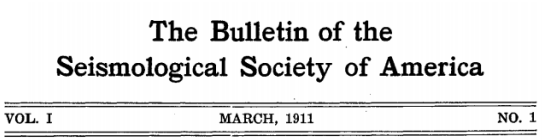
Wiechert Horizontal



Entrée de l'Observatoire du Cerro Santa-Lucia.



Wiechert Horizontal
80 kg, ampl 80



Observation System

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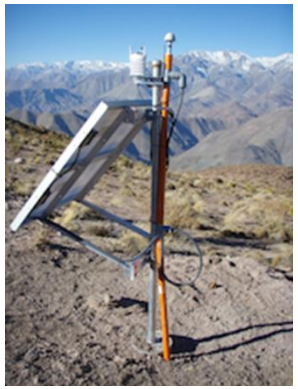
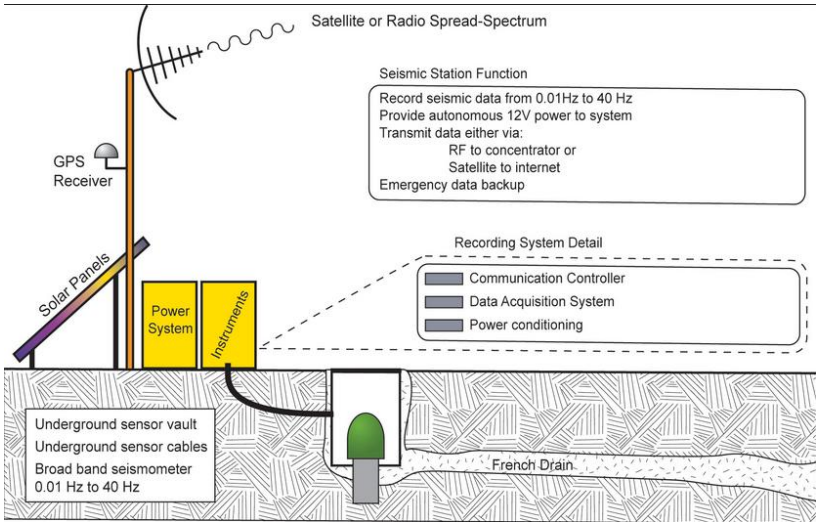
20 estaciones IPOC
10 estaciones GRO IRIS
2 estaciones Geoscope (PEL, COY)
3 estaciones GSN (RPN, LCO, LVC)

- *64 estaciones(BB+SGM real time)*
- *130 GNSS (real-time)*
- *297 acelerómetros (Minvu)*

Para despliegue rápido

- *40 sistemas portátiles*





VA06 Catapilco

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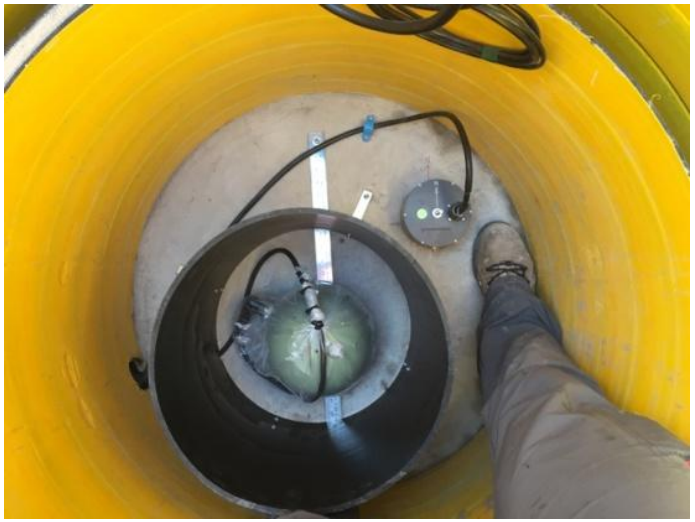

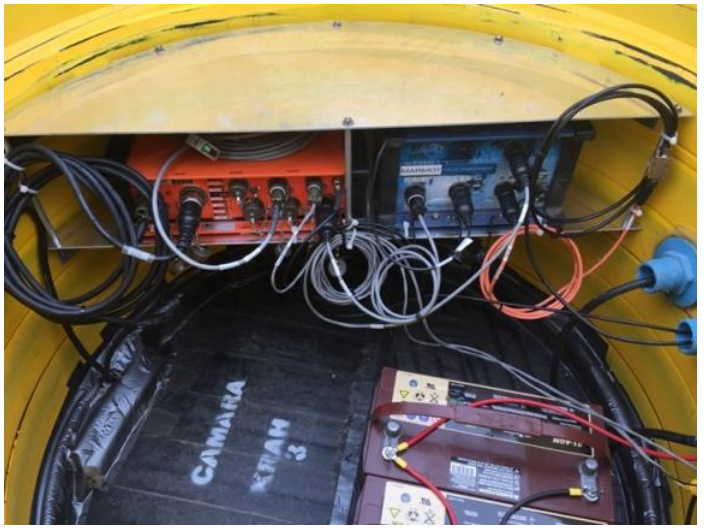

VA06 Catapilco

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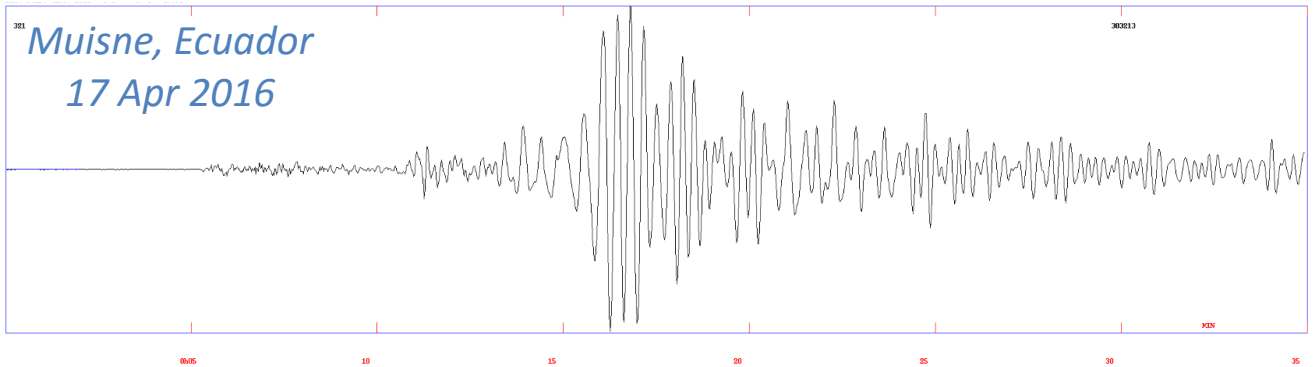
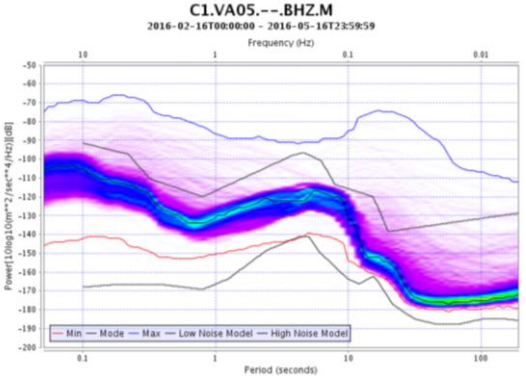
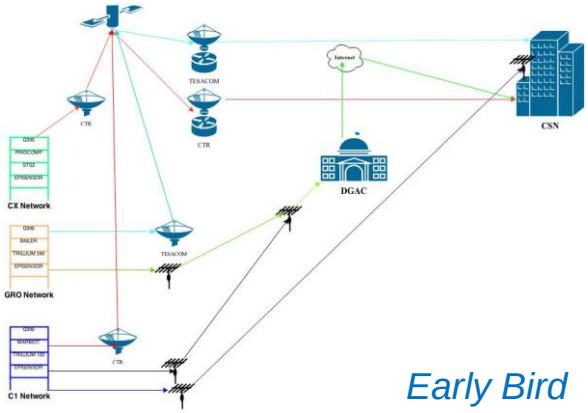


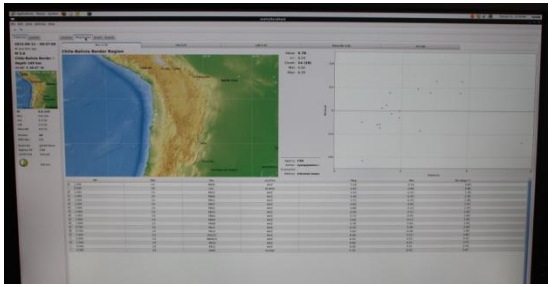


Data Center

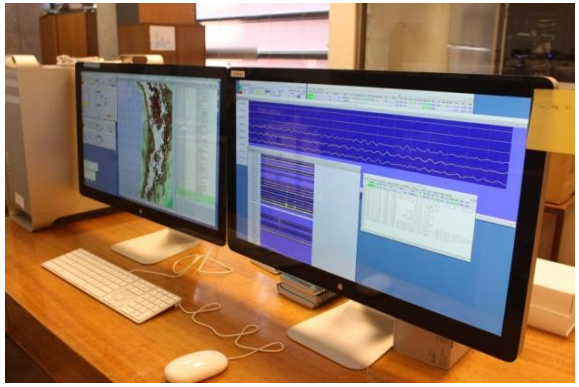


Early Bird

Similar systems installed at ONEMI and SHOA



SeisComP



Antelope (Kinemetrics)

W-Phase

Observation System

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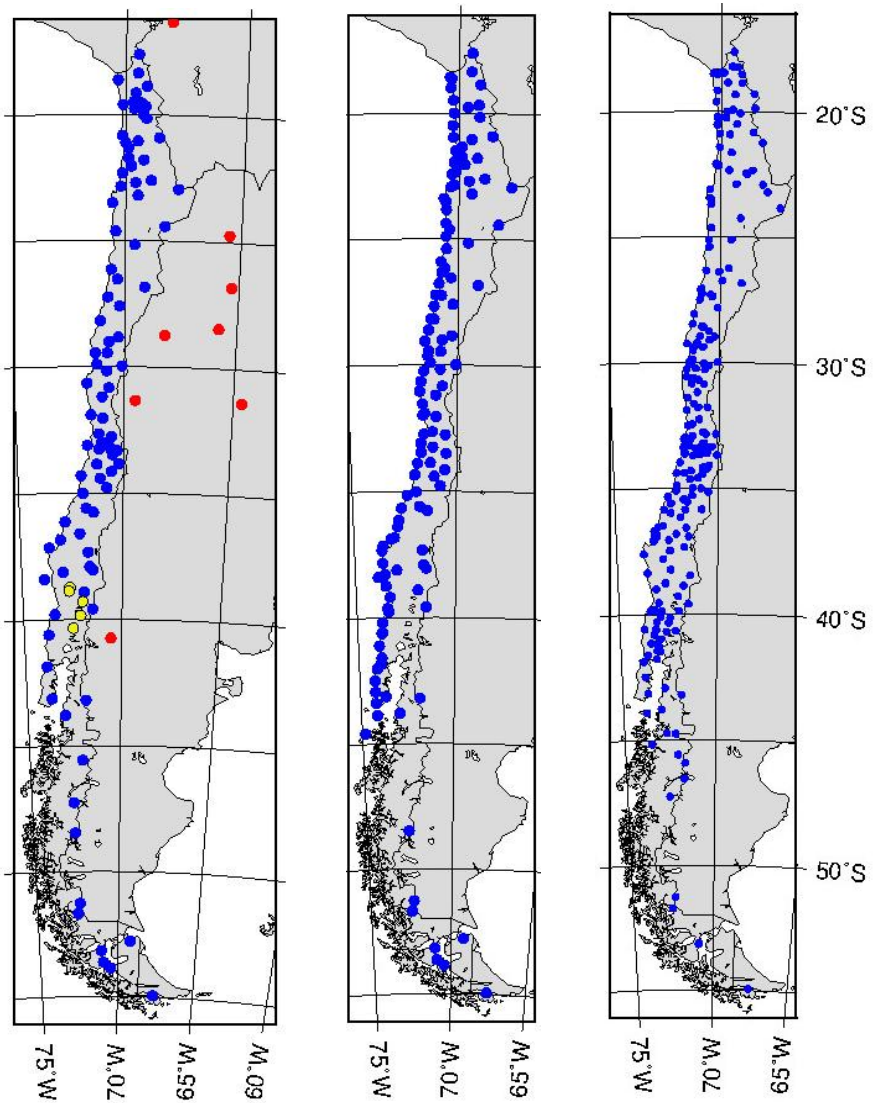
Broad-band
103

GPS
130

Strong Motion
297



Data Exchange

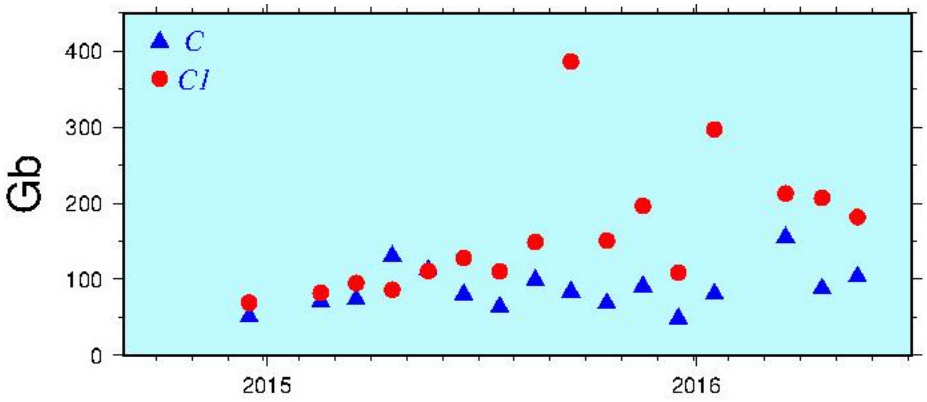
CSN intercambia datos con:
IGP (Peru), INPRES (Argentina), IRIS (USA), USGS, Universidad de Sao Paulo, Universidad de Brasilia
En conversaciones con:
Servicio Geológico Colombiano,
Observatorio San Calixto, La Paz, Bolivia
Instituto de Geofísica - Escuela Politécnica Nacional

Red C1 (ejemplo) Dirección	Total: 101.765 GB Gigabytes	Porcen.
seis.sc.edu	26.0927 GB	25.6 %
152.74.5.224	17.7106 GB	17.4 %
speedy.com.ar	17.0364 GB	16.7 %
cm.vtr.net	7.0944 GB	7.0 %
186.73.45.	6.5386 GB	6.4 %
226/24.bsnl.in	5.5567 GB	5.5 %
152.74.55.64	5.5187 GB	5.4 %
intersat.net.ar	4.2099 GB	4.1 %
baf.movistar.cl	2.7744 GB	2.7 %
intercity.net.ar	1.2121 GB	1.2 %
static.tie.cl	0.9067 GB	0.9 %
ideay.net.ni	0.7823 GB	0.8 %
ptwc.noaa.gov	0.7785 GB	0.8 %
fixed-189-174-56.iusacell.net	0.6859 GB	0.7 %
prod-empresarial.com.mx	0.5275 GB	0.5 %
205.156.56.42	0.4753 GB	0.5 %

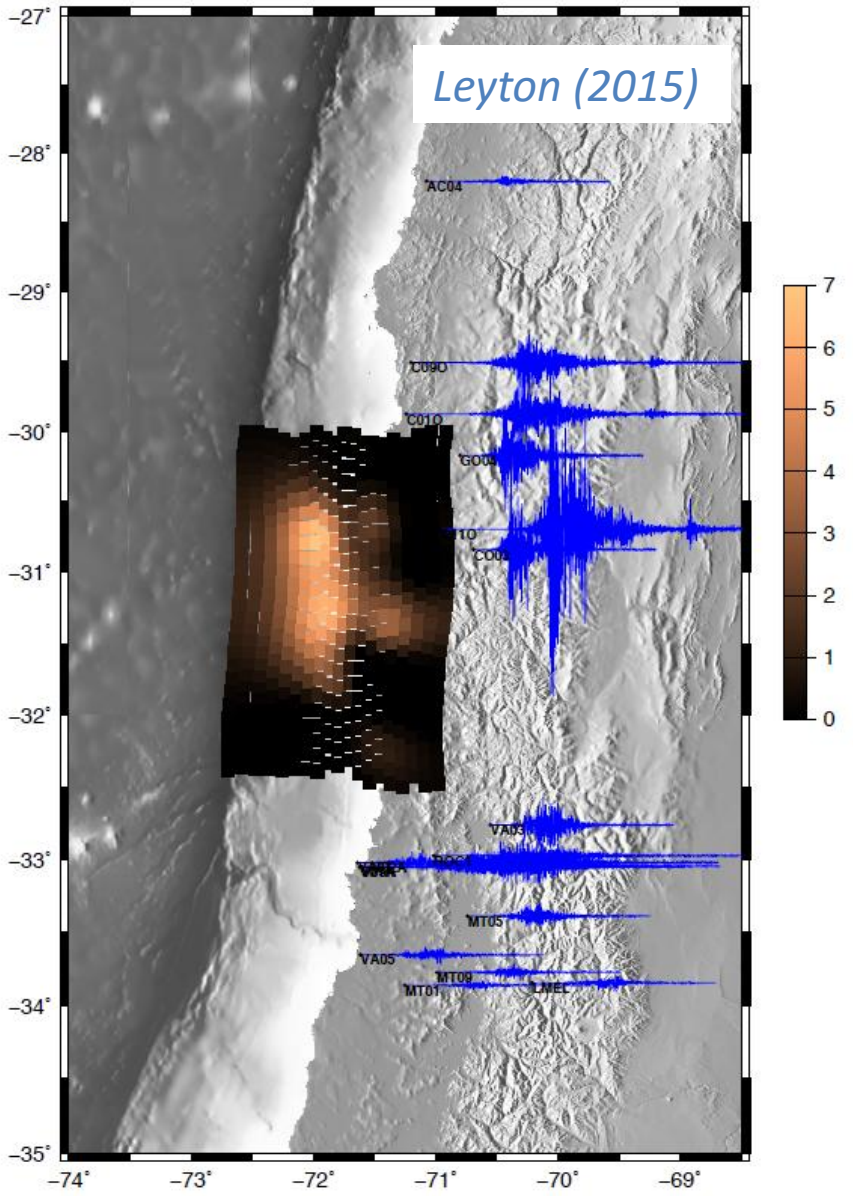
CSN intercambia datos con:
IRIS
USGS
PTWC
EMSC
ISC
UNAVCO
JAXA, NASA

Acuerdos alcanzados con:
ENDESA (para estaciones)
AES-Gener (para estaciones)
SERNAGEOMIN (para respaldo datos)

http://www.csn.uchile.cl/



Strong Ground Motion



Strong Motion

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CSN CENTRO SISMOLÓGICO NACIONAL UNIVERSIDAD DE CHILE

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Filter events

	Min	Max	Format Help
Date:			
Magnitude:			
Latitude:			
Longitude:			
Depth [km]:			

Submit

Events Data Base

Choose ASCII and/or Binary for data format and click on "Download" button

Download Selected Items | ASCII | Binary

Time UTC	Latitude	Longitude	Magnitude	Depth [Km]	Detail
2015-11-22 22:16:54	-23.627	-69.052	5.1	97.4	
2015-11-21 23:05:28	-30.607	-71.797	6.0	34.9	
2015-11-11 02:46:16	-29.552	-72.261	6.9	11.6	
2015-11-11 01:54:36	-29.46	-72.12	6.9	32.9	
2015-11-10 12:58:37	-30.798	-71.456	5.0	56.7	
2015-11-09					

About Data Base

[ENG] The data base contains instrumental information about an specific events catalogue prepared by CSN seismologists. To obtain information about latest events published by CSN, please follow to CSN Official Website

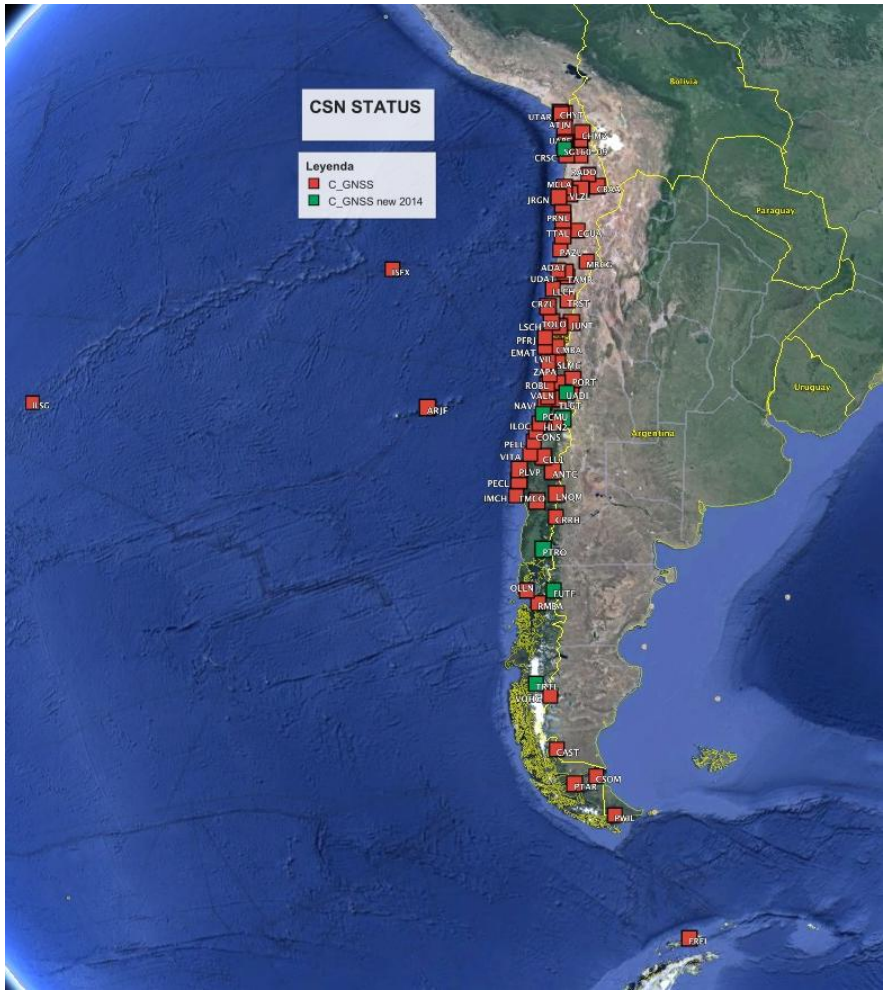
In case of any data error you found, please mail to evtdb@csn.uchile.cl. Please check Frequently Asked Questions (FAQ) section before sending a mail.

[SPA] La base de datos contiene información instrumental sobre un catálogo específico de eventos preparado por nuestros sismólogos. Para obtener información sobre los últimos eventos publicados por el CSN, dirigirse al Sitio Oficial CSN

En caso de dudas o errores

evtdb.csn.uchile.cl

GNSS Observation System



- *Stations*
  - *86 ready installed*
  - *44 to be installed*
  - *at 6-component sites*
  - *4 vandalized*
- *Comms*
  - *40 PPP (RTX)*
  - *Vsat, 3-G, Internet*
  - *Not all of them connected yet*
- *92% replacing existing ENS/IPGP/CALTECH/CAP/FENIX (UNAVCO et al), UdeC (Baez et al)*

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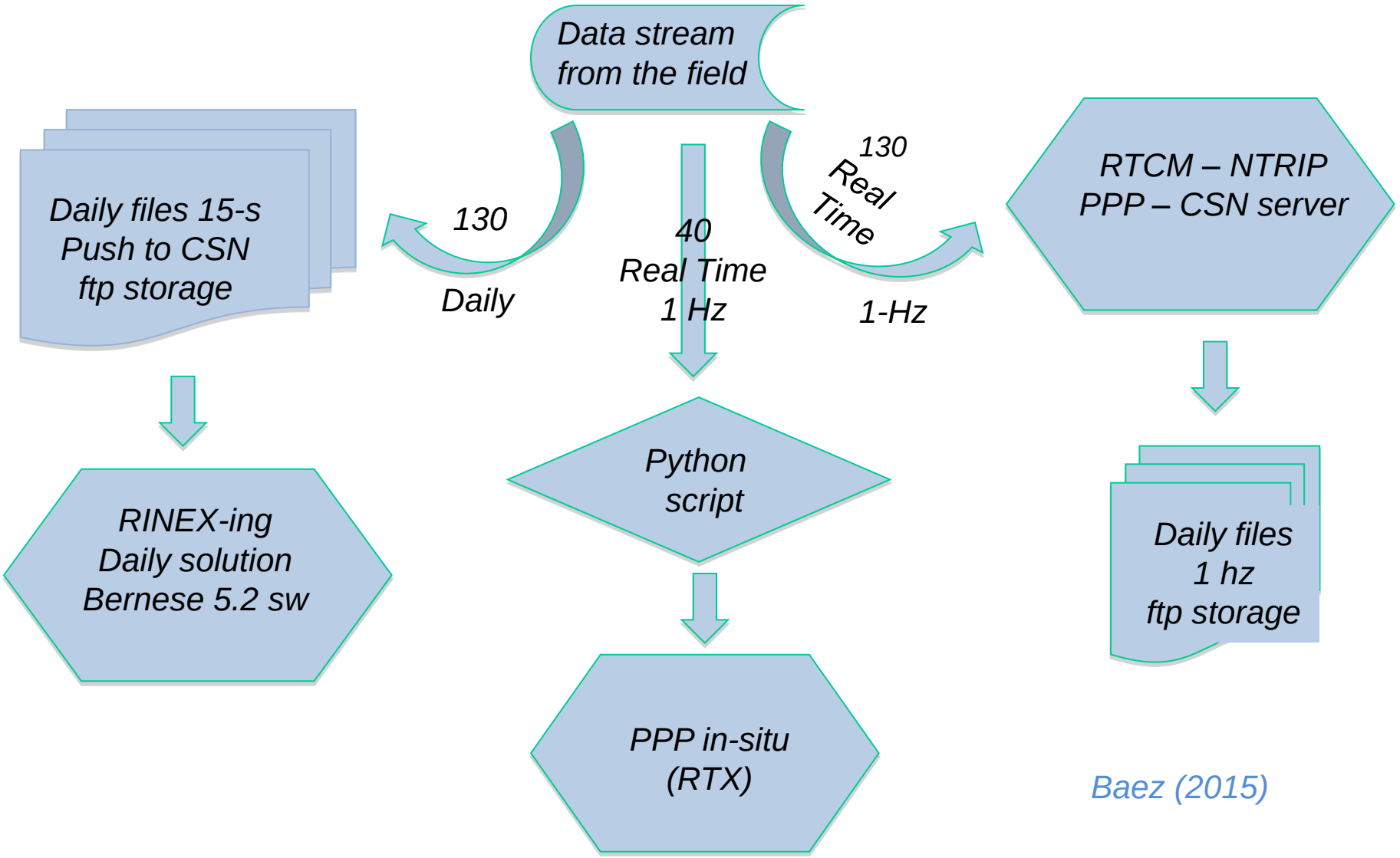
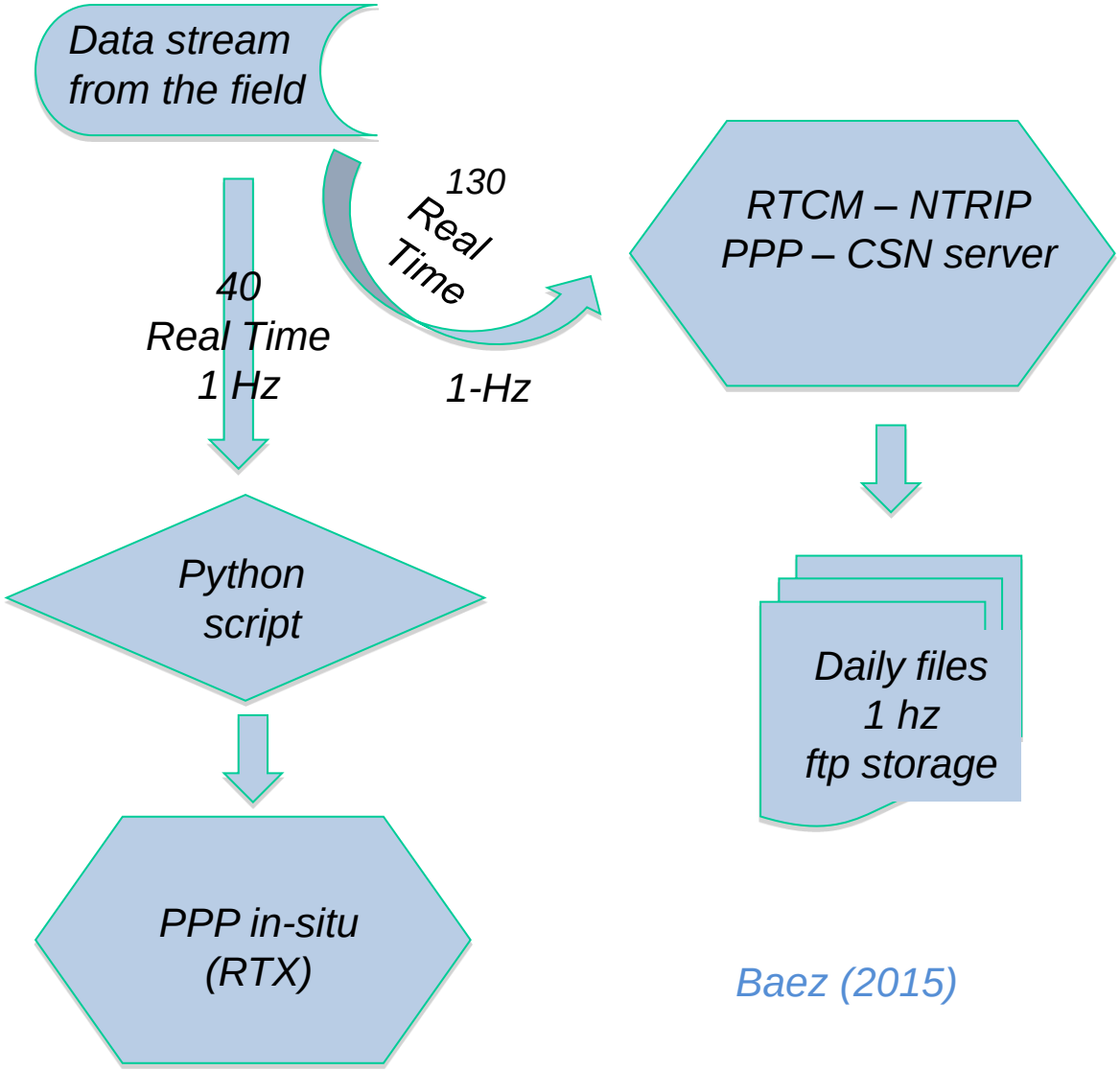
Data Flow



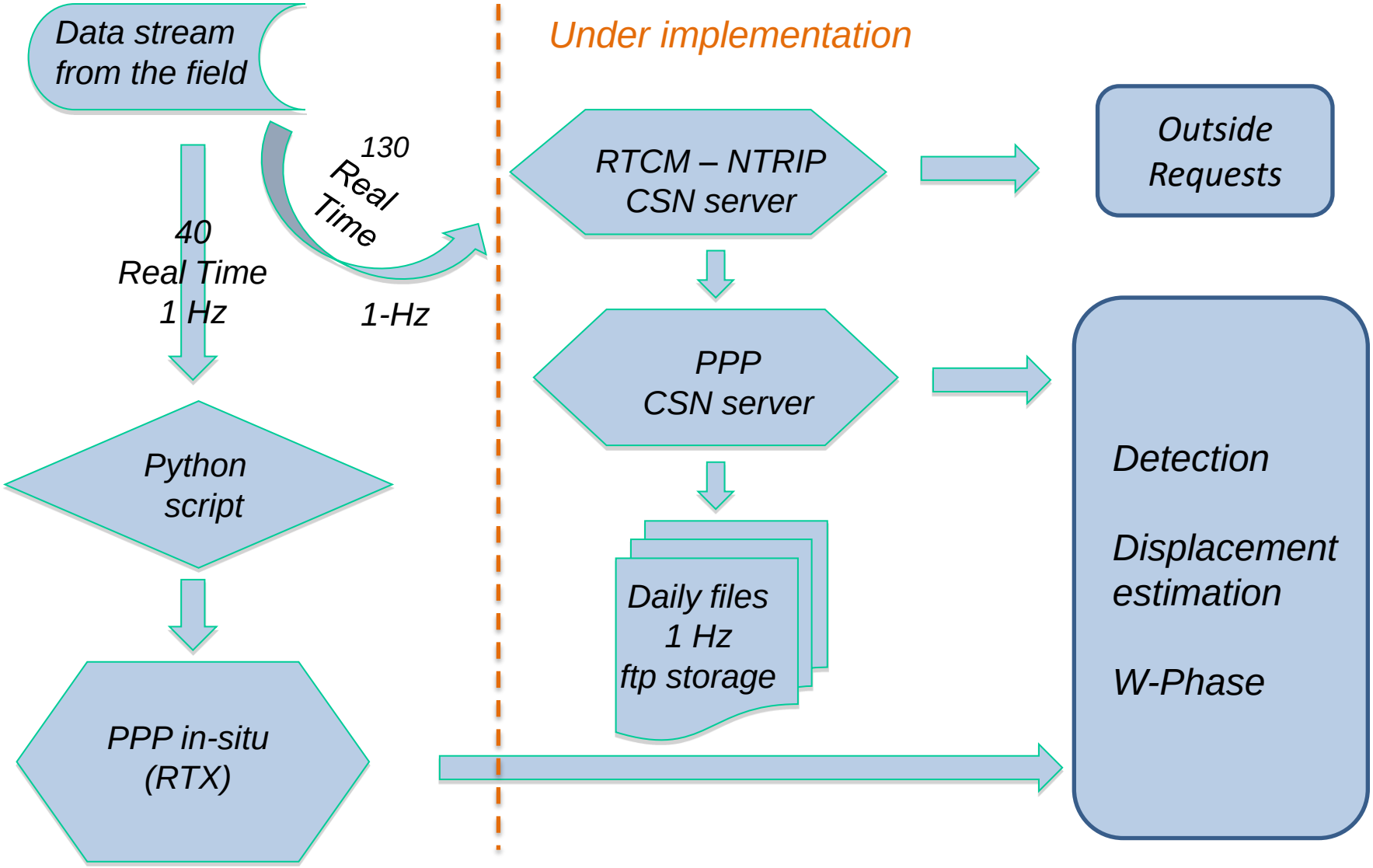
Baez (2015)

Data Flow



Baez (2015)

Data Flow


Data stream from the field
130 Real Time
40 Real Time 1 Hz
1-Hz
Python script
PPP in-situ (RTX)
Under implementation
RTCM – NTRIP CSN server
PPP CSN server
Daily files 1 Hz ftp storage
Outside Requests
Detection
Displacement estimation
W-Phase

GNSS Iquique 2014

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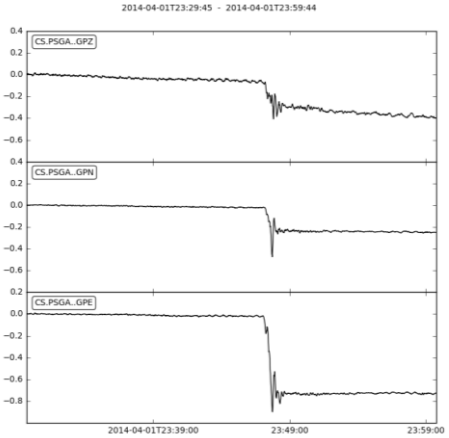
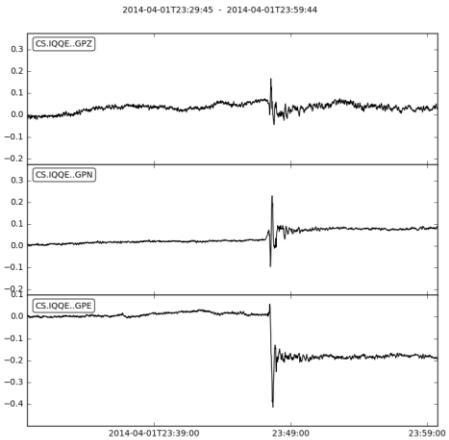
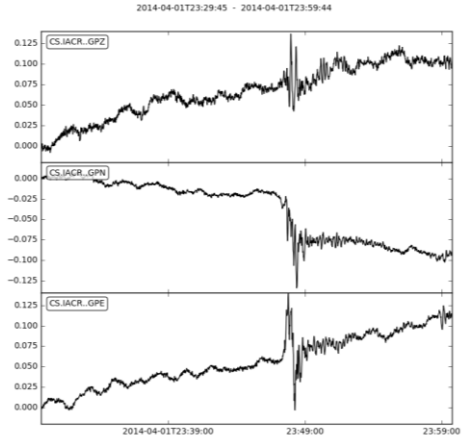
Pisagua

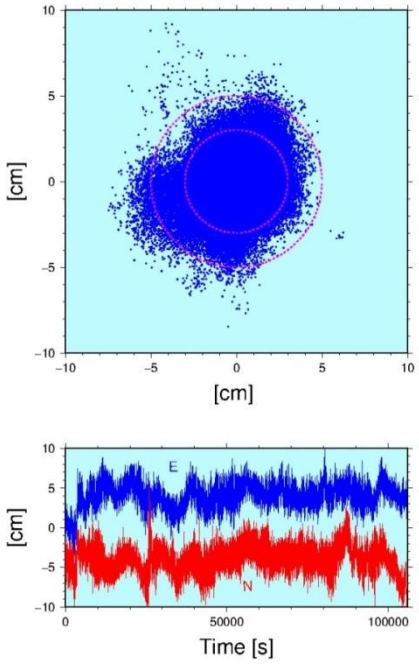


Iquique



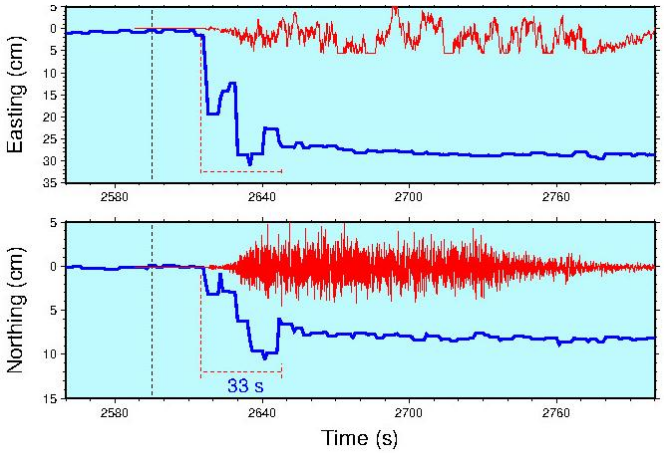
Arica



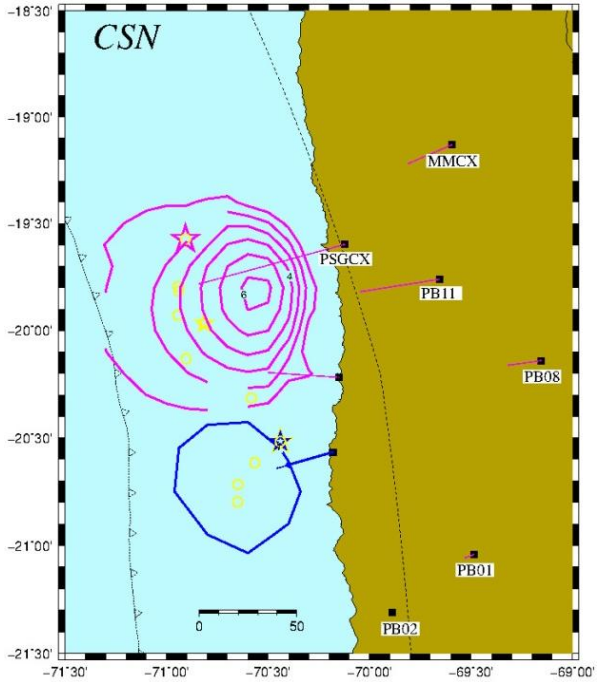


Iquique 2014
Réplica 3-Apr-14

RTX



[Real time data]



Illapel Earthquake (Báez)

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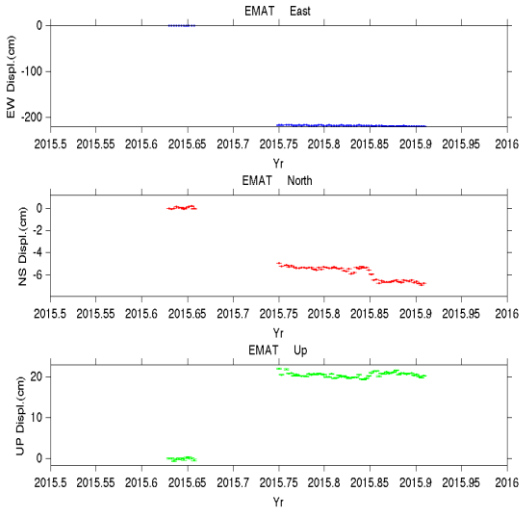
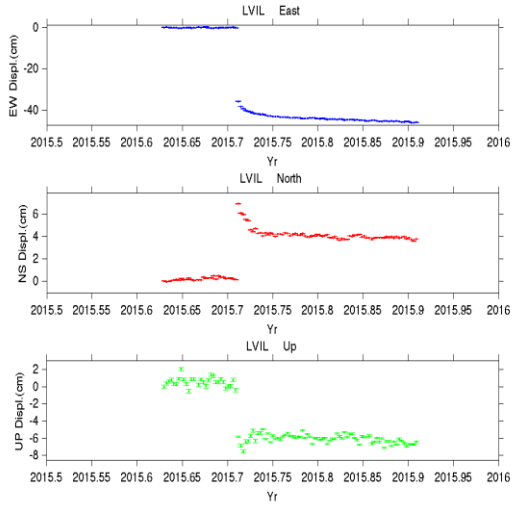
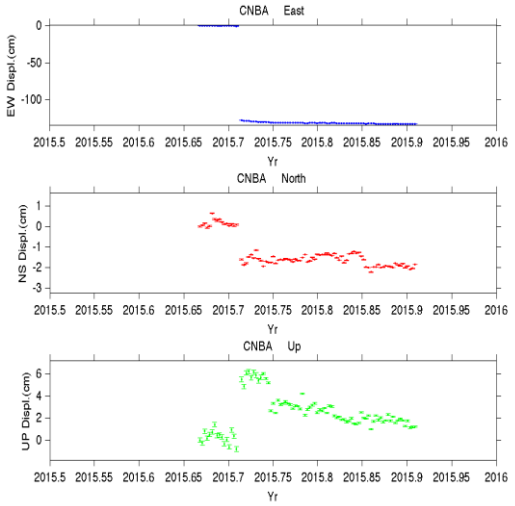
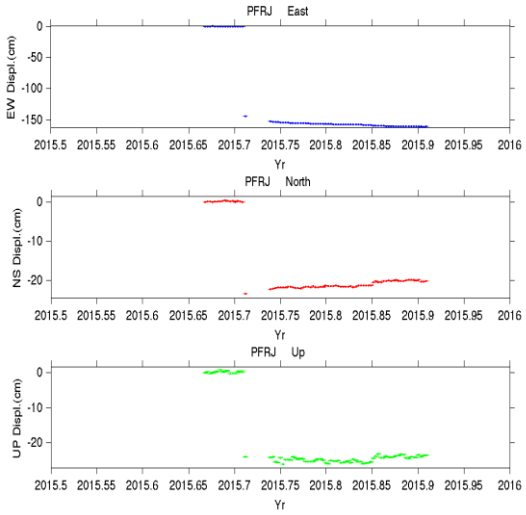


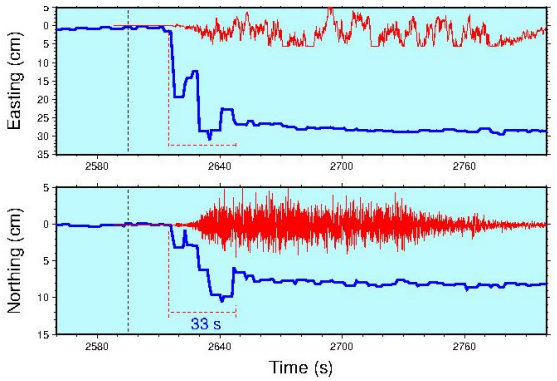


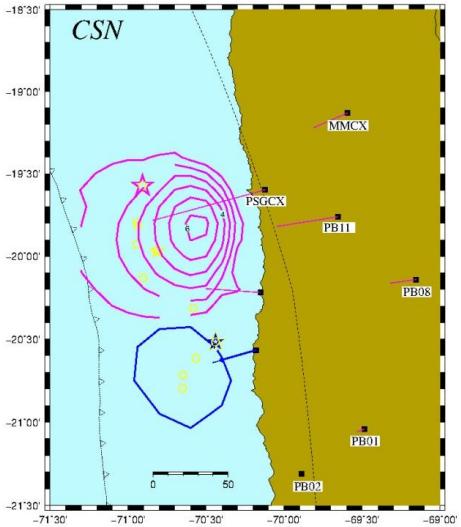




RTX

Iquique 2014
Aftershock 3-Apr-14





GNSS and horizontal displacements

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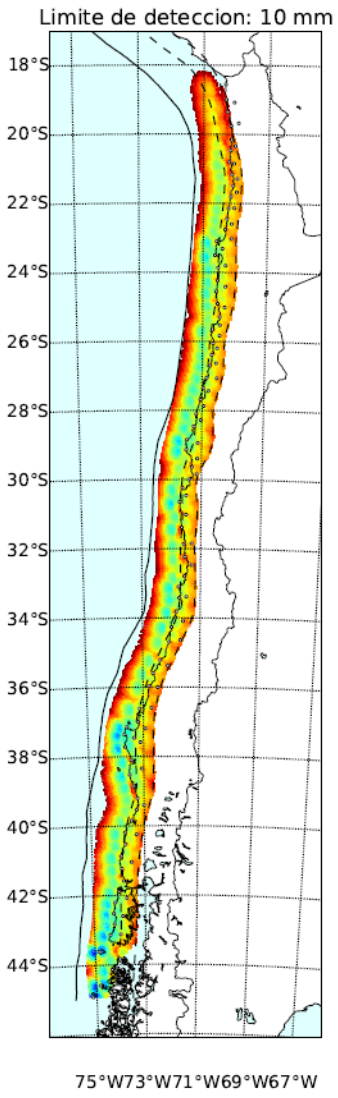
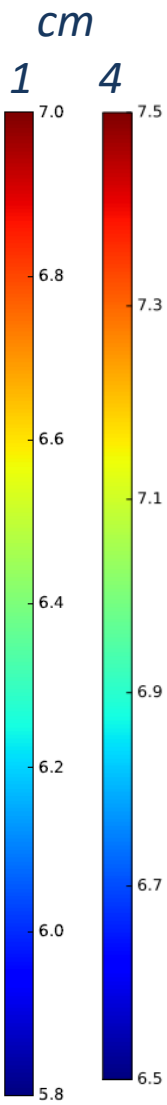
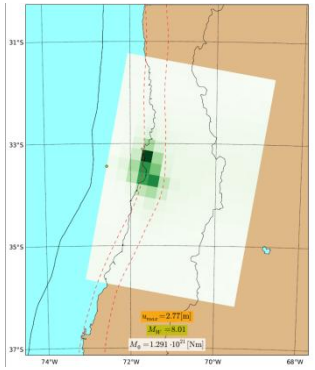
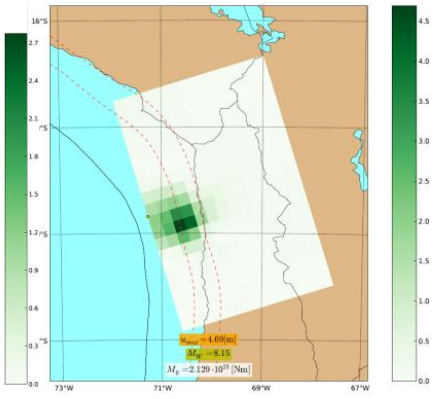




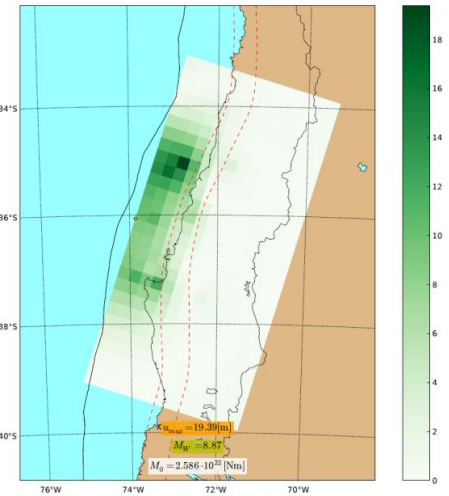
1985 M=8.0



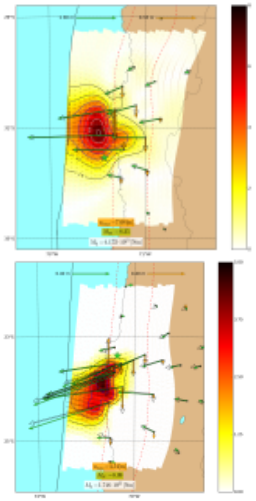
2014 M=8.2



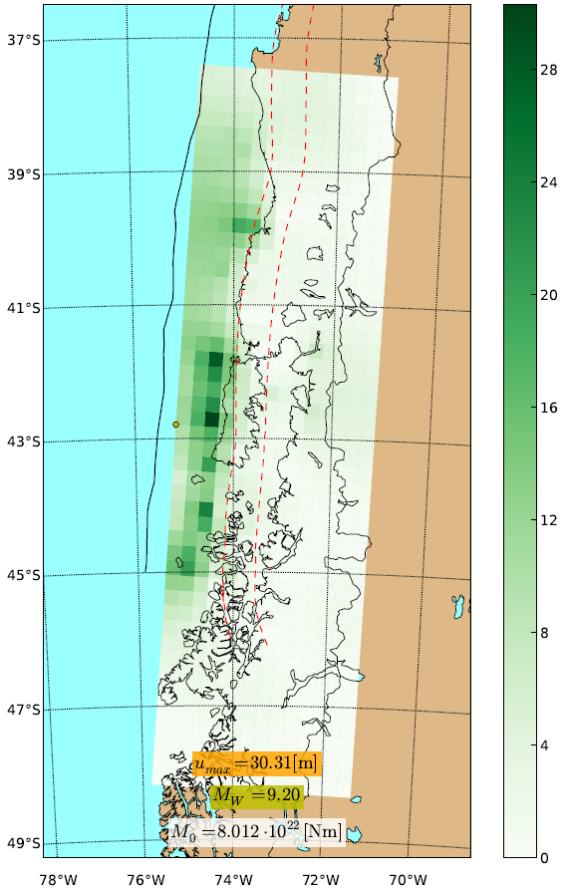
2010 M=8.8



2015 M=8.3



1995 M=8.0



1960 M=9.5

W-Phase (S. Riquelme)

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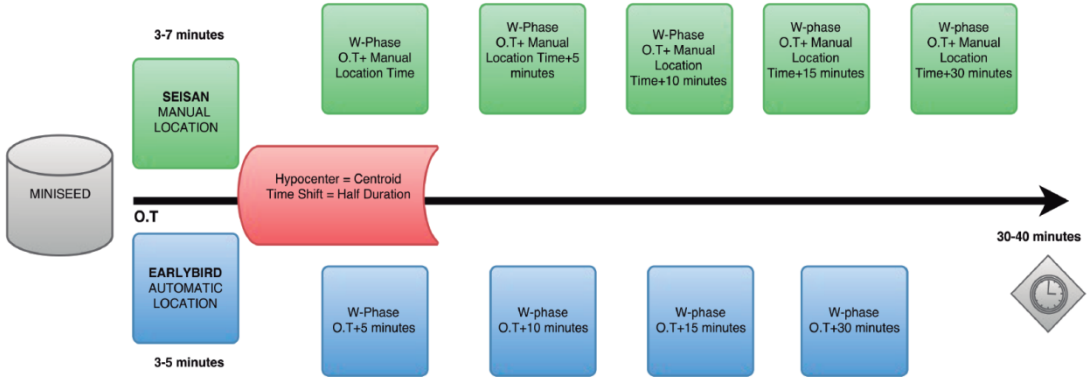
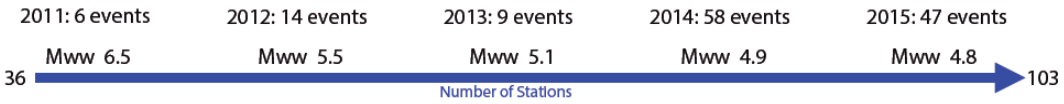
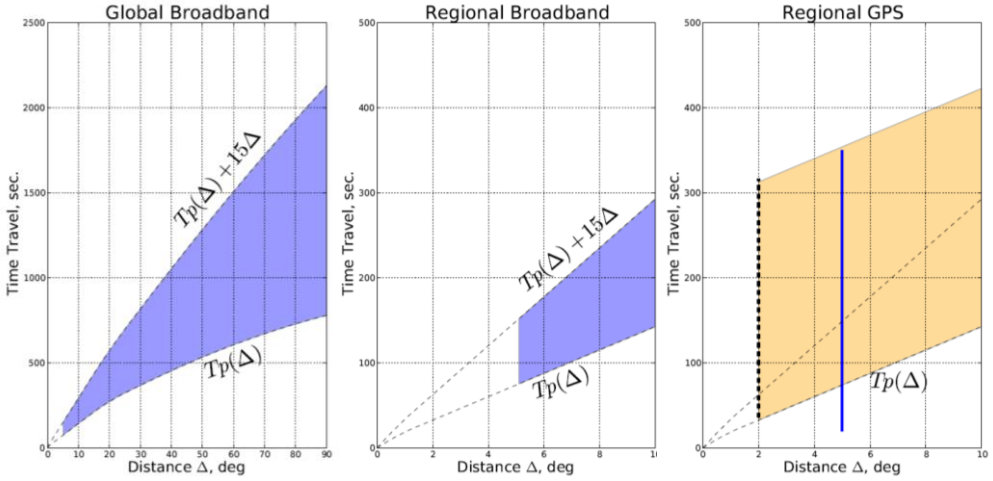
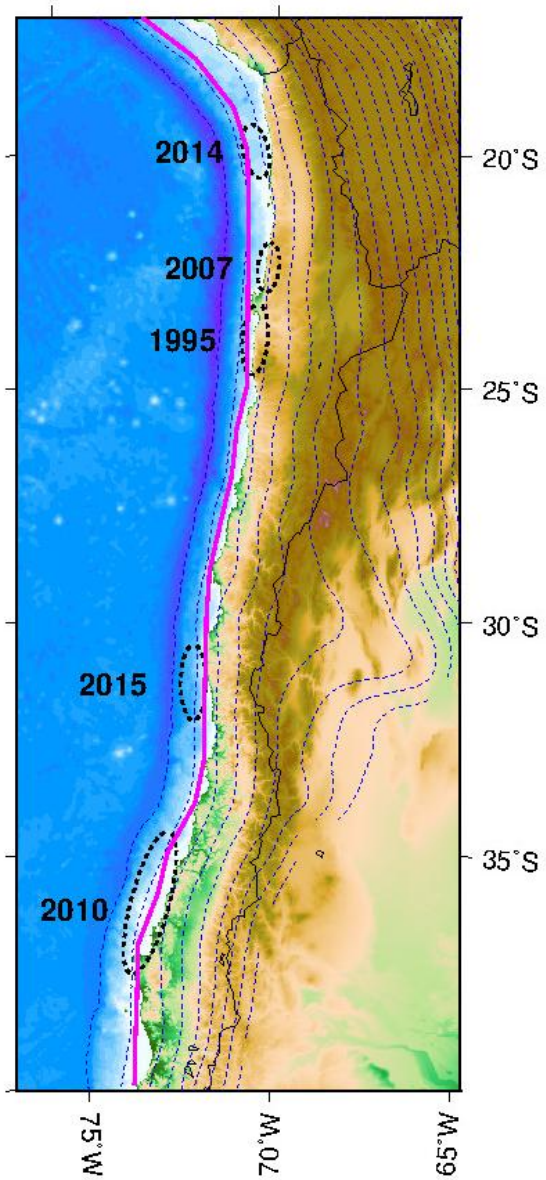






	Mww USGS	Mw PGD	Mww GPS	Focal Mechanism USGS	Focal Mechanism WGPS	Number of Stations and Channels	Gap °
El Mayor -Cucapah	7.2	7.18	7.4			28 & 31	211
Maule, Chile	8.8	8.85	8.9			12 & 20	343
Tohoku, Japan	9	9.09	9.0			375 & 534	171
Iquique, Chile	8.2	8.19	8.1			11 & 11	173
Iquique, aftshck	7.7		7.9			14 & 29	188
Illapel, Chile	8.3	8.19	8.4			15 &18	118

GNSS

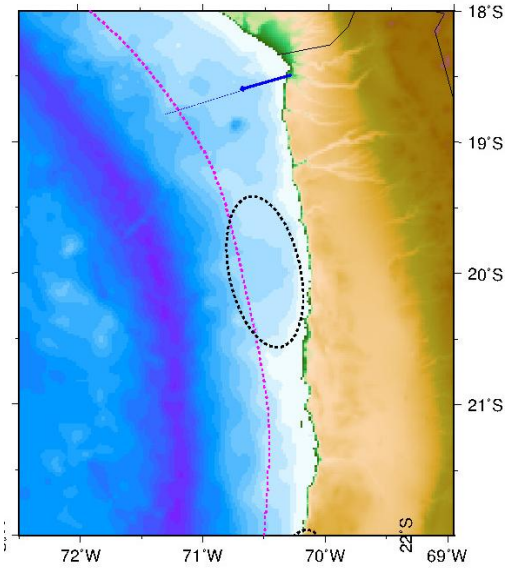


Rupture zones of recent reverse thrust earthquakes in Chile

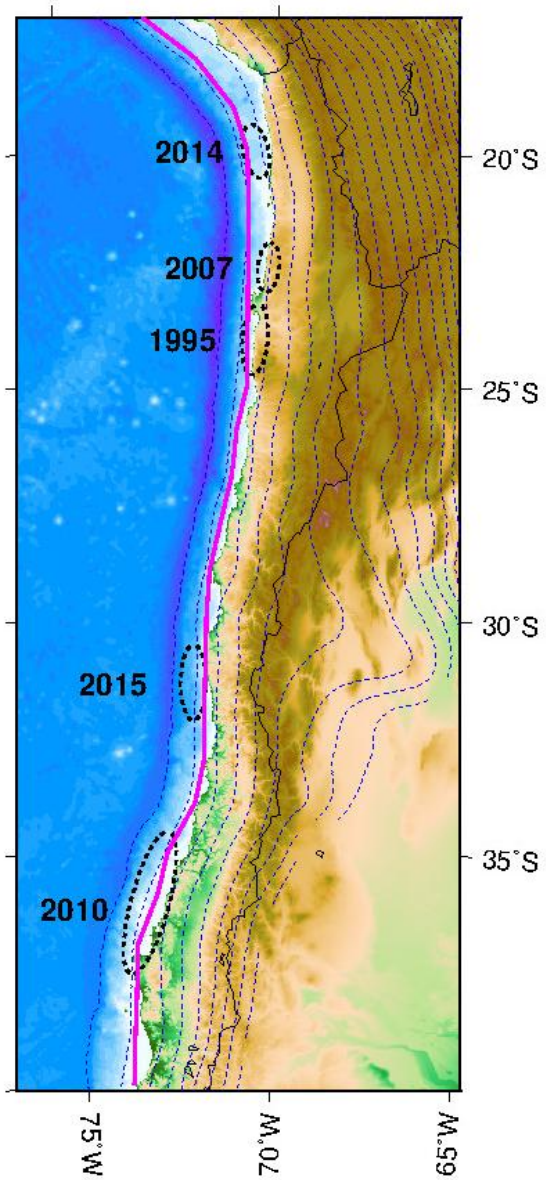
Slab 1.0 (Hayes et al, 2012)

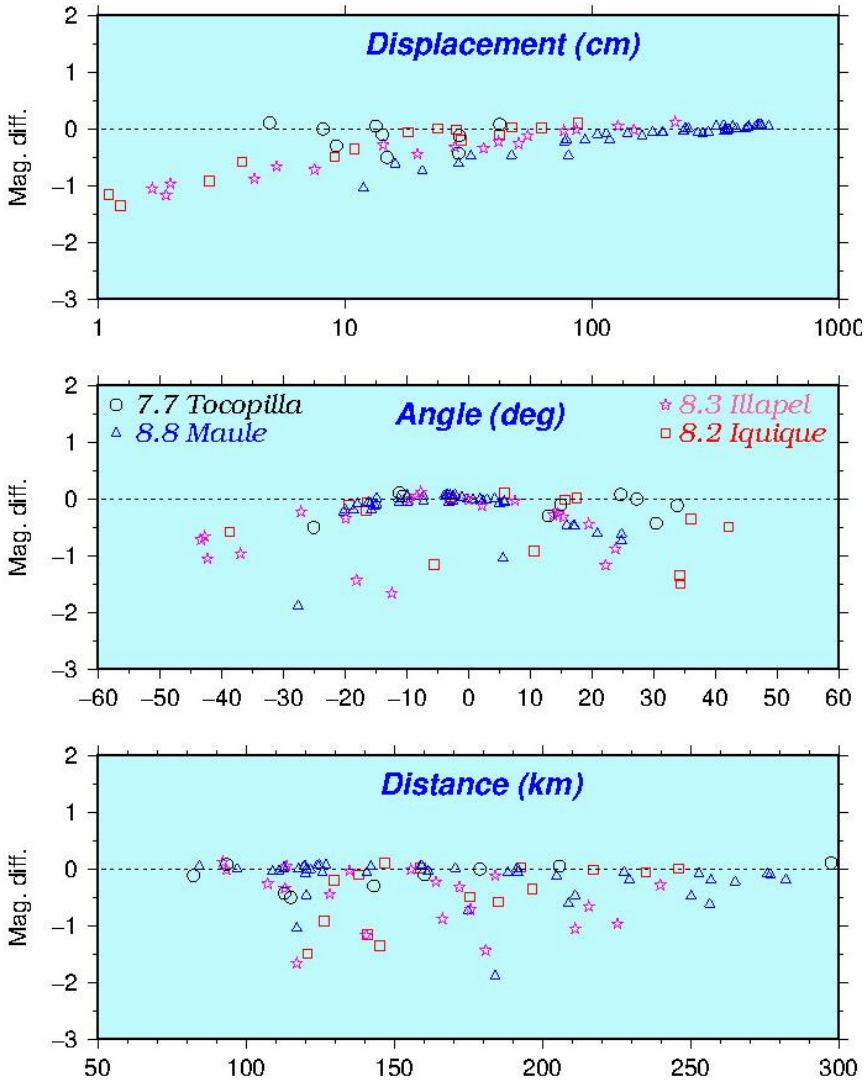
30-km-depth contour

Okada formulation
Strike, dip and rake fixed



GNSS


2014
2007
1995
2015
2010
20°S
25°S
30°S
35°S
75°W
70°W
65°W


Displacement (cm)
Angle (deg)
Distance (km)
Mag. diff.
7.7 Tocopilla
8.8 Maule
8.3 Illapel
8.2 Iquique

23 Agosto 2014 M=6.4

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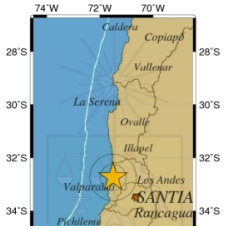
Informe de sismo sensible

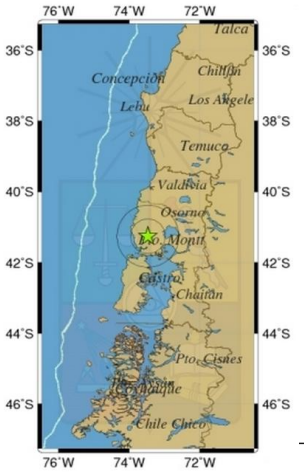
Volver

Hipocentro

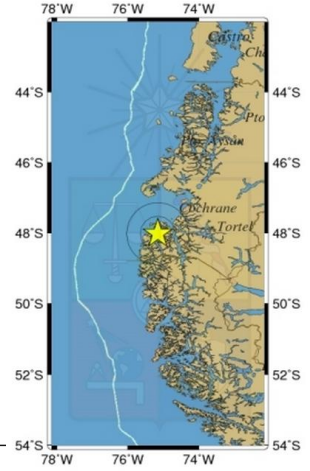
Hora Local	18:32:23 23/08/2014
Hora UTC	22:32:23 23/08/2014
Latitud	-32.737
Longitud	-71.498
Profundidad	40.1 Km
Magnitud	6.4 Mw GUC
Referencia	36 km al N de Valparaíso

Linares	V	Viña del Mar	VI
Pelarco	V	Zapallar	VI
Romeral	V	Buin	VI
Sagrada Familia	V	Calera de Tango	VI
Cabildo	VI	Colina	VI
Calera	VI	El Monte	VI
Casablanca	VI	Isla de Maipo	VI
Concón	VI	Lampa	VI
Hijuelas	VI	Padre Hurtado	VI
Juan Fernández	VI	Peñaflor	VI
La Cruz	VI	Puente Alto	VI
La Ligua	VI	San Bernardo	VI
Limache	VI	Santiago	VI
Nogales	VI	Talagante	VI
Olmué	VI	Tiltil	VI
Papudo	VI	Mostazal	VI
Petorca	VI	Navidad	VI
Quillota	VI	Pichilemu	VI
Quilpué	VI	Placilla	VI
Quintero	VI	Rancagua	VI
Valparaíso	VI	San Fernando	VI
		Talca	VII

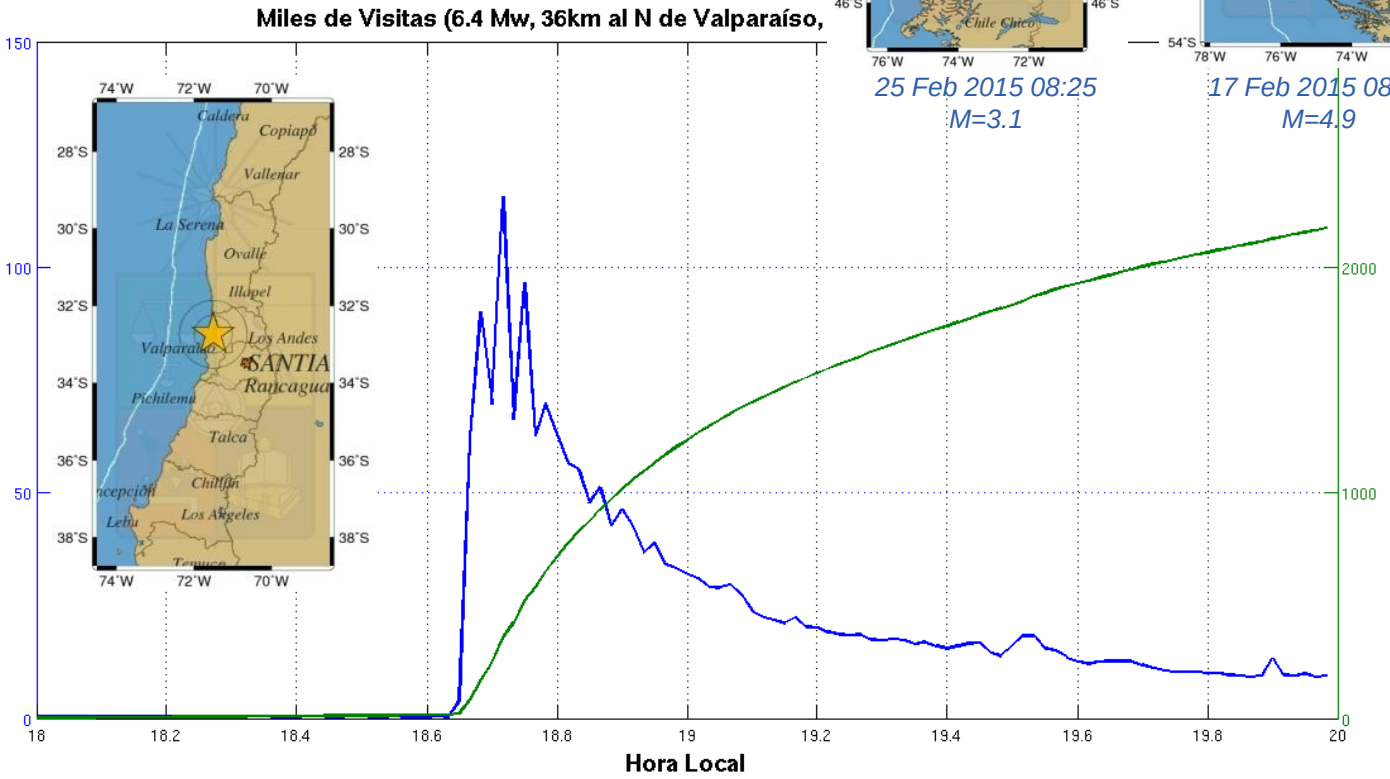




25 Feb 2015 08:25
M=3.1

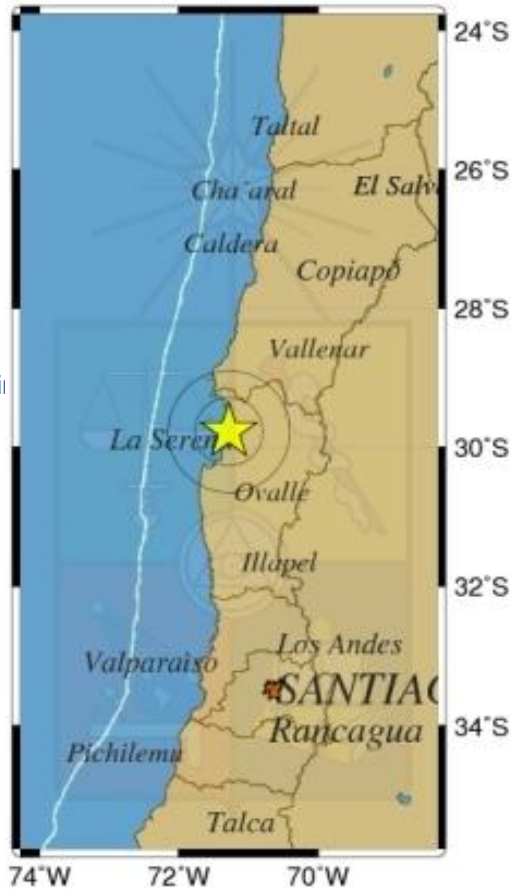


17 Feb 2015 08:25
M=4.9



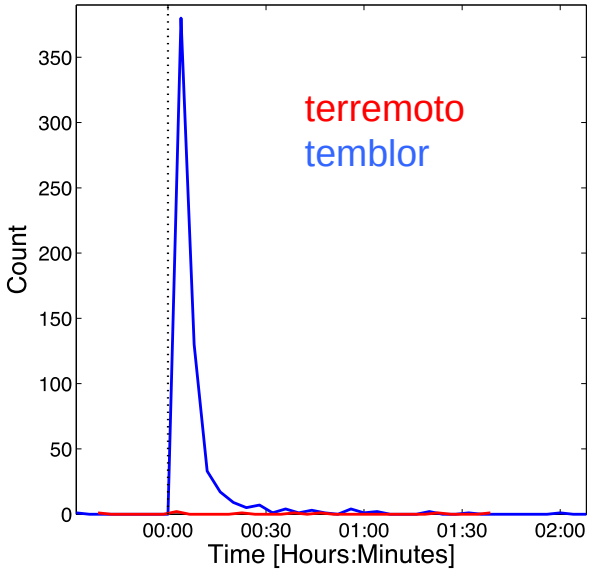
Twitter

Hora UTC: 13:30:17
Latitud: -29.776
Longitud: -71.281
Prof: 60 km
Mag: 4.8 Ml
Ref. Geog. 14 km al NO de La Serena
Sentido III en Coquimbo, La Serena, Ovalle,
Los Vilos, Paihuano, Río Hurtado, Vicuña



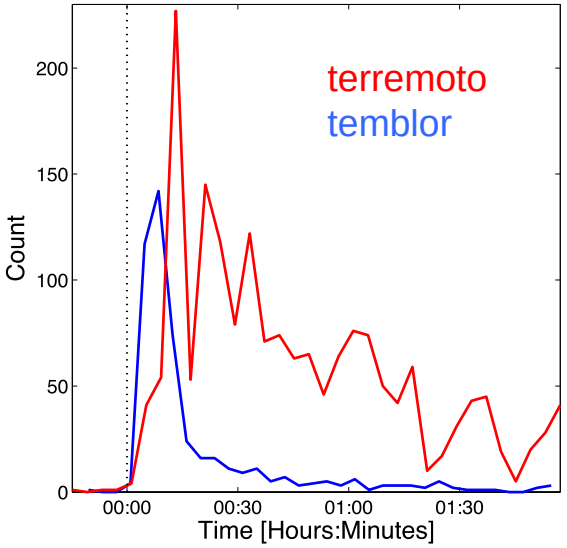
2014/11/29 13:31:54 UL: 4 REGION GEO: (none, not used)
TXT: Leve sismo en la conurbacion Serena-Coqbo
2014/11/29 13:31:54 UL: Pico La Pampa ^^ GEO: -35.696, -63.758 (C) GEOS: Maraco, Maraco, La Pampa, Argenti
TXT: Sigo aguardando el temblor
2014/11/29 13:31:45 UL: La Serena, Chile GEO: -29.902, -71.251 (C) GEOS: La Serena, Elqui, Coquimbo, Chile
TXT: Fuerte sismo en la serena
2014/11/29 13:31:44 UL: None GEO: (none, not used)
TXT: Uhh temblor
2014/11/29 13:31:34 UL: Coquimbo - Chile GEO: -29.954, -71.338 (C) GEOS: Coquimbo, Elqui, Coquimbo, Chile
TXT: Al buen temblor!!!!!
2014/11/29 13:31:30 UL: En mi hogar marmoteando GEO: 44.944, -86.418 (C) GEOS: , , Michigan, United States
TXT: El manso pencazo del temblor
2014/11/29 13:31:29 UL: No location string GEO: None
TXT: Temblor !!!! La cago pa fuerte !!
2014/11/29 13:31:28 UL: Valparaiso/Vi??a del Mar/Conc??n GEO: (none, not used)
TXT: Temblor ????????
2014/11/29 13:31:27 UL: la serena, chile GEO: -29.902, -71.251 (C) GEOS: La Serena, Elqui, Coquimbo, Chile
TXT: Temblor
2014/11/29 13:31:26 UL: La Serena, Chile GEO: -29.902, -71.251 (C) GEOS: La Serena, Elqui, Coquimbo, Chile
TXT: Largo temblor en La Serena!!!
2014/11/29 13:31:26 UL: None GEO: (none, not used)
TXT: Temblor en Coquimbo!
2014/11/29 13:31:25 UL: La Serena GEO: -29.903, -71.251 (C) GEOS: La Serena, Elqui Province, Coquimbo Region, Chile
TXT: temblor en la serena
2014/11/29 13:31:24 UL: LA SERENA GEO: -29.903, -71.251 (C) GEOS: La Serena, Elqui Province, Coquimbo Region, Chile
TXT: Temblor en la serena

Twitter



2014-04-04 9:52:07
M5.2,
Depth 95 km

Max MMI IV

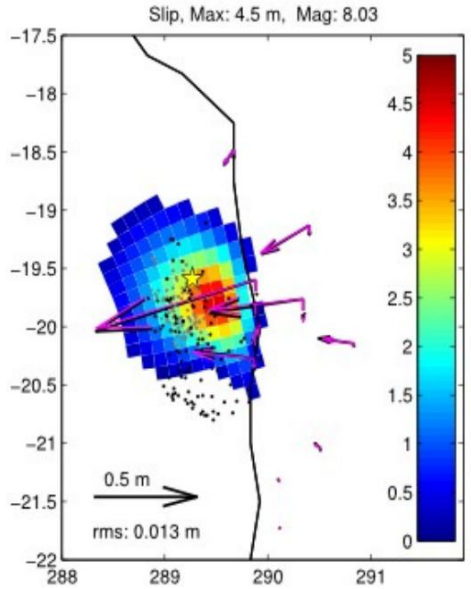


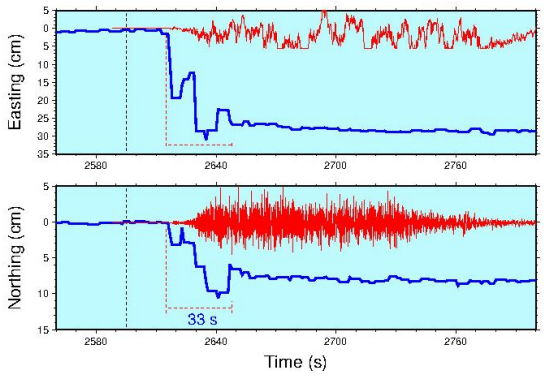
Earle et al (2014)

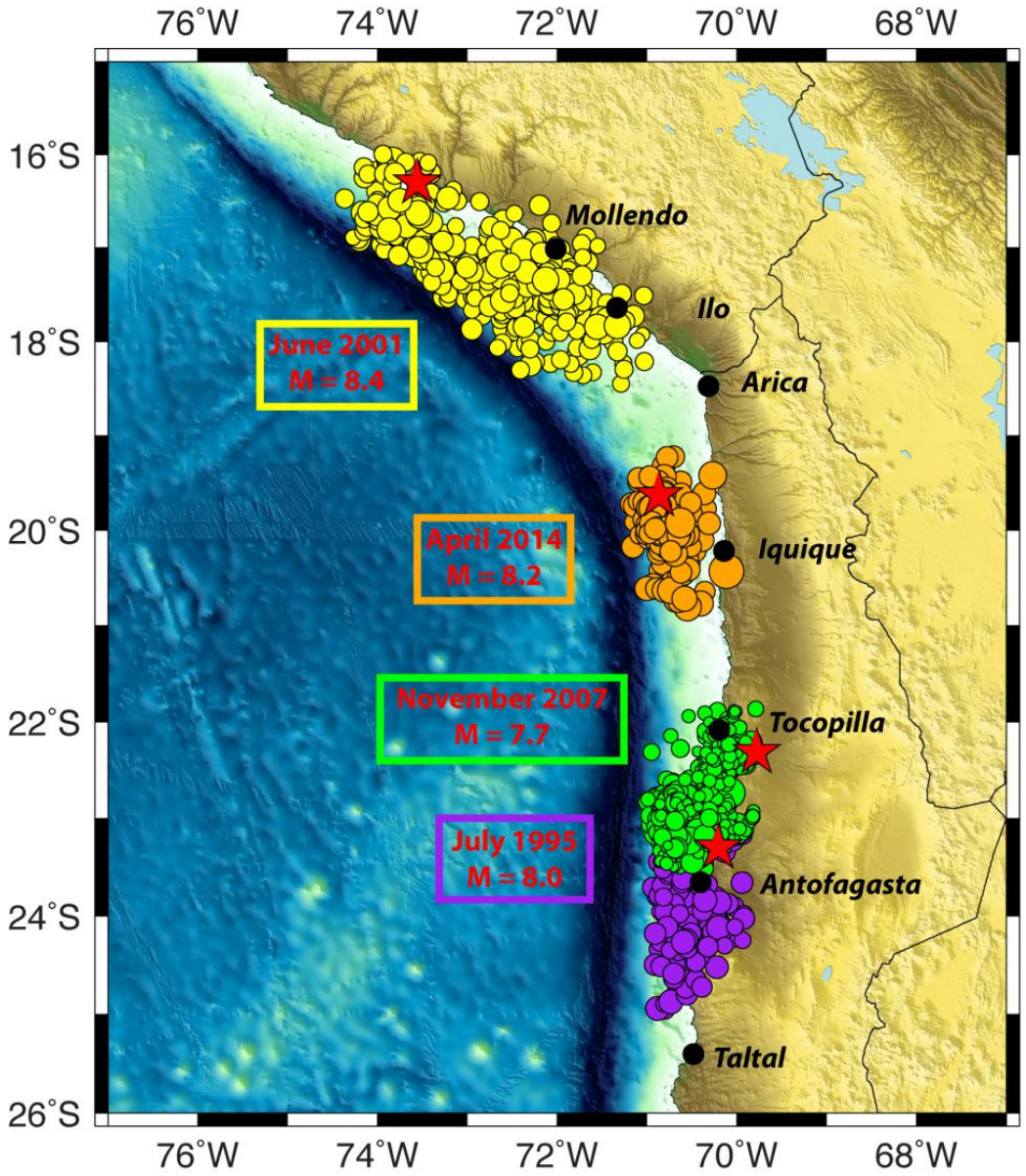
2014-04-01 23:46:46
M8.2,
Depth 20km

Max MMI VII

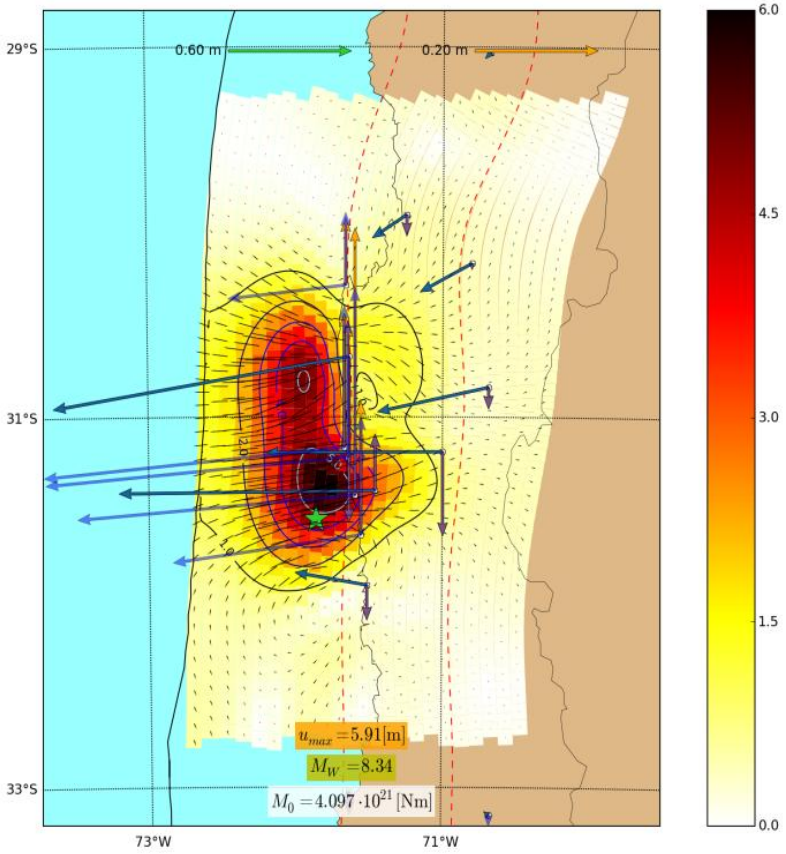
Fault Displacement



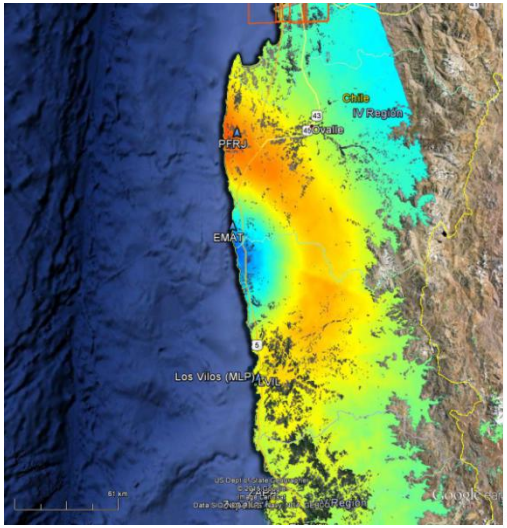


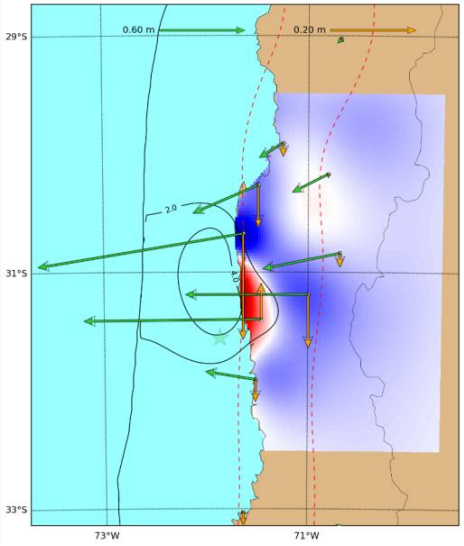


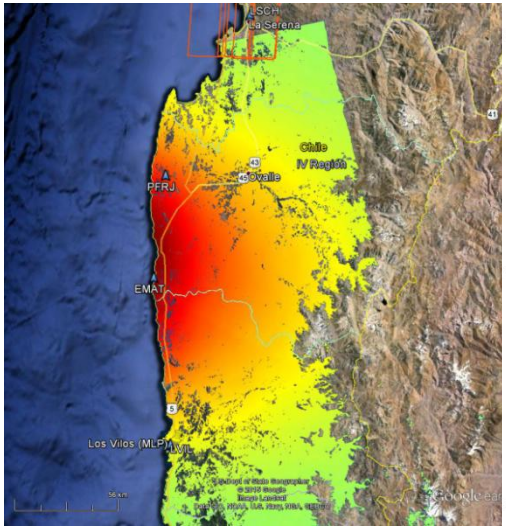
16-Sept-2015 Illapel M=8.4

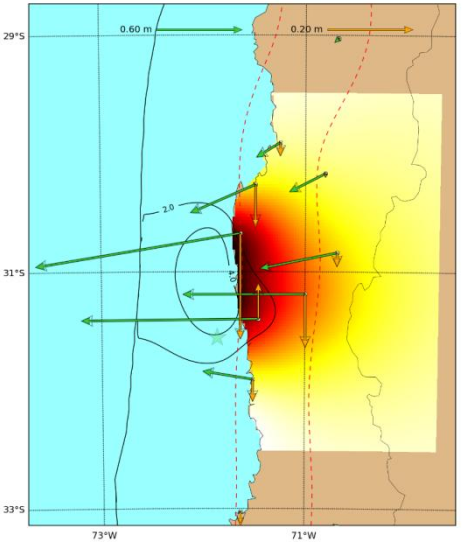


Fault Displacement (m) derived from GNSS vectors





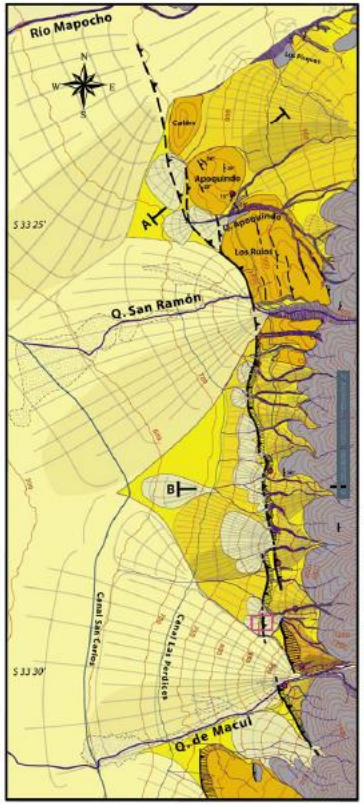


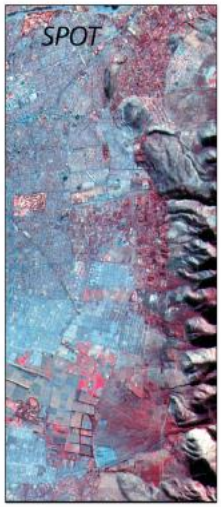


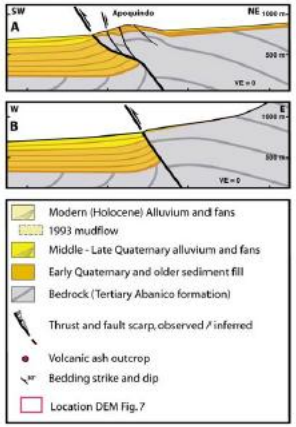
Sentinel-1, www.insarap.org

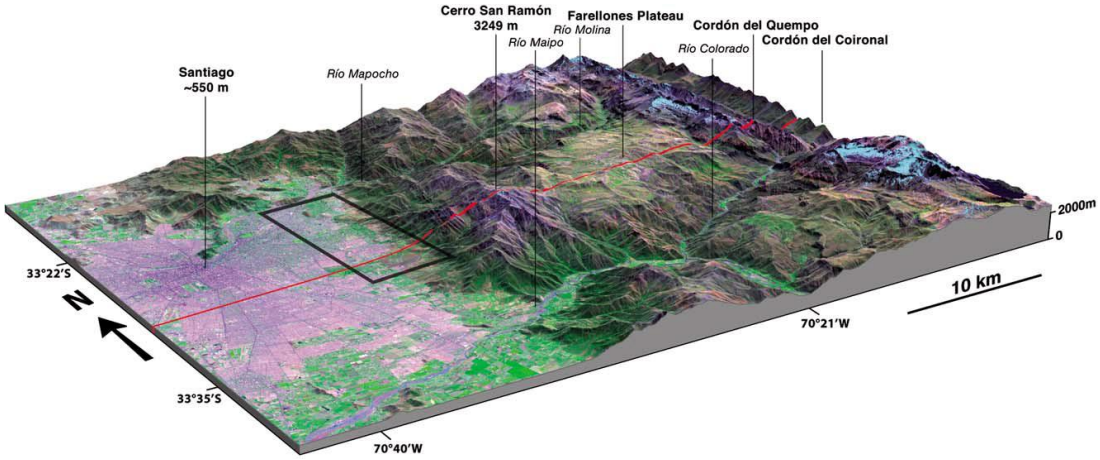
San Ramón Fault

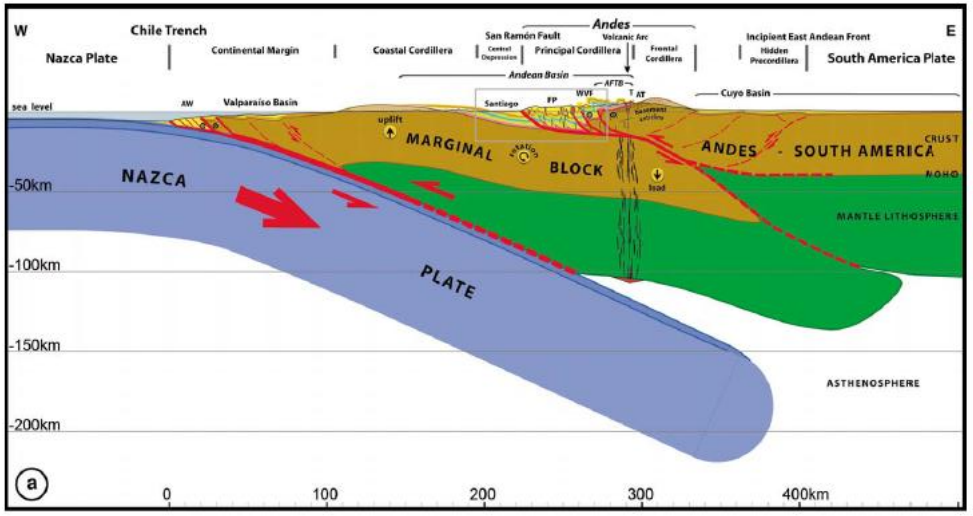
17.000 yr
8.000 yr
3-5 m scarp



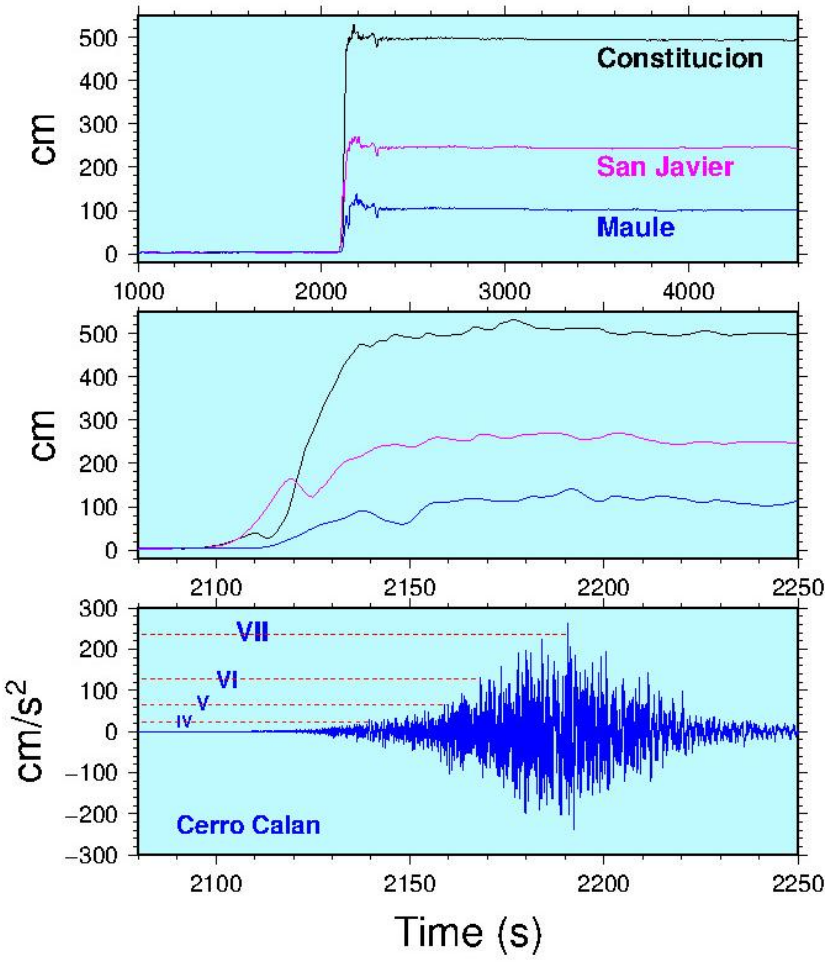


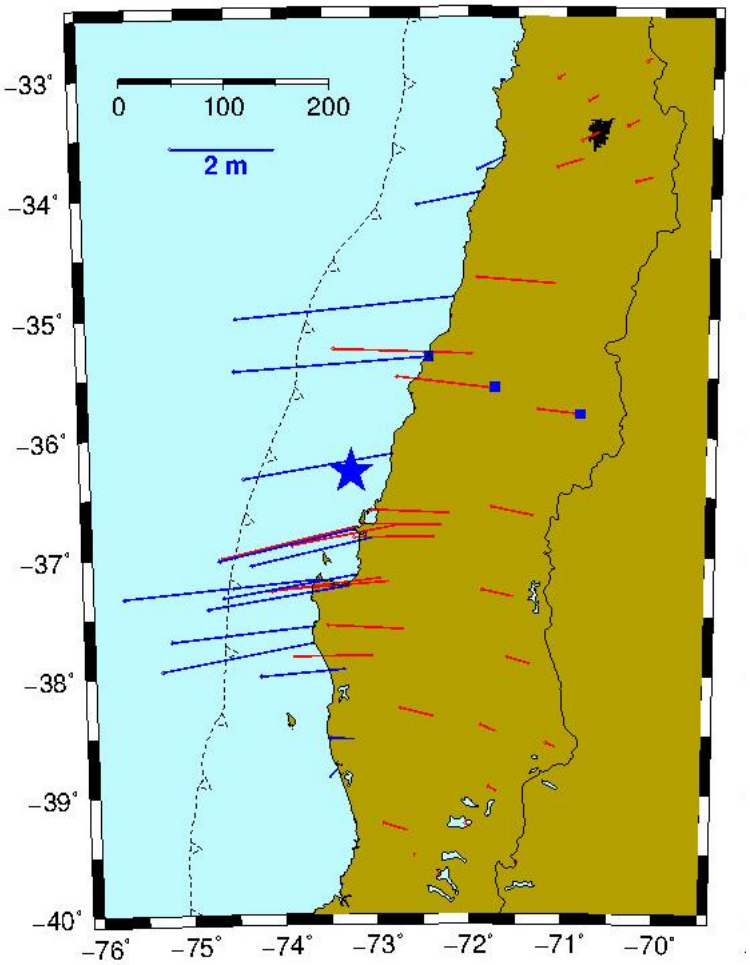




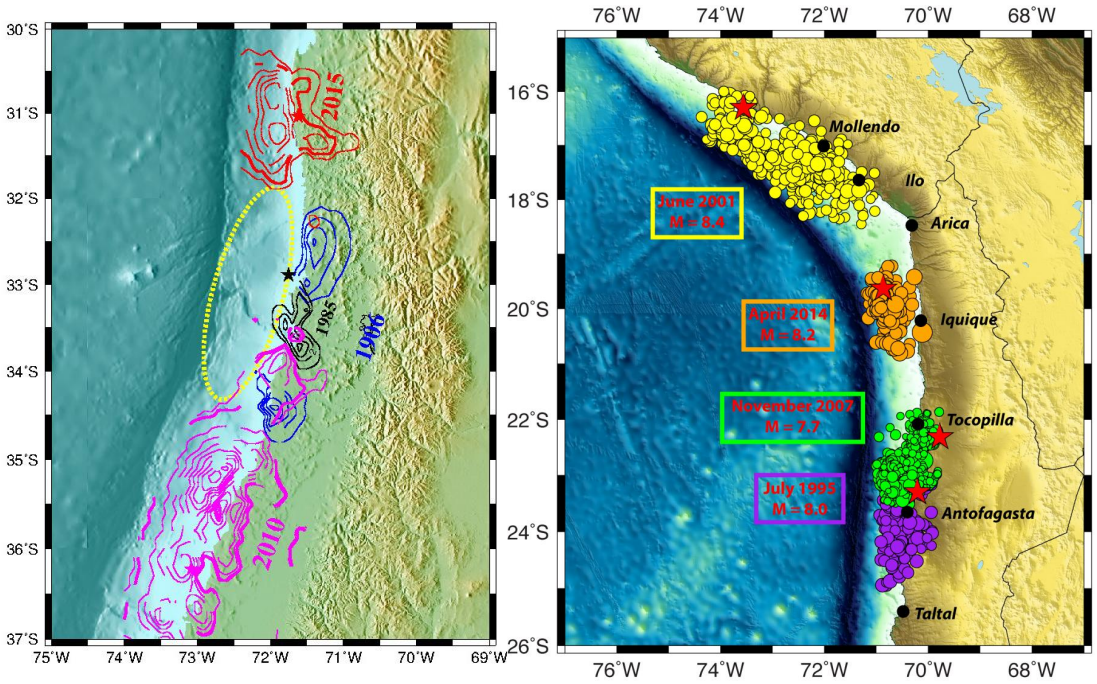


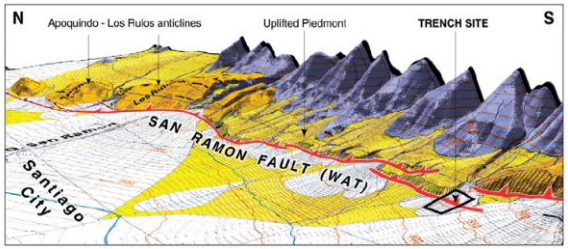
EEW Maule Earthquake 2010

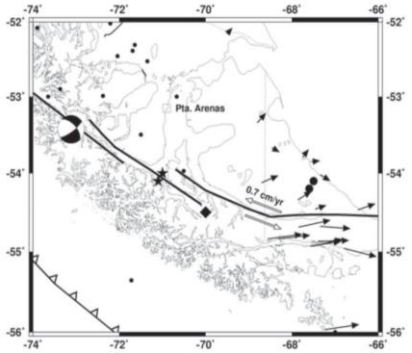


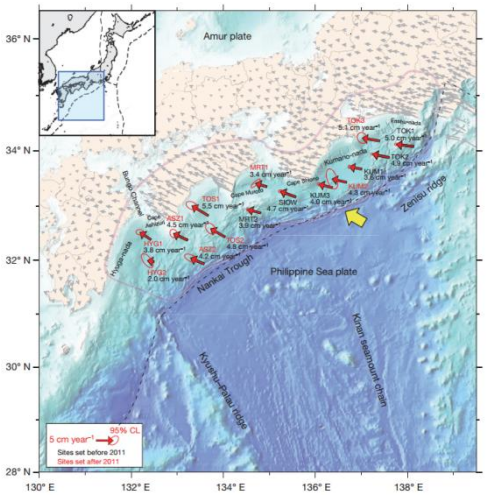


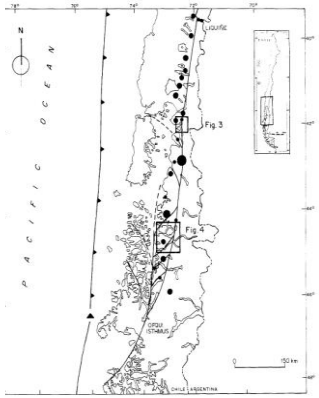
Future Work











- *Complete the geodetic system for rapid responde*
- *More instruments in Aysén and Magallanes*
- *More instruments in the Metropolitan Region (SRF)*
- *Two Kestrels (acceleration and displacement)*
- *Smartphones experiment*
- *EEW prototype for Central Chile*
- *Submarine Observation*

Nepal Earthquake

ChEAP Project

CSN CENTRO SISMOLÓGICO NACIONAL UNIVERSIDAD DE CHILE

http://escweb.wr.usgs.gov/share/highrate-gps/qed

Work to Date & Plan for 2016: *Proyecto ChEAP*

- Android Software ("QED")
- GPS printed circuit board
- AC/DC enclosures
- Server socket manager

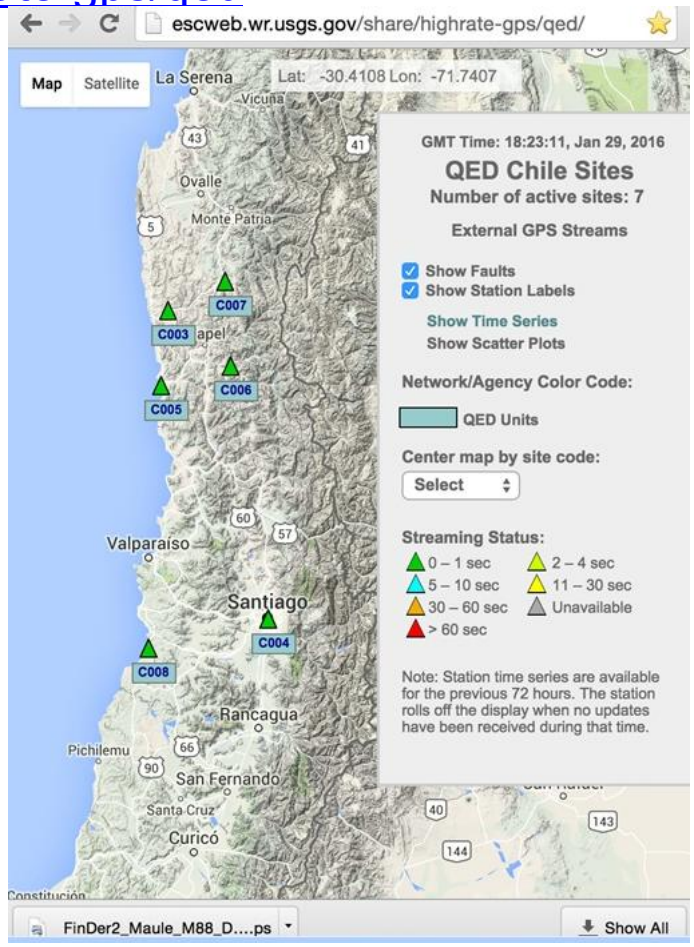
Nov. 2015:
- install prototypes

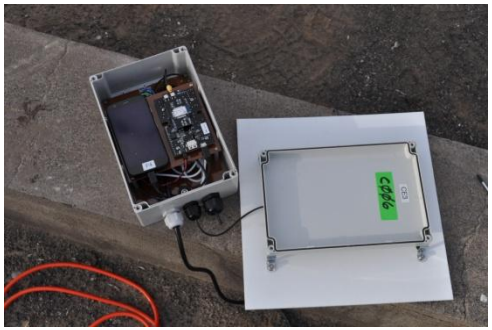
Feb 2016- Dec 2016:
- Build out network
- Tune algorithms
(FINDER/BEFOREs)

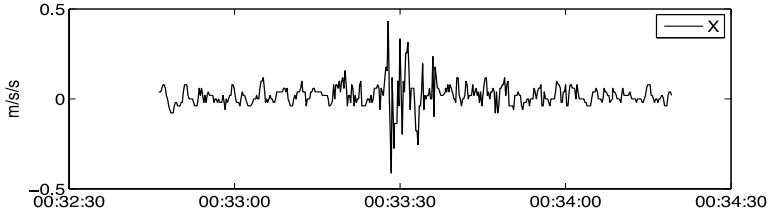
OBJECTIVES
1. Demonstrate the crowd-sourced EEW approach with a low-cost sensor network
2. Test & develop new algorithms, ground-truth observations (CSN network)
3. Further CSN/USGS collaboration

USGS science for a changing world

CSN







Thanks

CSN
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