Scanning of Unusual Seismic Activity in the Mendocino Triple Junction Region

S43A-1047

A. Guilhem, D.S. Dreger, and R.M. Nadeau
University of California, Berkeley
aurelie@seismo.berkeley.edu

A. Abstract

Anomalous seismic activity has been detected in the vicinity of the Mendocino Triple Junction (MTJ) and offshore transform faults. Among those unusual earthquakes are non-volcanic tremors, repeating earthquakes and slow-rupture or low-stress-drop earthquakes. These unusual events together with 'typical' earthquakes provide clues regarding the mechanics of faulting in the offshore region. We present broadband observations of these events over a multiple-year period ending in 2007 as well as their characteristics that allow one to detect and recognize them. One difficulty in the study of seismicity of the region is that events located far offshore may go undetected or they may have poor locations with large uncertainty. Another difficulty is that there is a class of events that have either low stress drop or have slow rupture processes that make detection difficult. To improve our monitoring capability in the region we have implemented a low-frequency continuous waveform scanning method to detect, and locate events in the offshore region, as well as compute the seismic moment tensor. Using waveforms of a few known slow earthquakes as references, we also perform a cross-correlation analysis over multiple years of bandpass filtered continuous seismic data recorded at several broadband stations in northern California with the goal of detecting unknown slow-rupture events similar in waveform to known slow events. Finally, the continuous scanning method we are implementing offers improved response time for rapid characterization of earthquake and tsunami hazard from offshore earthquakes.

B. Mendocino Triple Junction

The Mendocino Triple Junction (MTJ), off the coast of Cape Mendocino in northern California, lies in a structurally complex region of tectonic and lithologic diversity. The North American, the Pacific and the Juan de Fuca-Gorda plates intersect to form the triple junction that defines the northern termination of the San Andreas Fault, the southern part of the Cascadia subduction zone and the beginning of the Mendocino Transform Fault.

This region presents the highest rate of seismic activity in northern California, extending to over 40 km depth. Three unusual seismic events have been identified in the general area: the repeating, the slow/low-stress-drop earthquakes and the nonvolcanic tremors (Figure 1).

The MTJ region revealed numerous repeating micro-earthquakes (M<3.5) on faults, between 5 and 25 km depth (Figure 2). Their average slip rates are consistent with the distribution of rates for the various faults in the region. They are called "Characteristic Sequences" because of their large similarities in their waveforms, magnitude and source mechanism.

The slow/low-stress-drop events show discrepancies (>0.5) between Mw and ML. Their magnitudes varie between 3.5 and 6.8, for a range of depth between 5 and 30 km. Studies show that they present a long source time function (up to 10 sec), meaning a low-stress drop (0.4 bars has been found in the MTJ) (Figure 3).

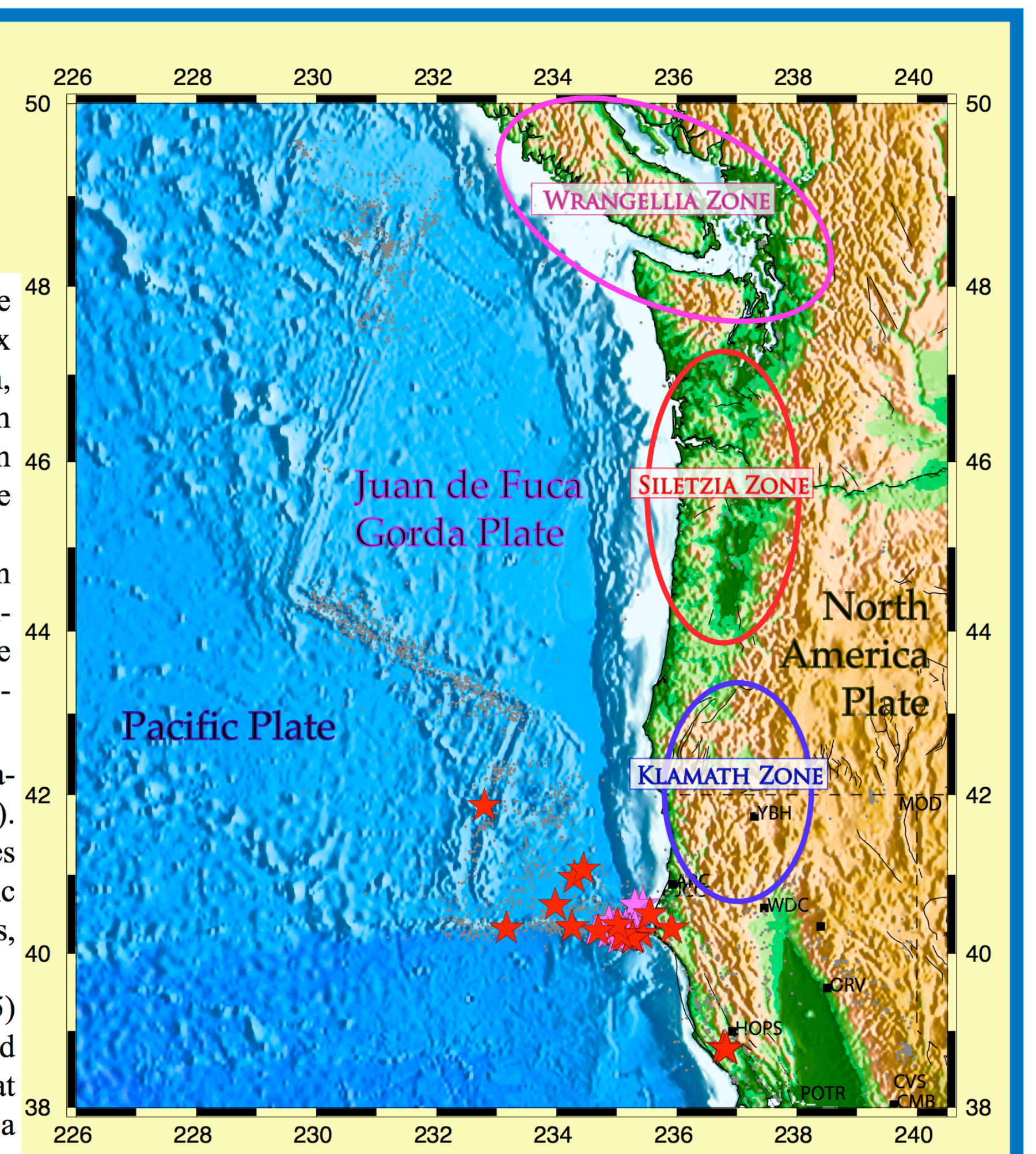


Figure 1: General map of the unusual seismic activity in Mendocino
The repeating earthquakes are represented by the pink stars, the slow/low-stress-drop earthquakes by the red stars and the areas of nonvolcanic tremors by the ellipses (Brudzinski and Allen, 2007). The black squares are the BDSN stations.

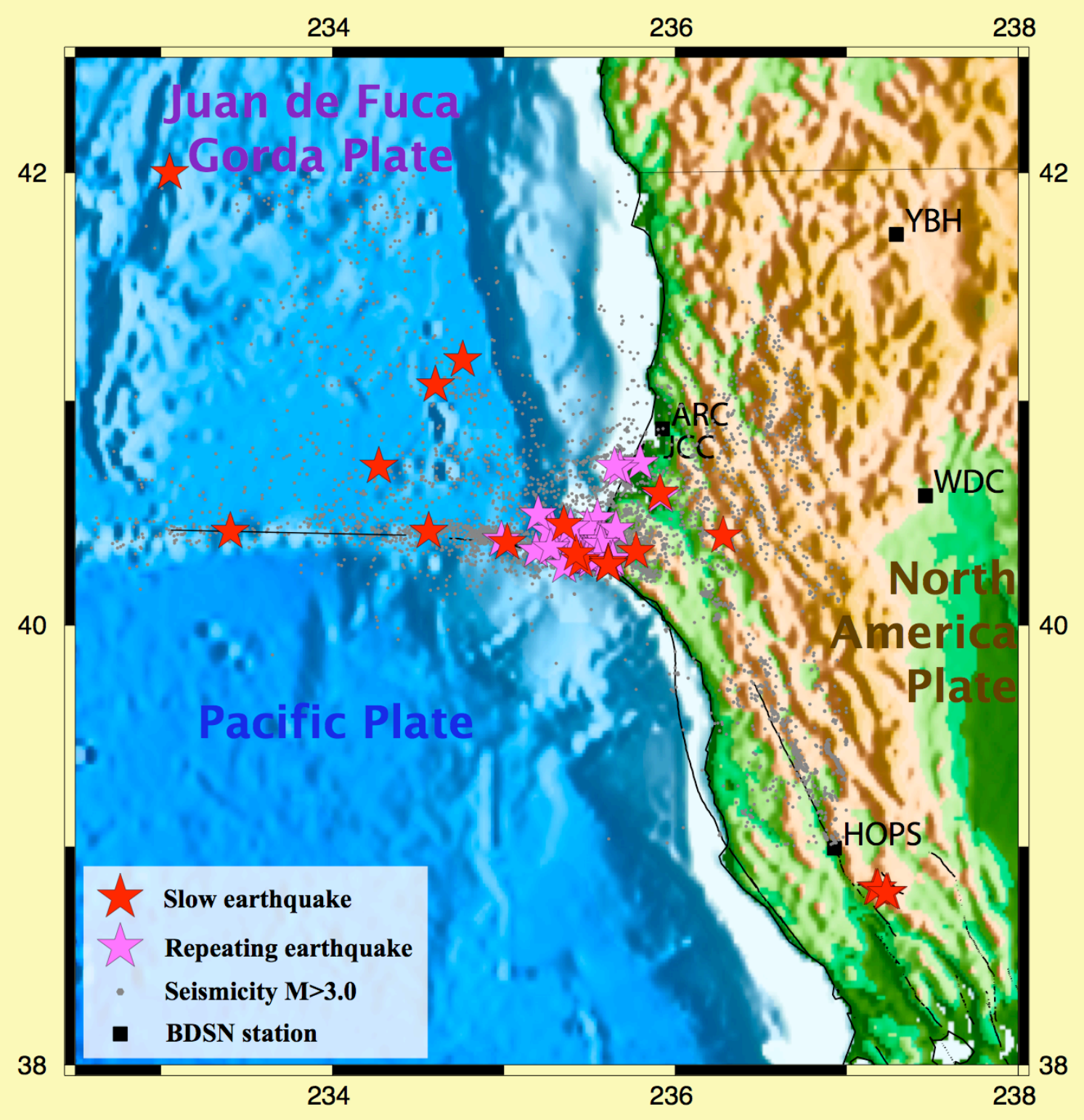


Figure 2: Map of the unusual seismicity in the Mendocino Triple Junction
The slow/low-stress-drop events are represented by the red stars, the repeating earthquakes by the pink stars. The black squares indicate the BDSN stations.

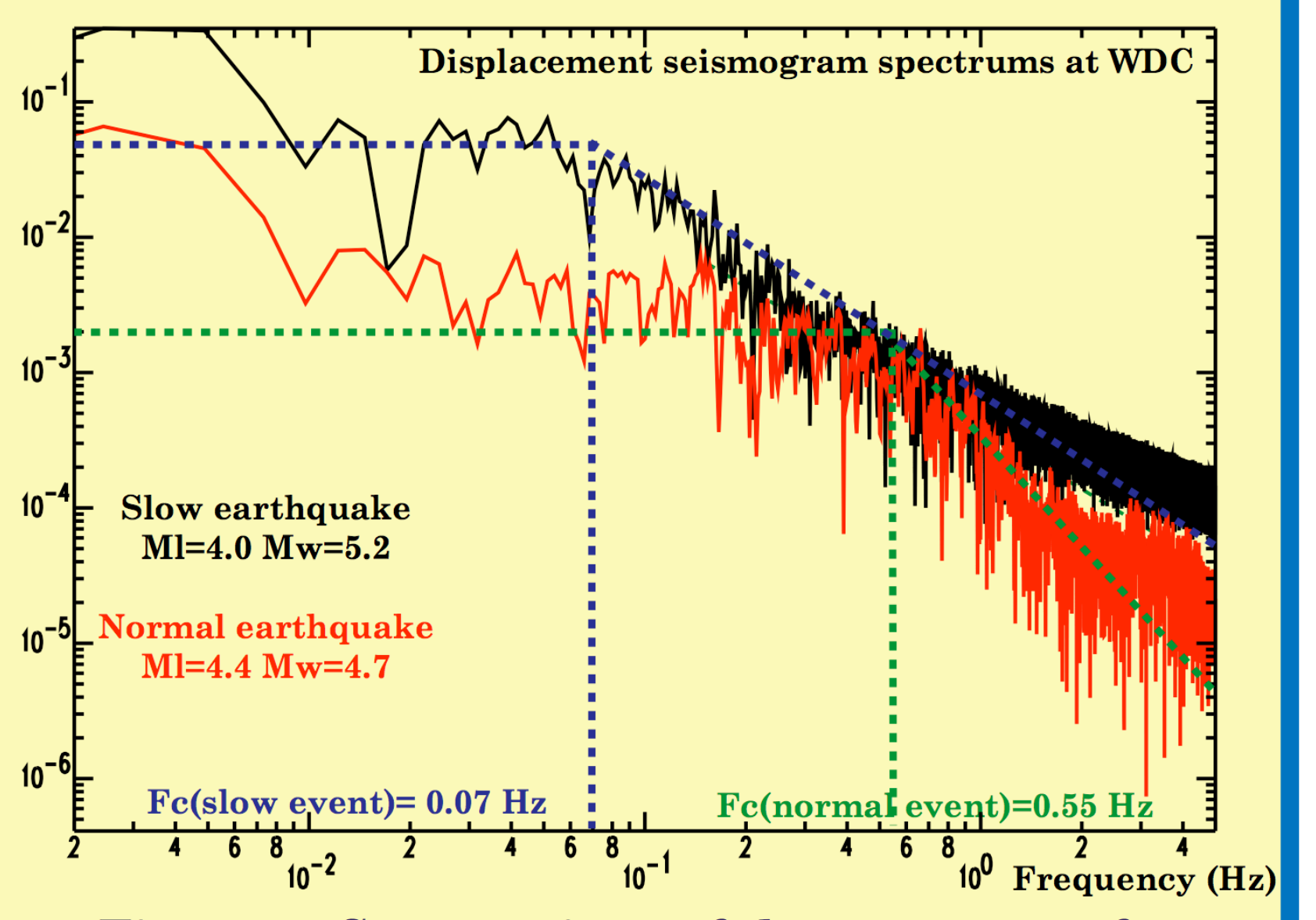


Figure 3: Comparaison of the spectrum of a slow/low-stress-drop earthquake and a "normal" earthquake
In red is the spectrum of the slow earthquake, in black the spectrum of a "normal" earthquake of similar magnitude and location. We can see the difference in the corner frequencies of the similar size earthquakes.

C. Study of a slow earthquake

We present here the analysis of an unknown slow earthquake that occurred on December 6th, 2000 around 08:00 GMT. This earthquake, first identified as a slow earthquake by Goran Ekstrom's group, had not been detected at Berkeley. It had been located onshore in northern California (Figure 5). We investigate it using several methods: triangulation (Figure 4), particle motions (Figure 5) and moment tensor grid search (Figure 6).

The move-out of the waveforms at low frequency (0.02-0.05 Hz) indicates an offshore origin (Figure 4). This observation is verified by the study of the particle motion of Pn arrivals at six stations and of the Rayleigh waves (Figure 5).

Figure 6 presents the results of a moment-tensor grid search using four stations of the BDSN network. The inversion was computed using the 1D velocity structure GIL7, for three depths (5, 8 and 11 km). The earthquake appears to have a normal mechanism (Figure 7), which is consistent with the spreading center at proximity. One can also notice the large CLVD component obtained. Tests of the velocity model are presented in Figure 7 for an earthquake located on the ridge and presenting a large DC component and for a moderate quake that occurred on the transform fault.

Information about this December 2000 event is found in the ANSS catalog and agrees with our conclusions in term of magnitude and location.

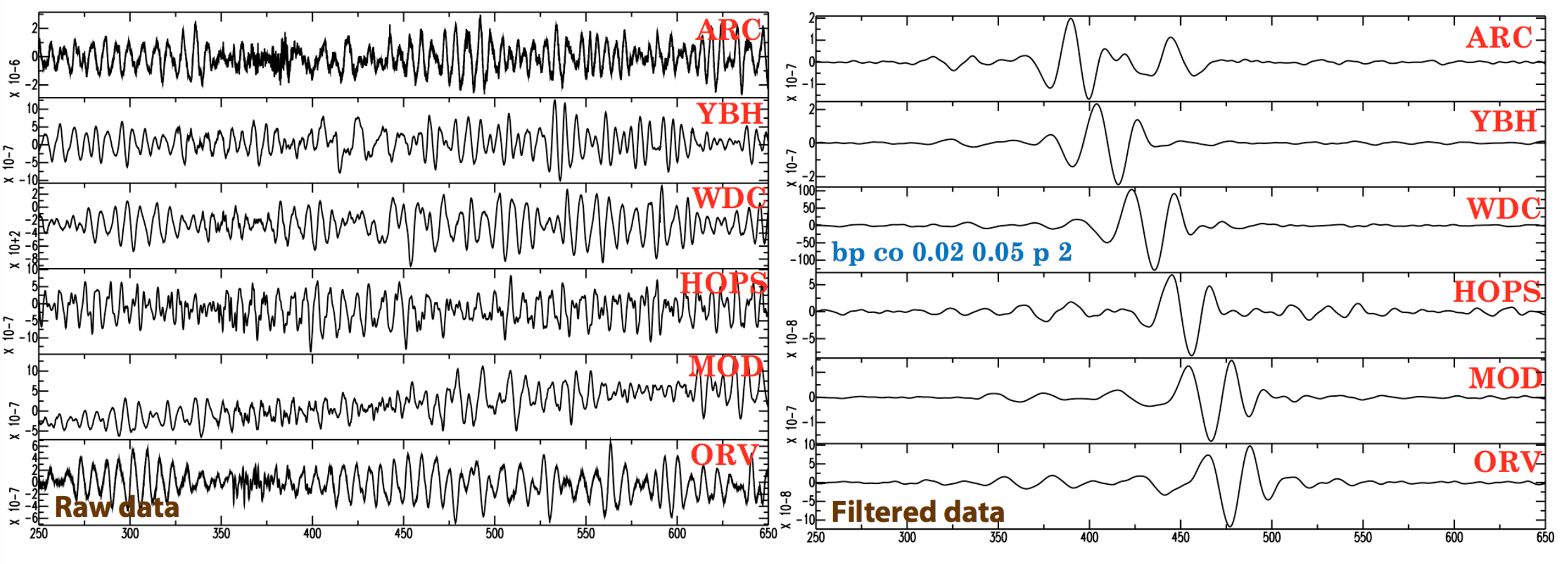


Figure 4: Raw and filtered displacement seismograms of the December 2000 slow earthquake
The raw data do not show a clear earthquake signature on contrary to those same data filtered between 0.02 and 0.05 Hz. The first arrivals in ARC, followed by YBH and WDC, indicate an oceanic origin instead of a continental one.

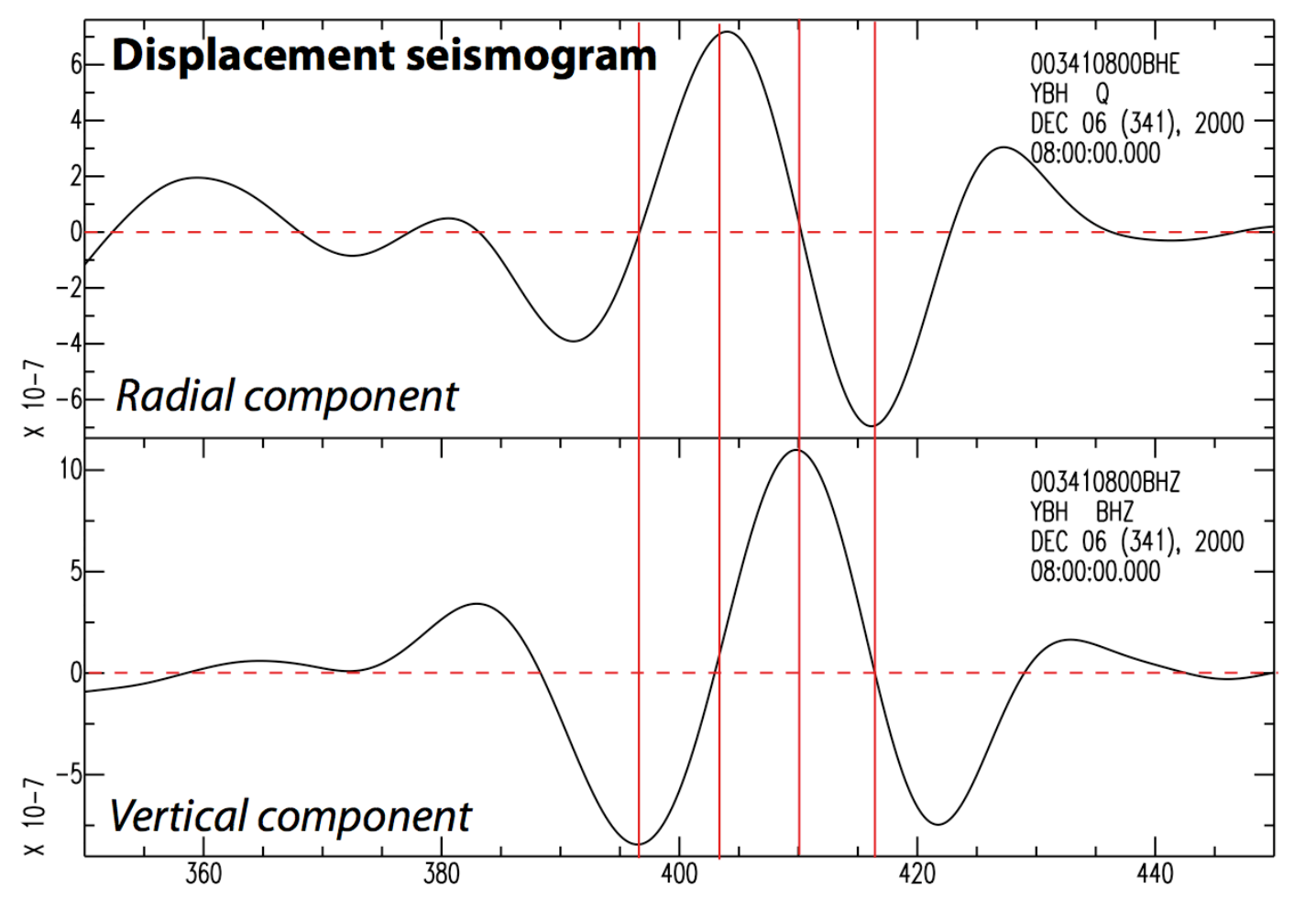


Figure 5: Verification of the particle motion with the Rayleigh wave at YBH

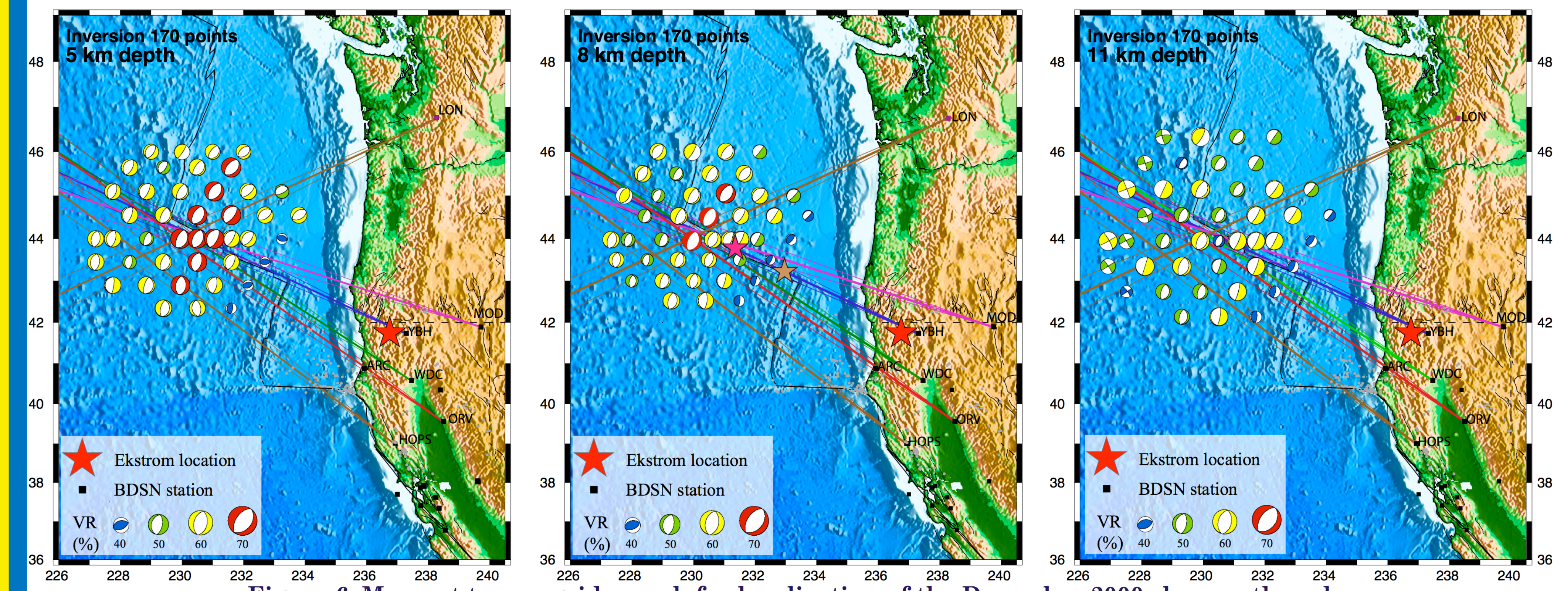
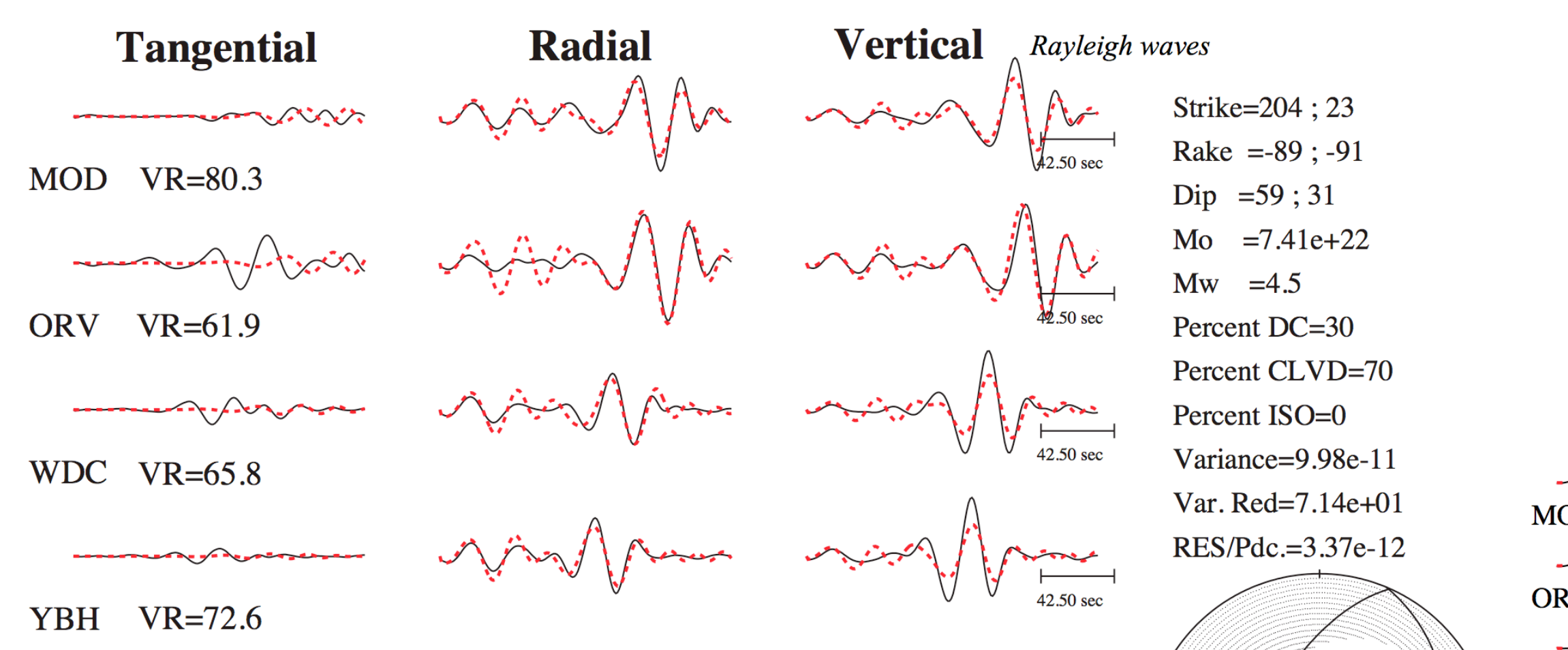


Figure 6: Moment tensor grid search for localization of the December 2000 slow earthquake
The variance reduction (VR) is used to get the best location. A first location of the event is shown by the red star. The color lines illustrate the azimuthal rotations for each station using the particle motion of the Rayleigh wave. The squares represent the seismic stations. The pink star represents the location of the ridge event and the brown star is the location of the transform fault earthquake studied in Figure 7.



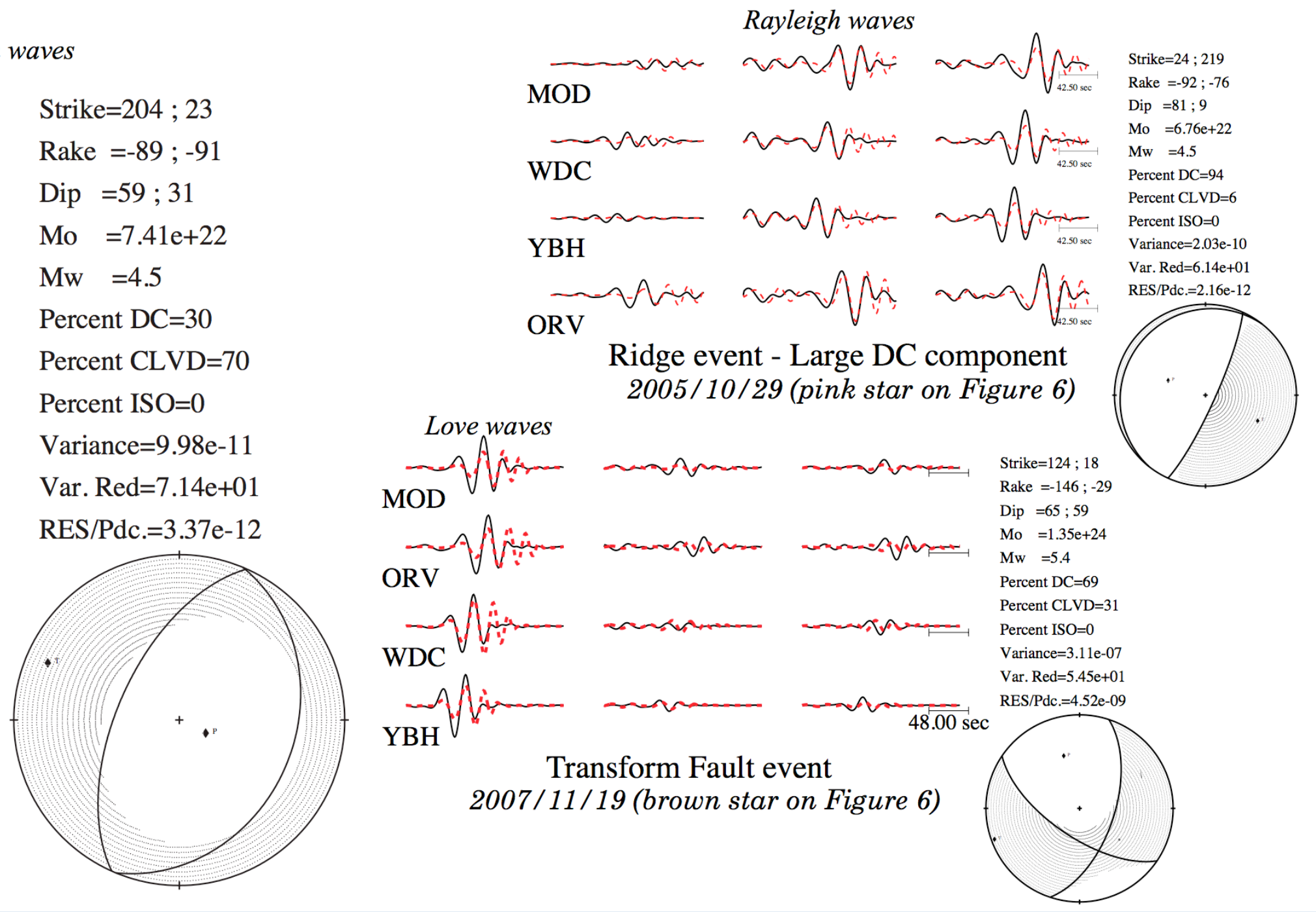


Figure 7: Best mechanism for the December 2000 earthquake
Data are in black and generated synthetics in red. It is compared to a similar size earthquake located on the same ridge segment presenting a larger DC component. Test of the results of the inversion is also done by the study of the moment tensor obtained for a transform fault event.

D. Research of possible missing slow earthquakes

Day	Hour	Latitude	Longitude	Depth (km)	ML	Mw	Mw-ML	Correlation	
04/25/92	18:06	40.33	-124.23	8	6.3	6.8	0.5		
06/05/92	21:46	40.29	-124.55	21	4.8	5.5	0.7		
03/04/95	21:51	40.71	-125.73	18	3.5	4.6	1.1		
11/11/95	20:19	40.40	-123.72	30	3.5	4.0	0.5		
12/24/95	7:41	42.00	-126.95	5	4.4	5.3	0.9	0.77	-
01/22/97	**7:17**	**40.27**	**-124.39**	**24**	**4.8**	**5.6**	**0.8**	0.86	0.72
01/26/97	**6:23**	**40.28**	**-124.39**	**21**	**4.0**	**5.2**	**1.2**	0.99	0.92
10/06/97	12:00	41.07	-125.40	24	4.1	4.6	0.5		
02/15/99	**6:00**	**40.28**	**-124.39**	**27**	**3.8**	**4.7**	**0.9**	0.89	0.96
12/26/99	**19:41**	**40.27**	**-124.39**	**24**	**4.2**	**4.8**	**0.6**	0.90	0.99
01/08/03	5:41	40.42	-125.44	8	4.2	4.7	0.5		
02/18/03	14:44	41.18	-125.24	11	3.7	4.2	0.5		
04/22/03	10:46	40.59	-124.09	27	3.9	4.4	0.5		
06/26/03	3:39	40.40	-126.57	14	4.1	4.6	0.5		
07/04/03	20:52	40.32	-124.58	21	3.7	4.3	0.6	0.92	0.87
08/26/03	2:29	40.45	-124.65	24	3.9	4.4	0.5	0.78	0.72
03/18/05	7:23	40.37	-124.98	18	4.4	5.0	0.6		
01/24/07	13:42	40.31	-124.58	20	3.7	4.4	0.7		

Table 1: Catalog of the slow/low-stress-drop earthquakes in MTJ and result of the cross-correlation analysis
Two of the four earthquakes in red color have been used as references in the cross-correlation study because of their similarity in magnitude and in space. The last colomn shows the results of the analysis with the two references (green for the 1997 event and blue for the 1999 event).

Because our slow/low-stress-drop event catalog is based on the discrepancy between ML and Mw and because Mw is only computed for a ML>3.5 at UC Berkeley, we may miss some possible slow earthquakes with smaller magnitudes or located farther onshore. We have developped a cross-correlation scanning over 14 years of data (from 1993 to 2006) using 4 stations: ARC-JCC, ORV, WDC and YBH. The data was sampled at 1 sample per second and filtered between 0.01 and 0.2 Hz in a daily basis.

Four known slow/low-stress-drop events show the same location (Table 1). We have used two of them (01/26/97 and 12/26/99) as references. The cross-correlation has been performed considering a minimum of 60% of similarities for at least three stations simultaneously. No new slow earthquakes has been detected. Only some known events have been recognized using those two references. However hits have been found for strong arrivals of P or S waves for teleseisms.

The method needs to be improved in order of cancelling the effects of teleseisms and we should also consider different references on various locations.

E. Discussion and future research

The study of the December 2000 earthquake gives positive results in both term of detection at low frequency, magnitude, location and source mechanism. It tests the feasibility of an automated broadband waveform inversion implementation for slow/low-stress-drop events that would detect, locate and give the mechanism of an event in real-time. A previous test of the method was done by Tajima *et al.* (2002) using "typical" seismic events in northern California.

The definition of the grid used in the automated broadband waveform inversion is presented in Figure 8.

The velocity model, GIL7, that is used for the onshore earthquakes of northern California, needs to be improved for further analyses to correspond to the oceanic path.

The continuous waveform scanning that we are implemented will provide considerable improvements in the response time for rapid characterization of earthquake and tsunami hazards for offshore Mendocino events.

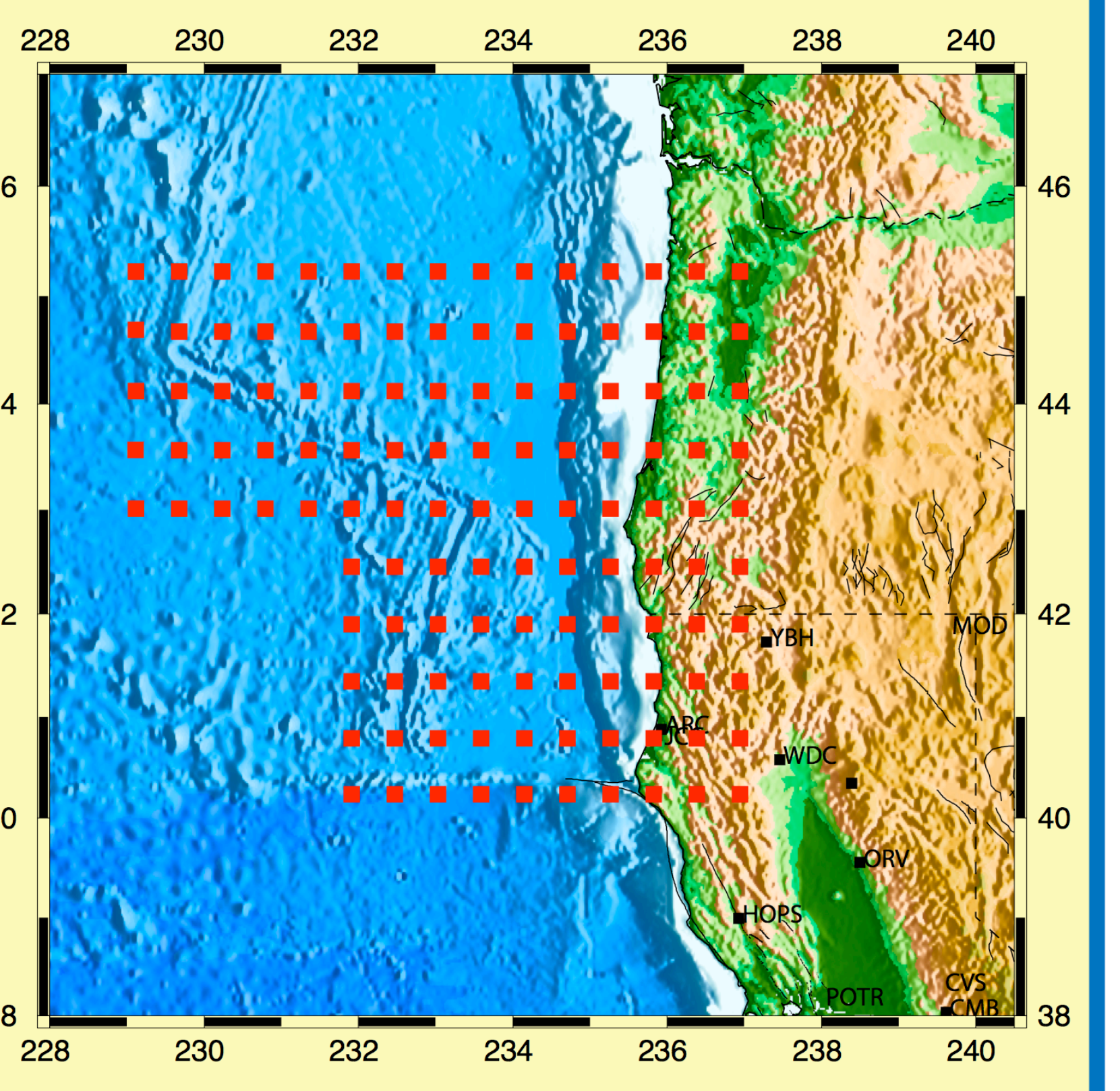


Figure 8: Map of the grid search for the automatic moment tensor
The red squares materialize the definition of the grid (0.5° x 0.5°) that is going to be used in the automatic search. The BDSN stations are shown in black.

F. References

* Brudzinski, M.R. and R. Allen, Segmentation in Episodic Tremor and Slip all along Cascadia, , Geology, 2007.
* Kawakatsu, H., On the realtime monitoring of the long-period seismic wavefield, Bull. Earthquake Res. Inst., vol. 73, pp. 267-274, 1998.
* Tajima, F., Megnin, C., Dreger, D.S., and B. Romanowicz, Feasibility of Real-Time Broadband Waveform Inversion for Simultaneous Moment Tensor and Centroid Location Determination, Bulletin of the Seismological Society of America, vol. 92, no. 2, pp. 739-750, 2002.