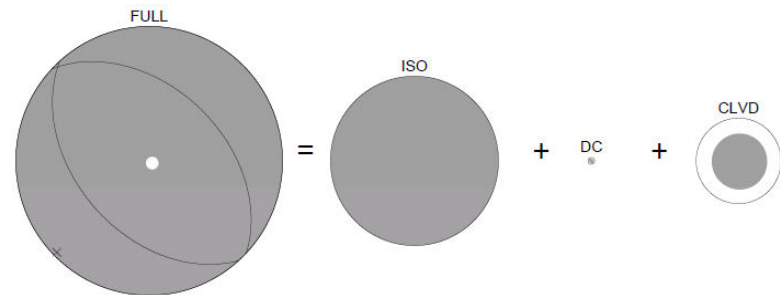


DE LA RECHERCHE À L'INDUSTRIE

cea

CONSTRAINING THE EXPLOSIVE NATURE OF THE DPRK NUCLEAR EVENTS AT REGIONAL SCALE USING MOMENT TENSOR INVERSIONS AND MSVMAX



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www.cea.fr

Theme 2: Events and Nuclear Test Sites

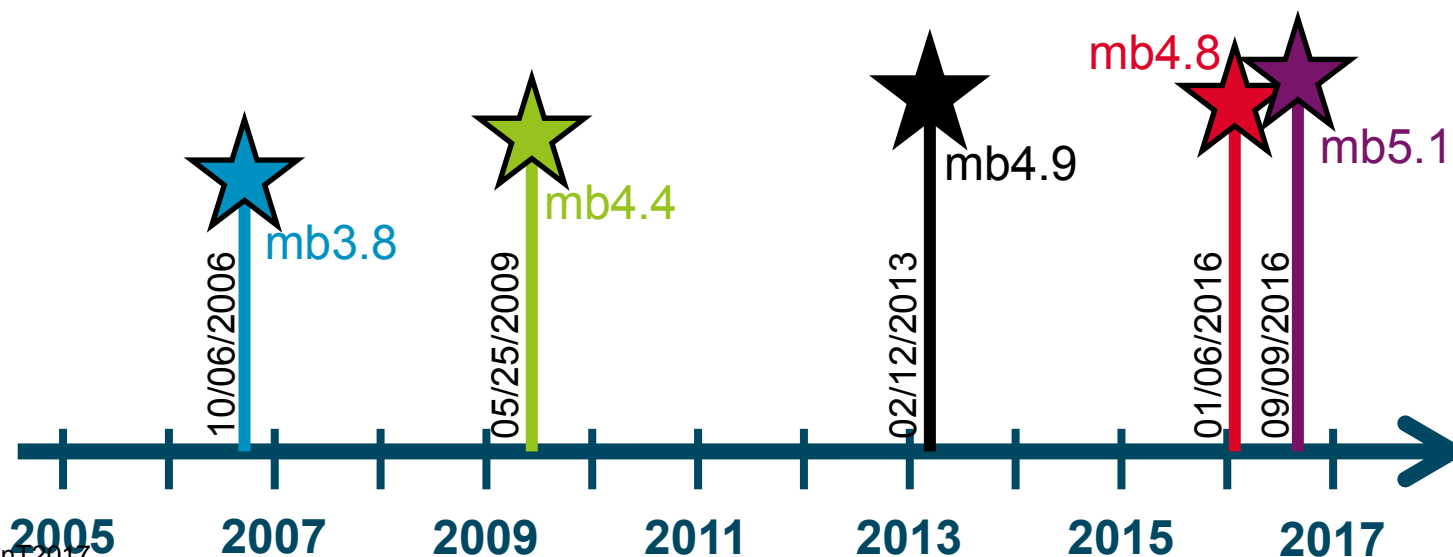
T2.1-03

CTBTO SnT2017

CTBT:
SCIENCE AND
TECHNOLOGY
2017 CONFERENCE

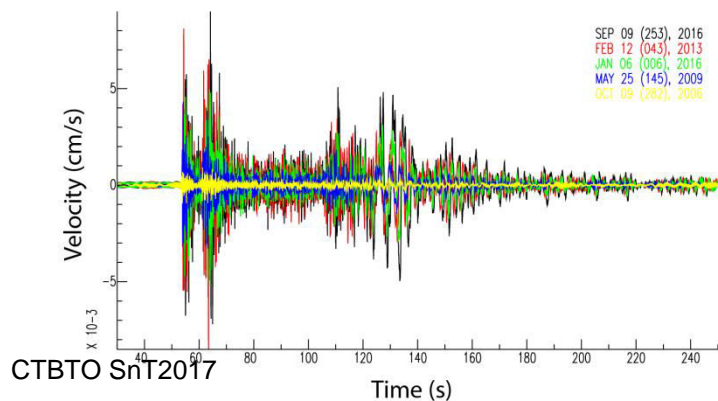
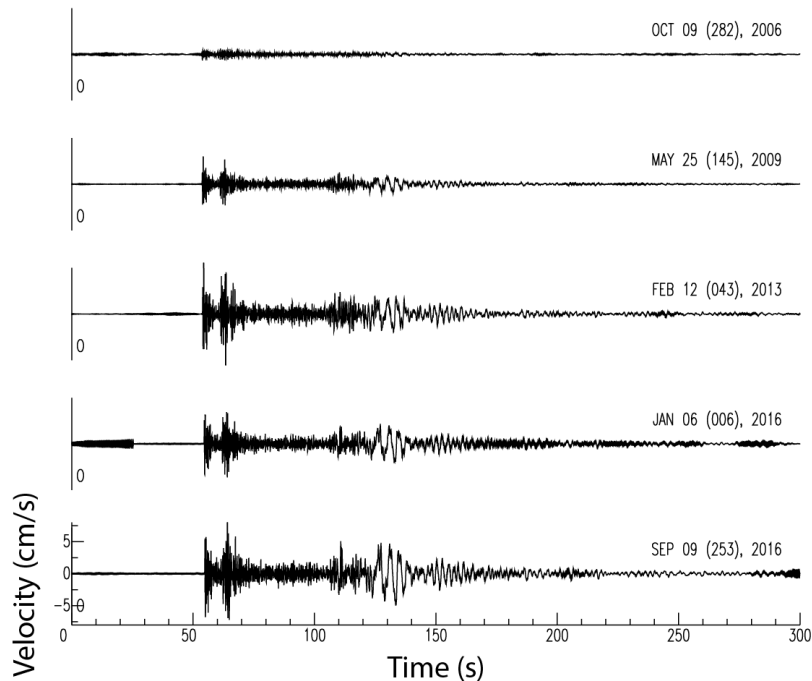
NORTH KOREA'S NUCLEAR TESTS

- The French Alternative Energies and Atomic Energy Commission (CEA) functions as the National Data Centre (NDC) in France. Its missions are defined to fight against nuclear proliferation and terrorism, which includes contributing its expertise to the International Atomic Energy Agency (IAEA) and the Comprehensive nuclear Test-Ban Treaty Organization (CTBTO).
- Continuous seismic monitoring
- Between 2006 and the end of 2016: **5 declared nuclear tests in North Korea** on the Punggye-ri site



NORTH KOREA'S NUCLEAR TESTS

MDJ station - 370 km



- ✓ Waveform similarities of the five events at regional distances
- ✓ Differences in the absolute amplitudes
- Indication of similar sources and locations but different yields
- ✓ Large P-wave energy and weaker S- and surface waves
- Indication of anthropogenic sources with isotropic components

mb:MS difference represents one **rapid approach to screen out seismic events** as potential explosions.

- mb is calculated on body-waves around 1Hz
- MS is typically calculated on surface waves around 20 sec period

MSVMAX extends this approach by allowing a **wider period band to estimate MS**, and thus to **help discriminate a larger set of events**.

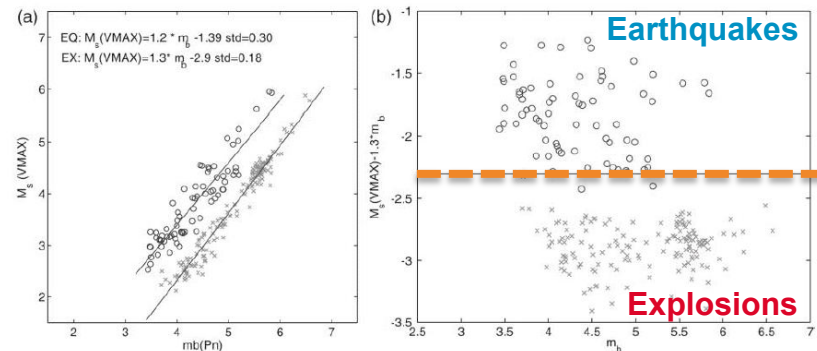
- Proposed by Russell (2006) and Bonner et al. (2006): 8-24 sec period
- Modified approach at CEA: 8-40 sec period

Advantages of MSVMAX:

- Broader range of frequency bands at which the magnitude can be measured
- Extension of the distance range of MS measurements
- Application to both Rayleigh and Love waves

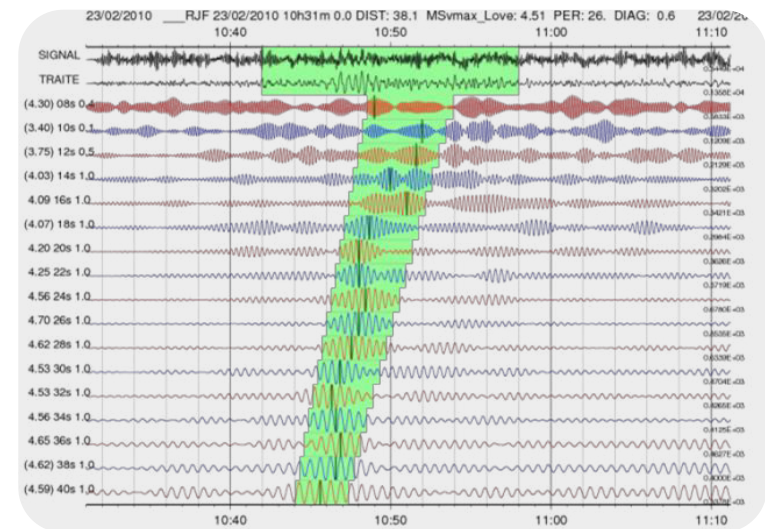
More mb:MS pairs for discrimination

Nevada Test Site



Explosions x
Earthquakes o

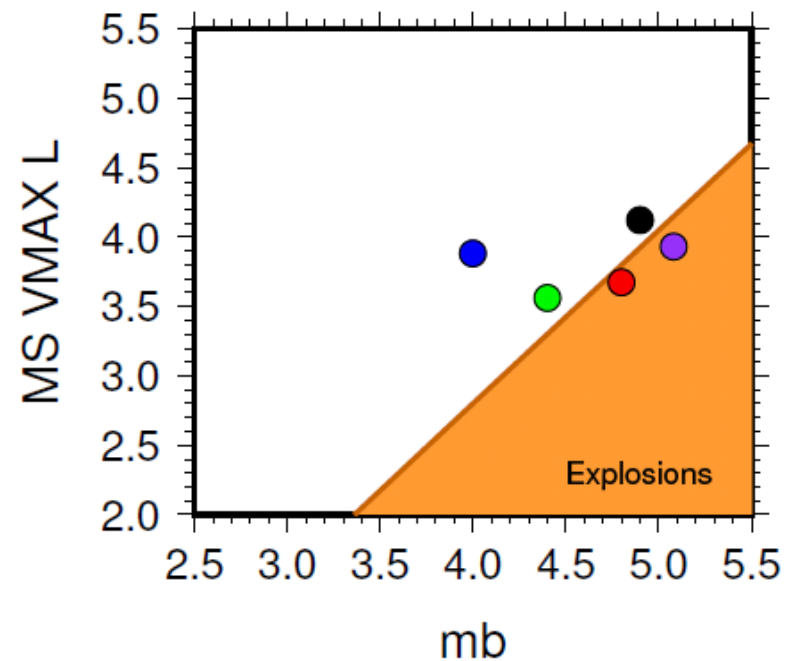
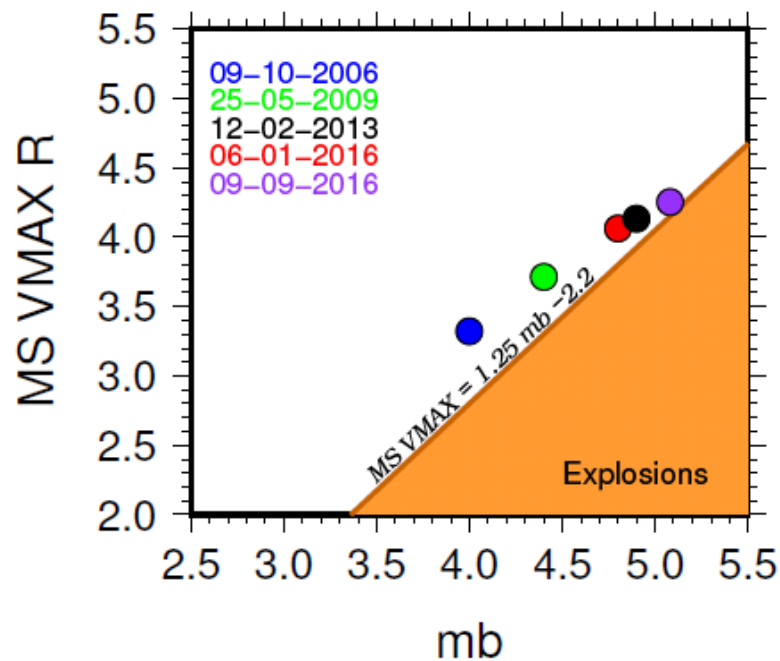
Bonner et al., BSSA (2006)



Guilhem et al. S&T 2015

MSVMAX FOR THE DPRK TESTS

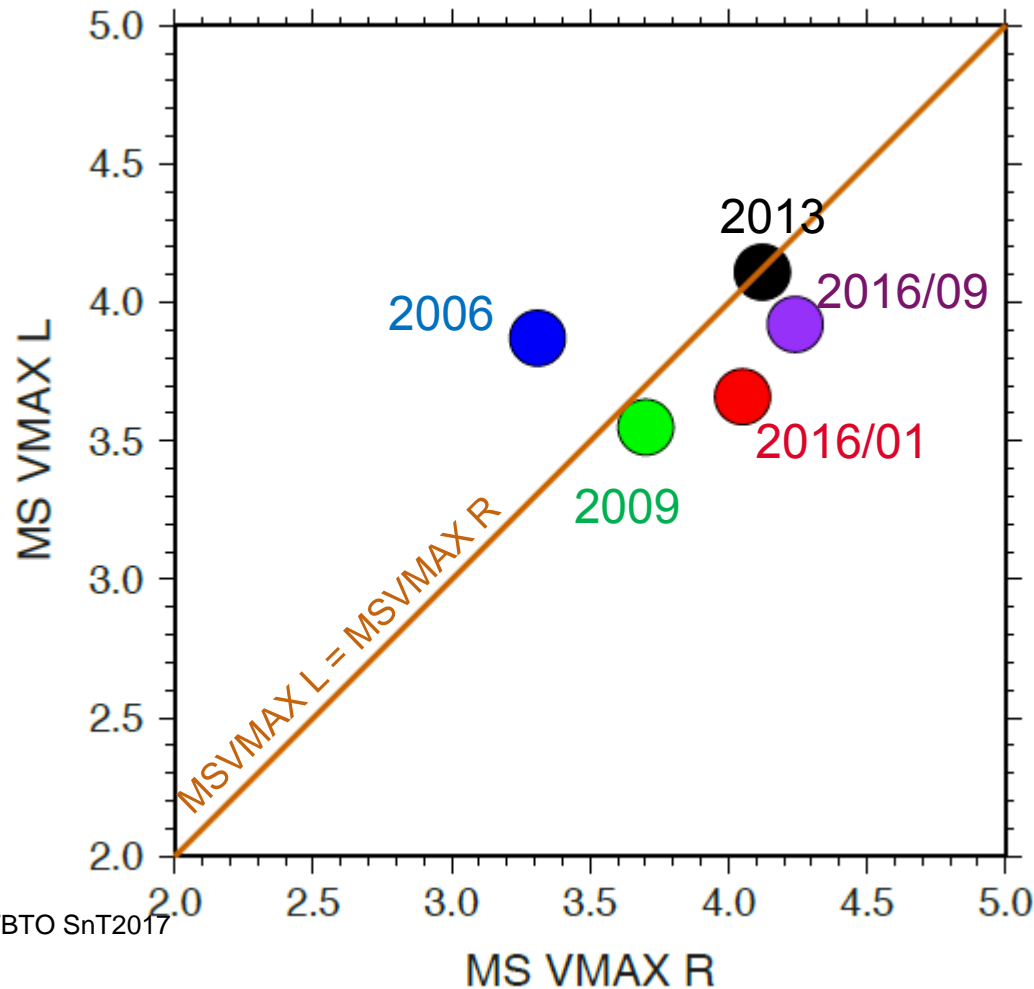
Using the empirical discrimination line defined by Bonner et al. (2006), the mb : MSVMAX method fails to identify DPRK tests as explosions except when using Love waves for the 2016 events.



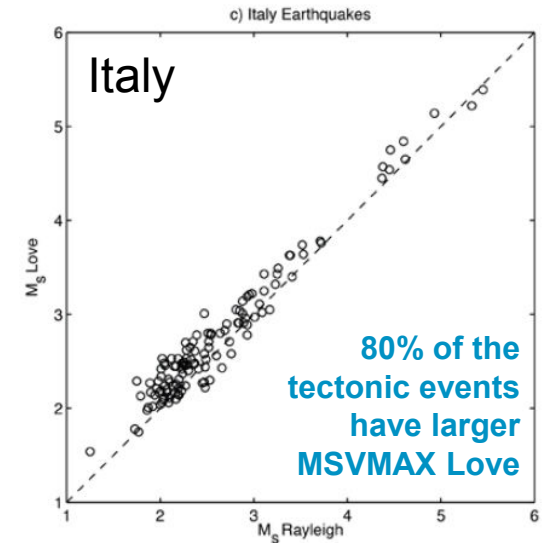
MSVMAX measured on Rayleigh waves (left) and Love waves (right) and comparison with the previous DPRK tests.

MSVMAX LOVE AND RAYLEIGH

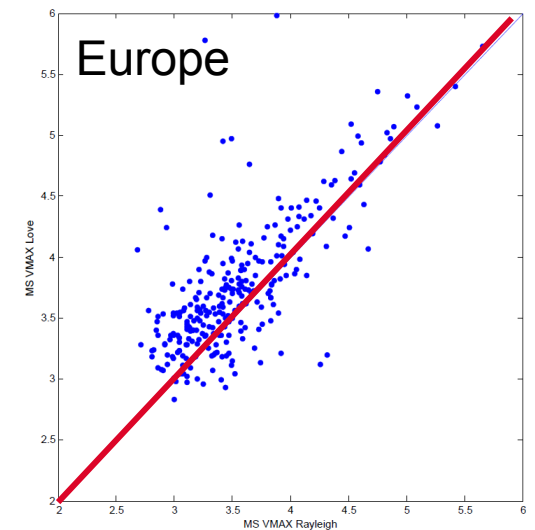
Except for the 2006 test, all the DPRK nuclear events have Love wave magnitude smaller than Rayleigh wave magnitude



CTBTO SnT2017



Bonner et al.,
Final Report AFRL (2012)



Guilhem et al., S&T 2015

MSVMAX AT REGIONAL DISTANCES

No isotropic pattern of the MSVMAX values

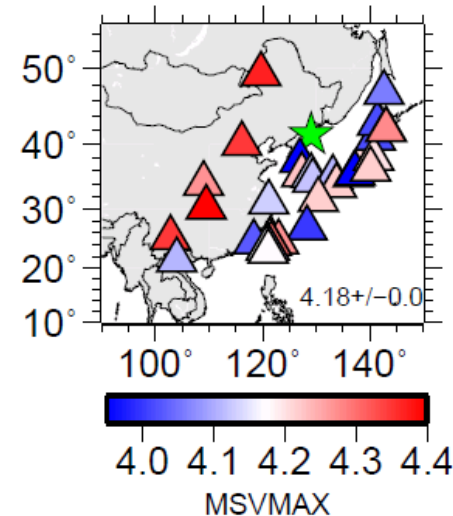
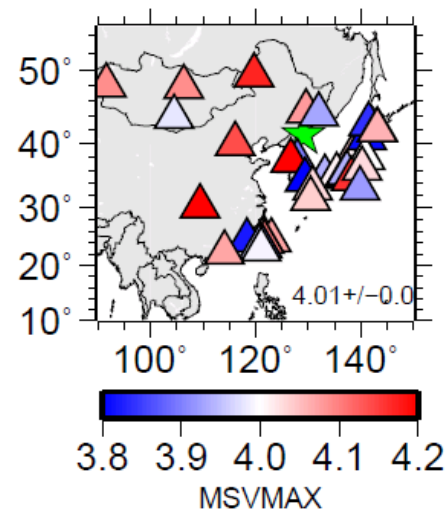
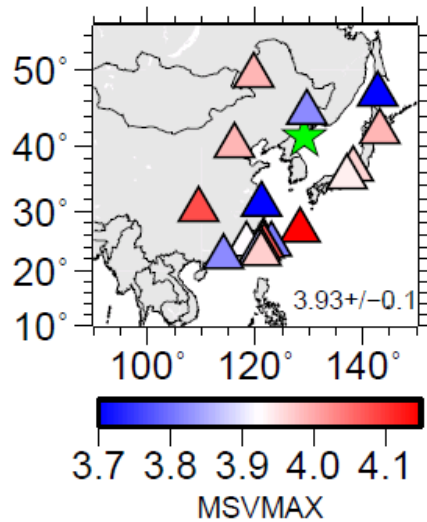
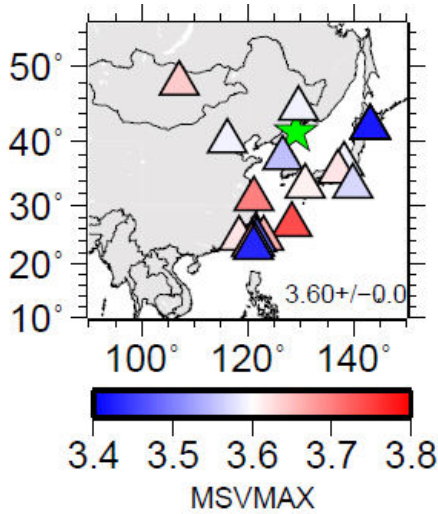
2009

2013

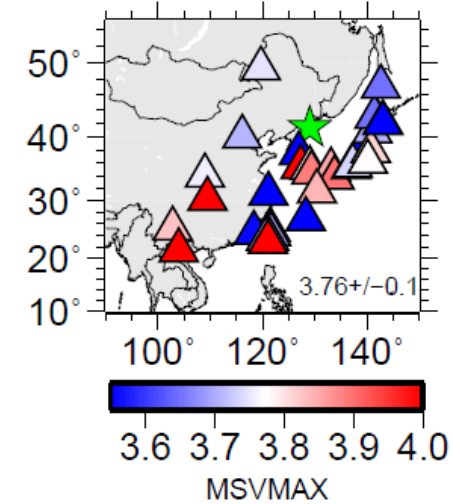
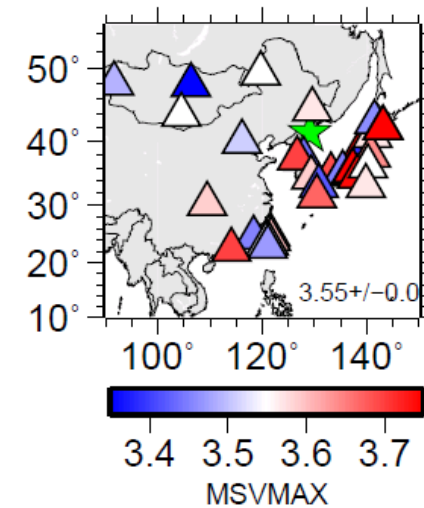
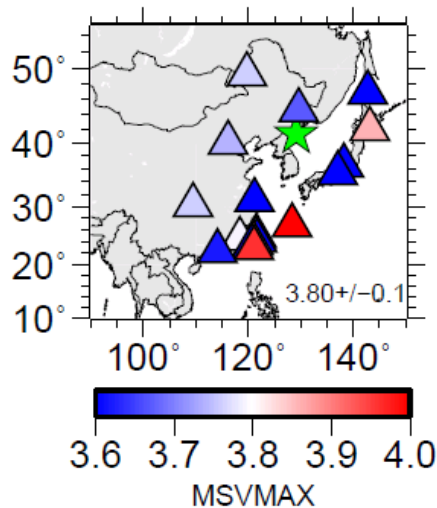
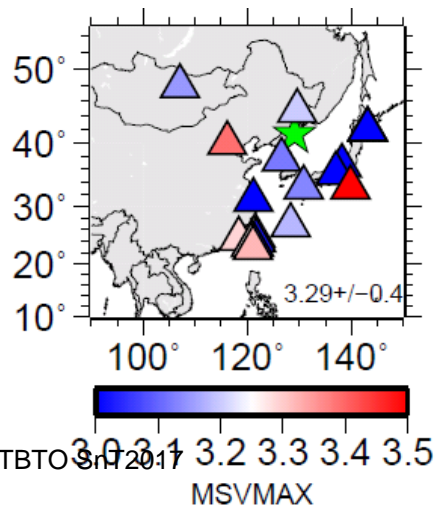
2016/01

2016/09

Rayleigh waves



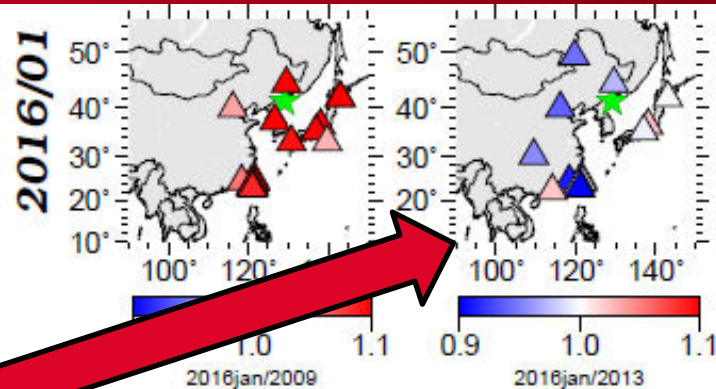
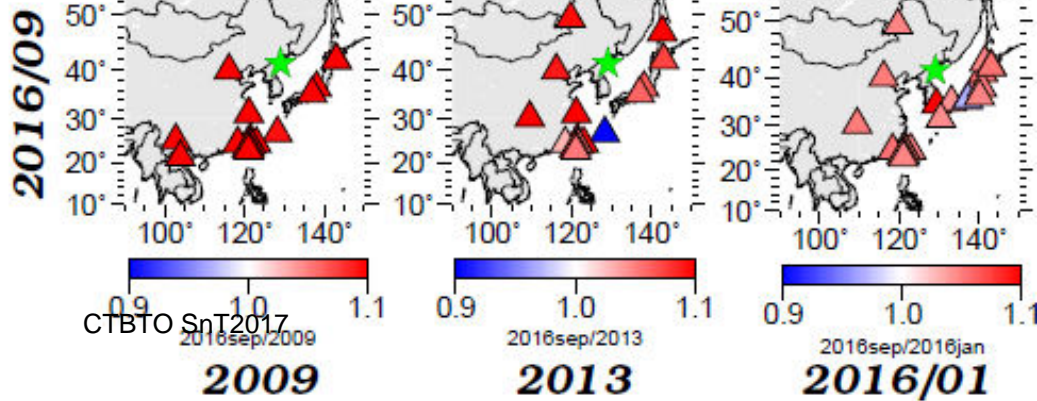
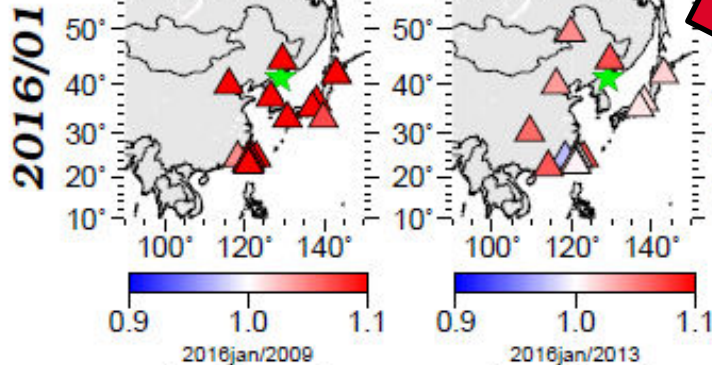
Love waves



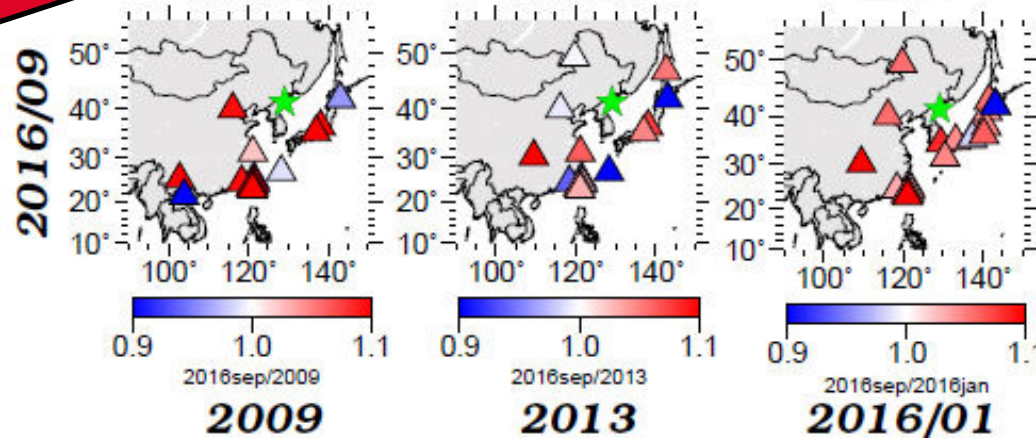
MSVMAX: LOVE VERSUS RAYLEIGH

Inversion of the magnitude values between 2013 and Jan 2016

Rayleigh waves



Love waves

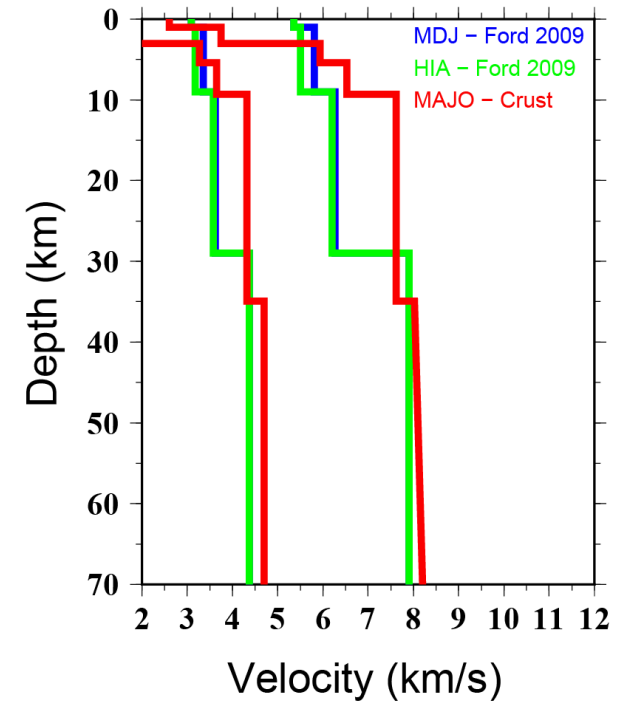
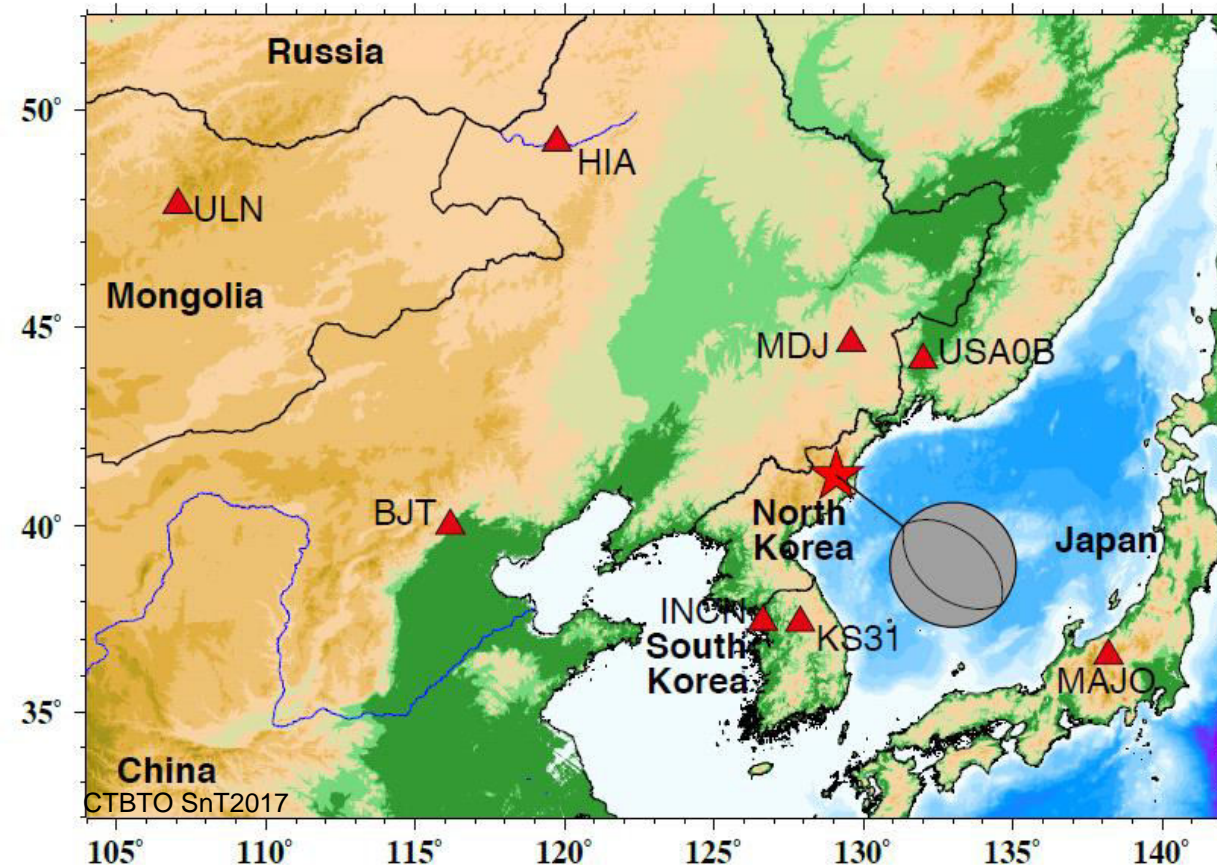


MSVMAX reveals that the 2013 event is enriched in Love waves compared to the other events

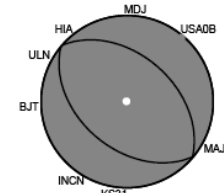
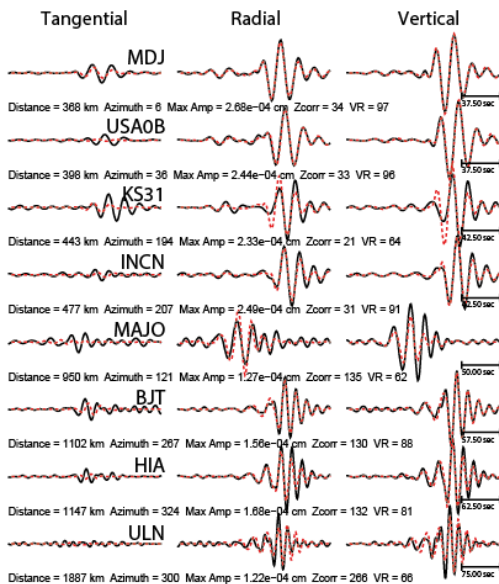
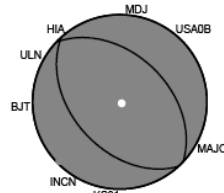
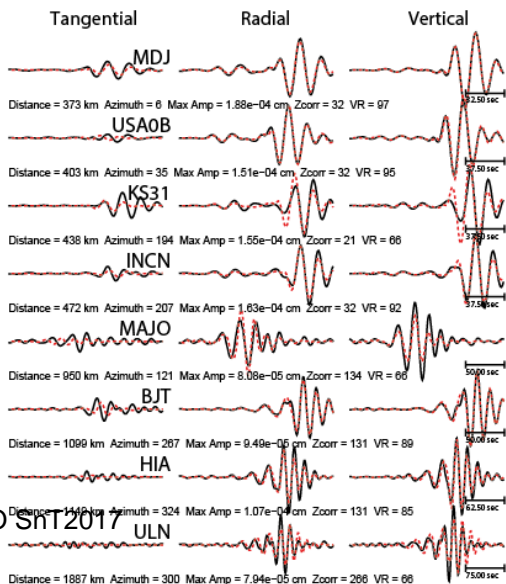
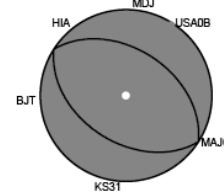
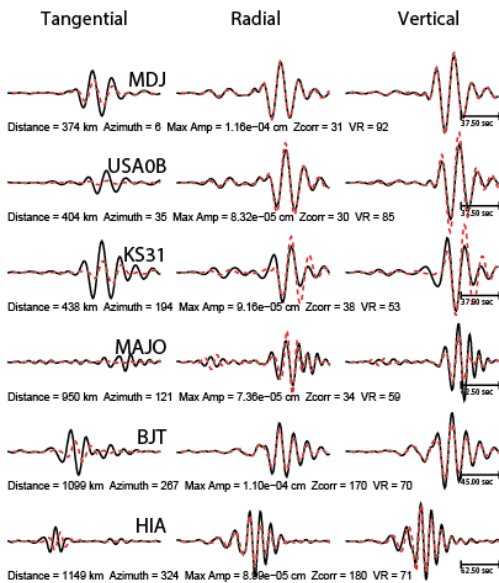
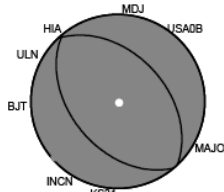
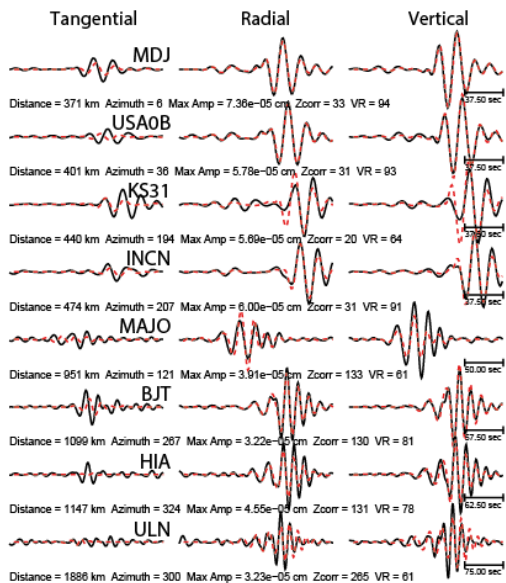
MOMENT TENSOR INVERSION

Identical parameters to help for source comparison

- 8 regional stations distributed around North Korea
 - 3 velocity models (Ford et al., 2009 + Crust2)
 - 15-30 s period
 - Fixed depth at 1 km

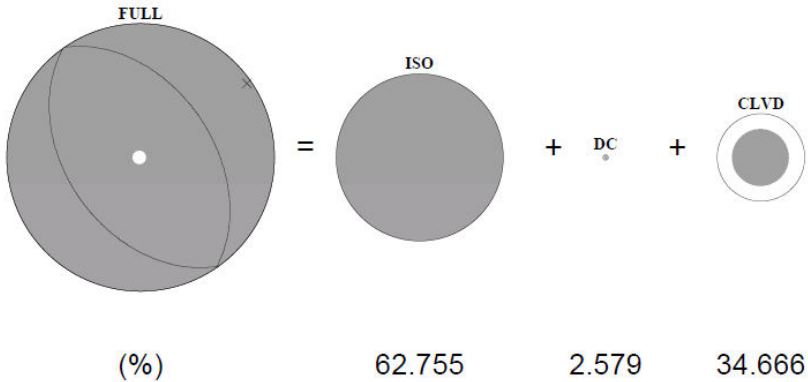


RESULTS OF THE SOURCE INVERSION

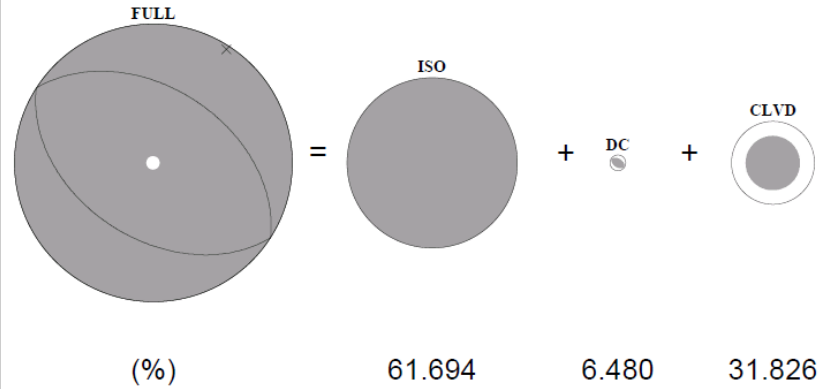


SOURCE COMPARISON

DPRK 2009

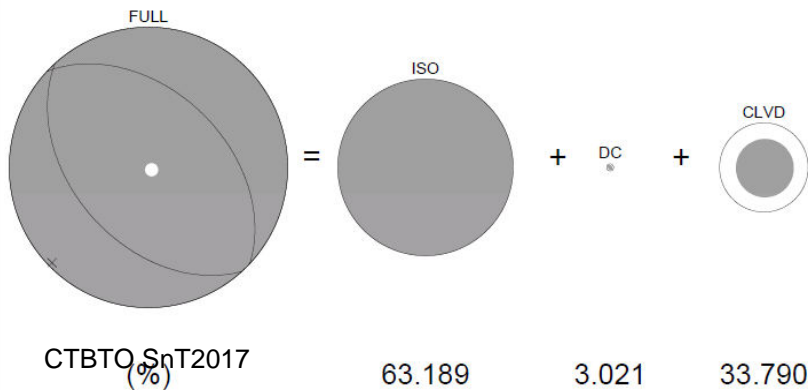


DPRK 2013

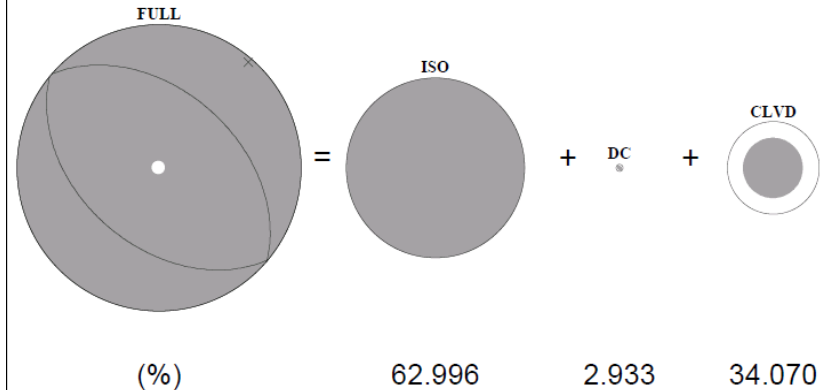


Dominant explosive component – Very low double-couple component

DPRK 2016 January



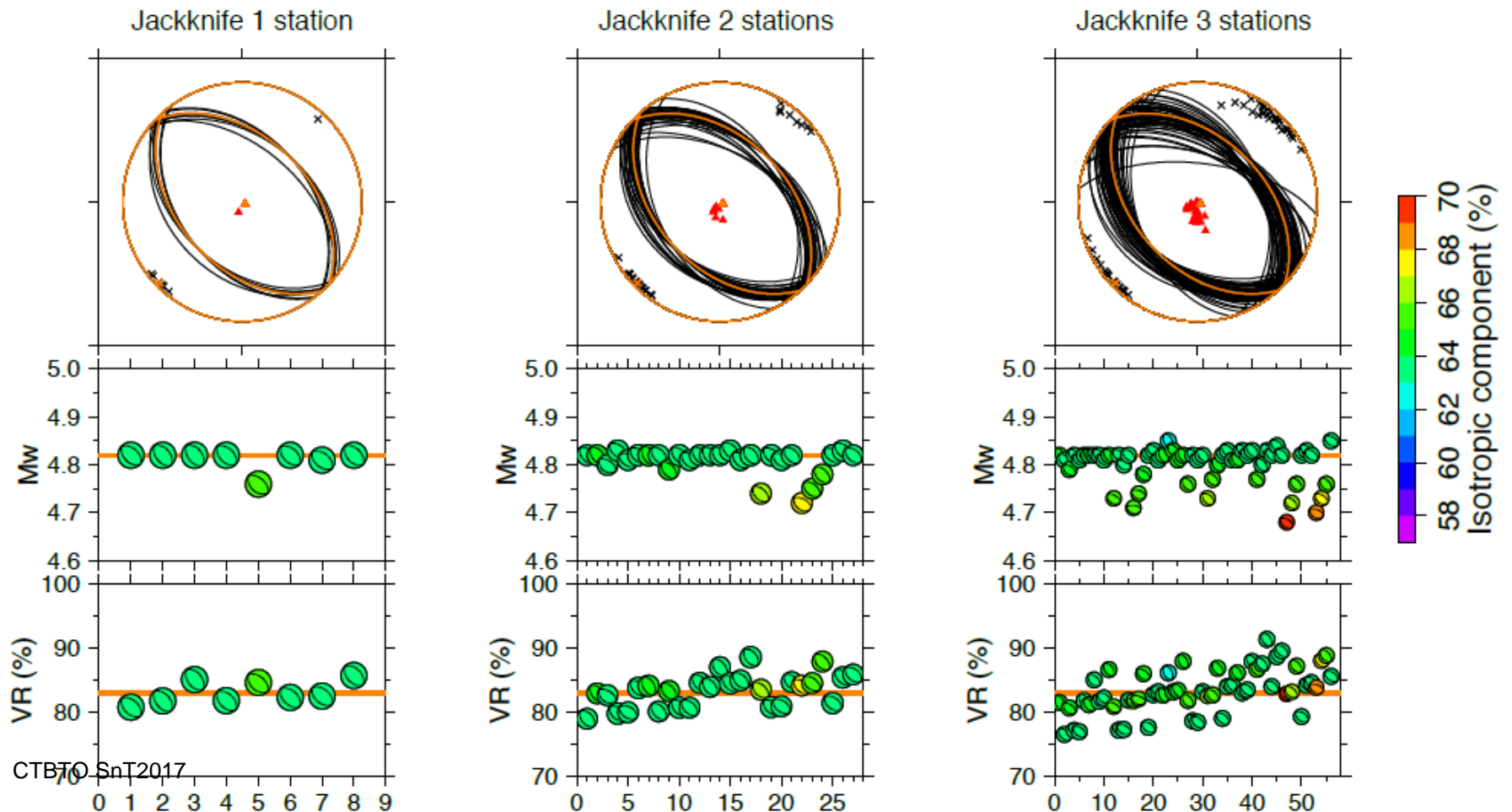
DPRK 2016 September



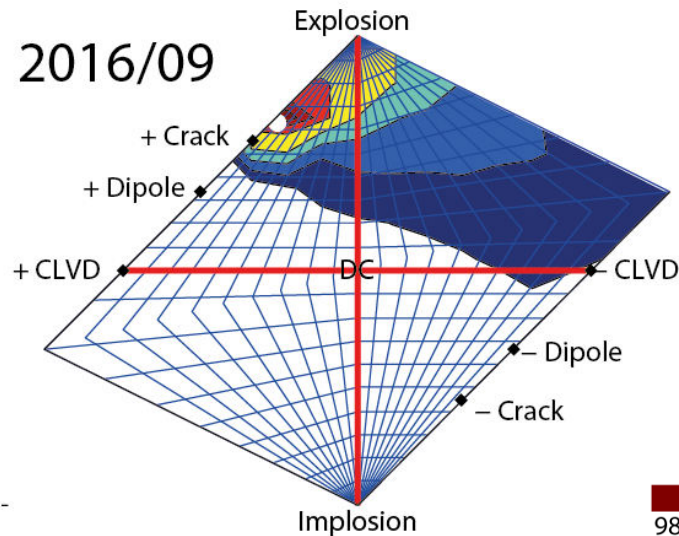
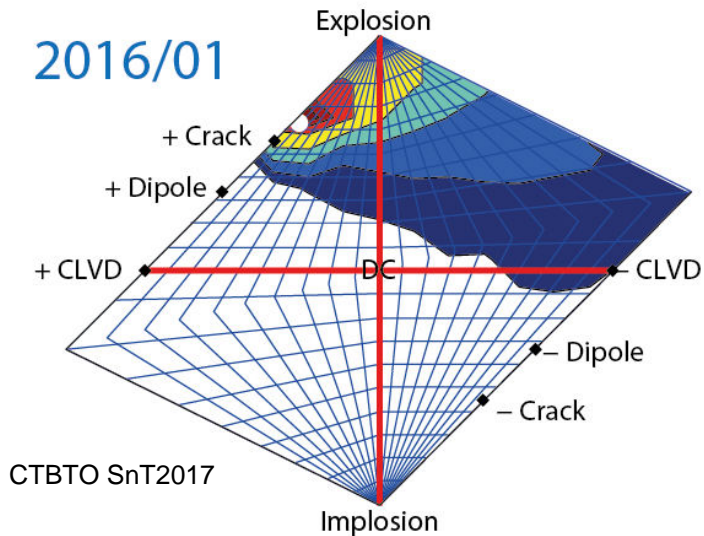
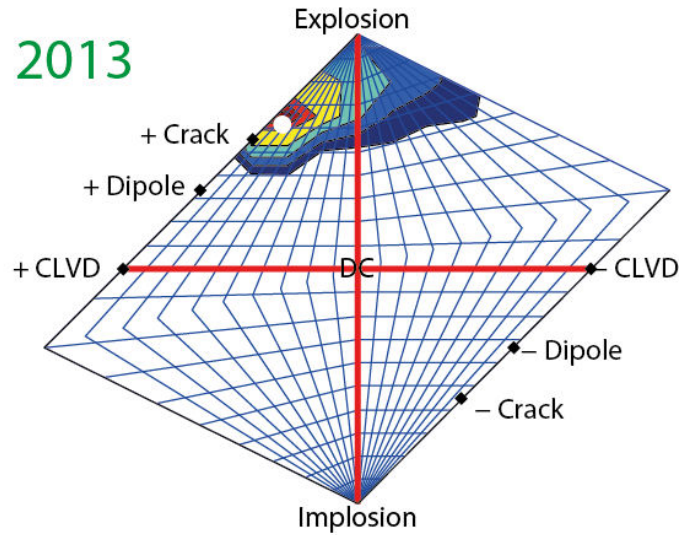
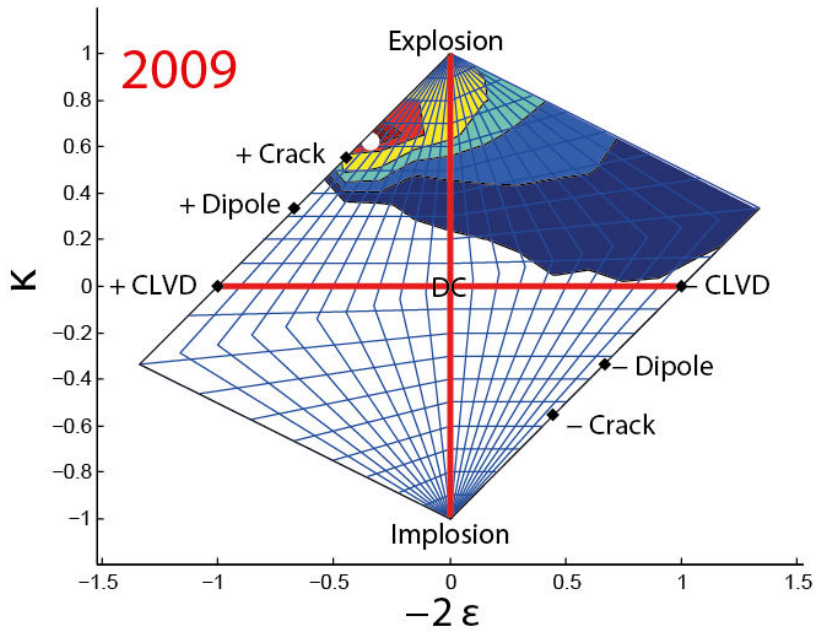
STABILITY OF THE SOLUTIONS

High level of fits (VR) and stability of the source solutions (Mw, isotropic component, mechanism) independently of the stations used

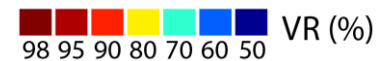
Example for the January 2016 event



NETWORK SENSITIVITY SOLUTIONS



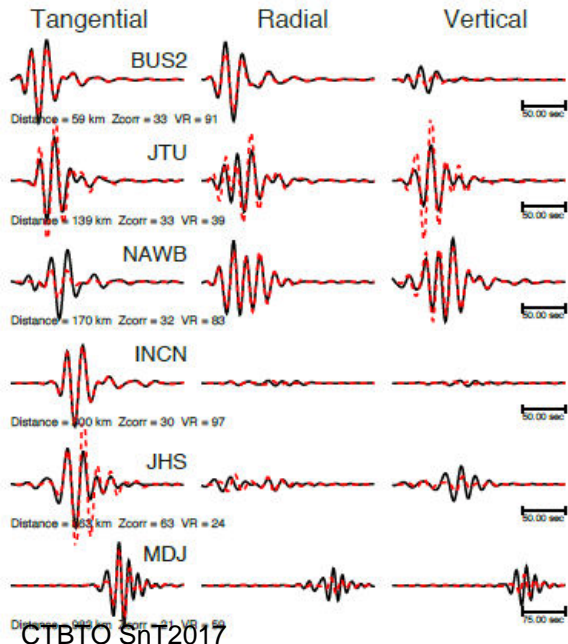
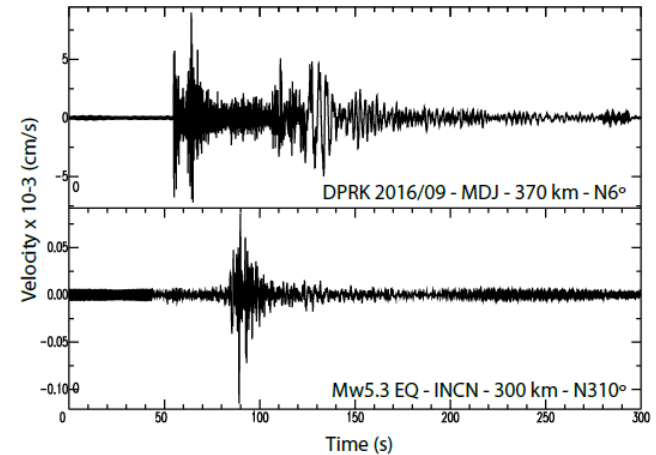
400 million random moment tensors tested against the seismic data



DISCUSSION (1)

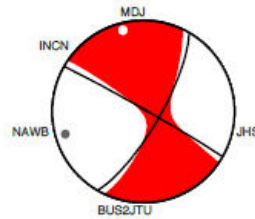
Application of the approach to the M5.3 South Korea earthquake sequence

- Occurred only a few days after the 2016/09 DPRK event
- The largest instrumented event of South Korea
- Similar magnitude range as the DPRK events
- Strong double-couple components for all three events



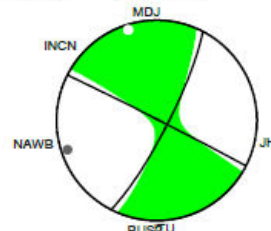
09/12/2016 11:32:54

Depth = 17 km
 Strike = 300 ; 30 °
 Rake = -14 ; -178 °
 Dip = 88 ; 76 °
 Mo = 1.96e+24 dyne cm
 Mw = 5.47
 DC = 70 %
 CLVD = 23 %
 ISO = 7 %
 VR = 80.2 %



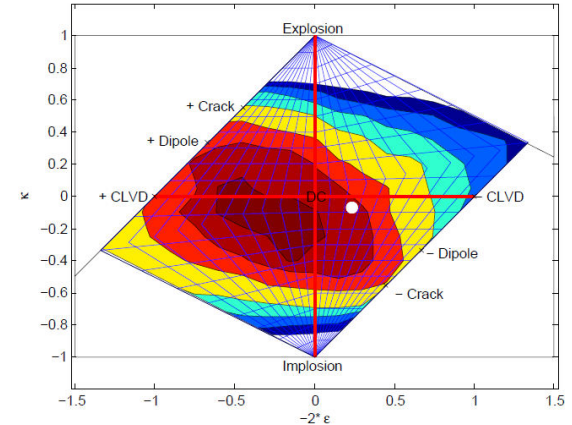
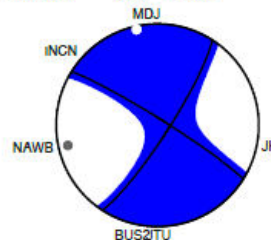
09/12/2016 10:44:33

Depth = 17 km Mo = 4.32e+23 dyne cm
 Strike = 297 ; 27 ° Mw = 5.03
 Rake = -9 ; -179 ° DC = 74 %
 Dip = 89 ; 81 ° CLVD = 20 %
 VR = 69.8 % ISO = 6 %



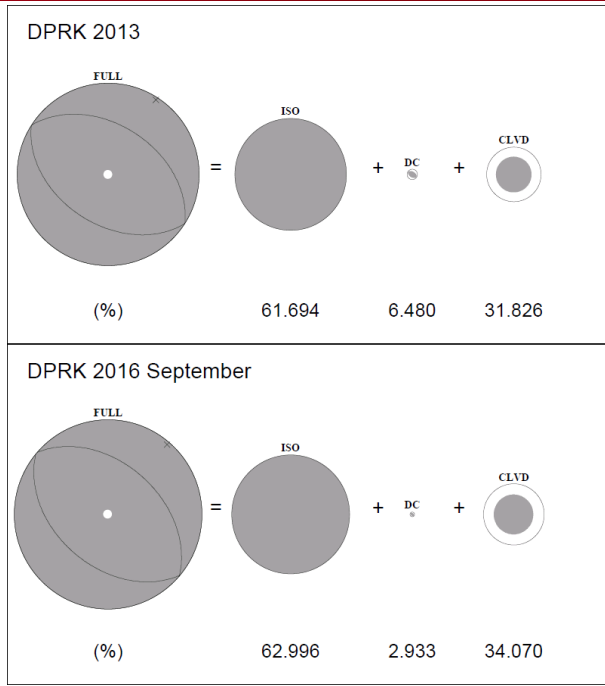
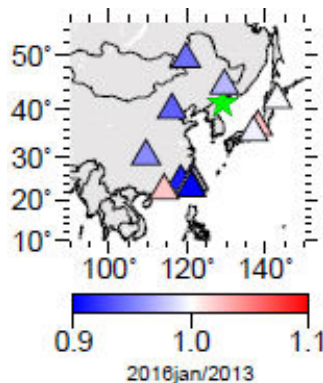
09/19/2016 11:33:58

Depth = 17 km Mo = 4.61e+22 dyne cm
 Strike = 302 ; 33 ° Mw = 4.38
 Rake = -9 ; -175 ° DC = 85 %
 Dip = 85 ; 81 ° CLVD = 2 %
 VR = 58.2 % ISO = 13 %

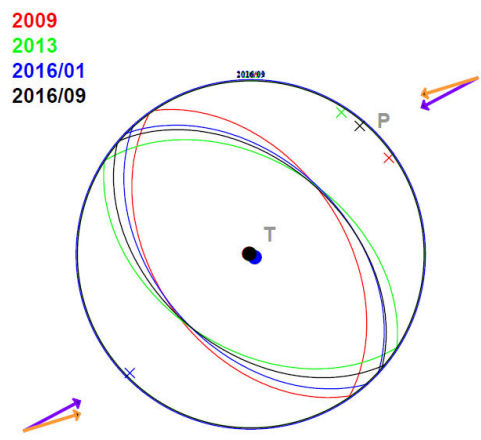
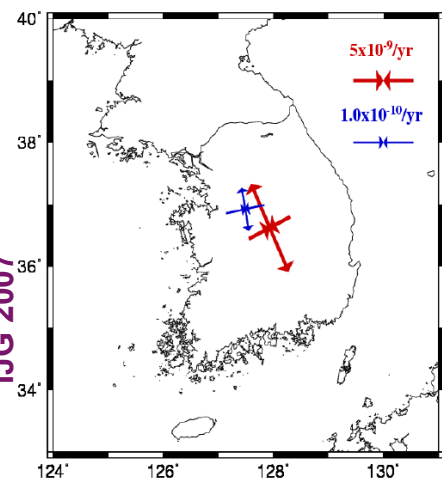


Almost the same solutions for all for DPRK events

- In agreement with the similar waveforms/location
- Slightly more DC component in 2013
Larger Love waves



Jin and Park, IJG 2007

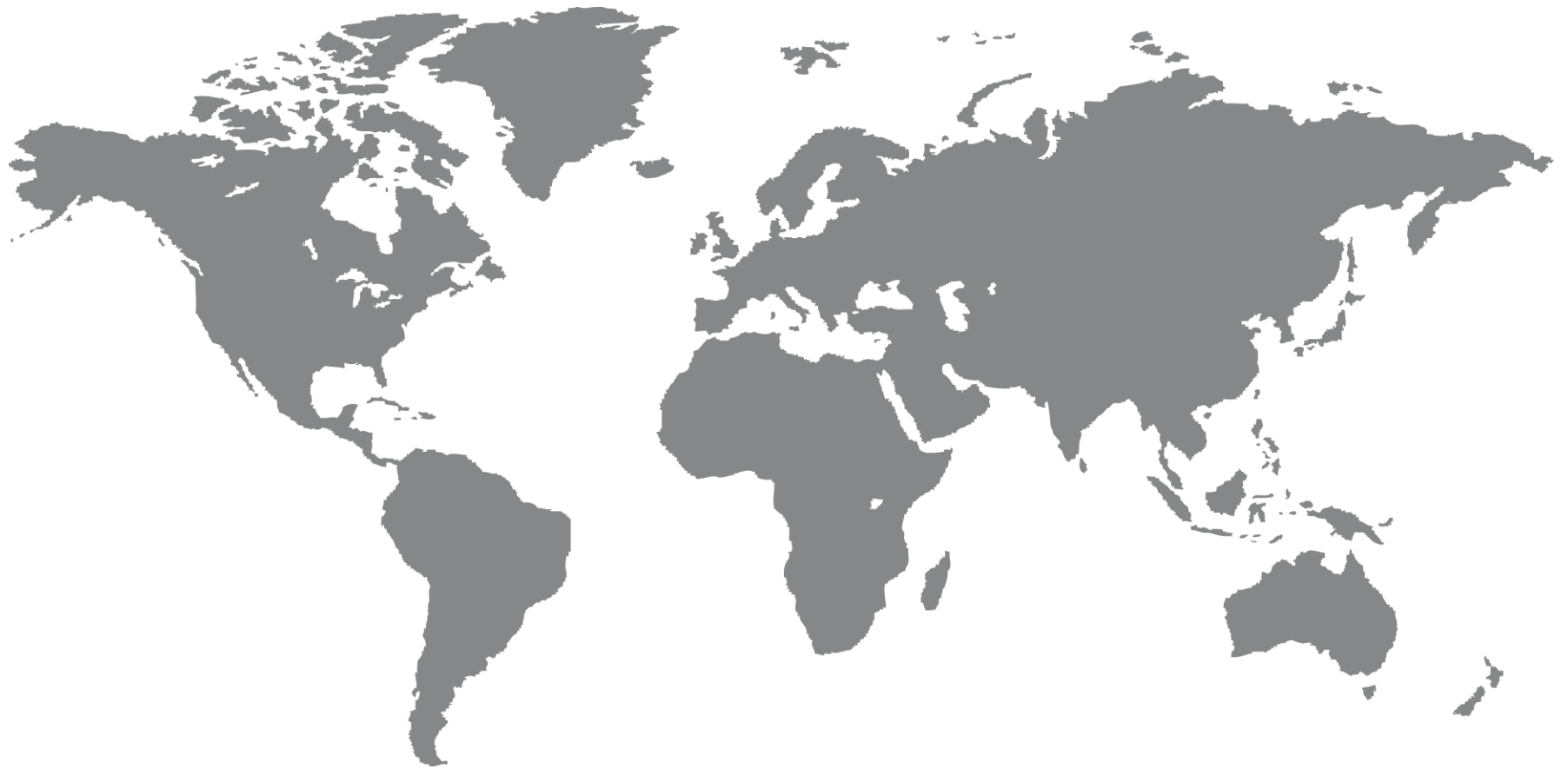


Agreement with the regional stress field

- The small DC component agrees with the regional stress field
- Slight deviation of the CLVD could explain a slight change in the Love wave amplitude.

Fig. 5 The principal horizontal axes of the strain rate tensors in South Korea. The red arrows (thick lines) are the GPS-derived strain rates and the blue arrows (thin lines) are the seismicity-derived strain rates.

Jin and Park 2007
GPS-derived
Seismicity-derived



Thank you very much!