Complex seismic source inversion method with the data covariance matrix: Application to the 2010 Haiti earthquake and the 2011 New Zealand Earthquake

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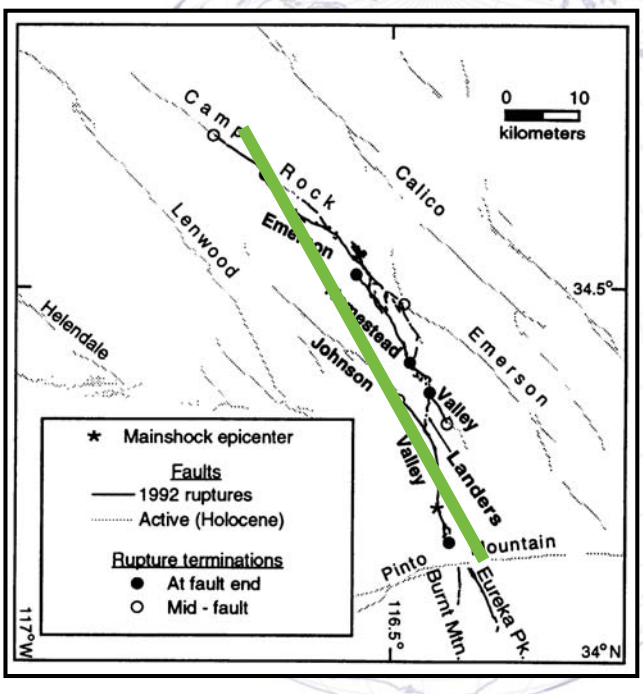
Complex fault zone



1992 Landers earthquake
(Sieh 1996)

Generally, in waveform inversion,
Seismic Source Area
~ Simple Planer Fault

This fault model is not able to represent real fault geometry often accompanied by bending and branching.

This fault geometrical error may bring down biased solution !

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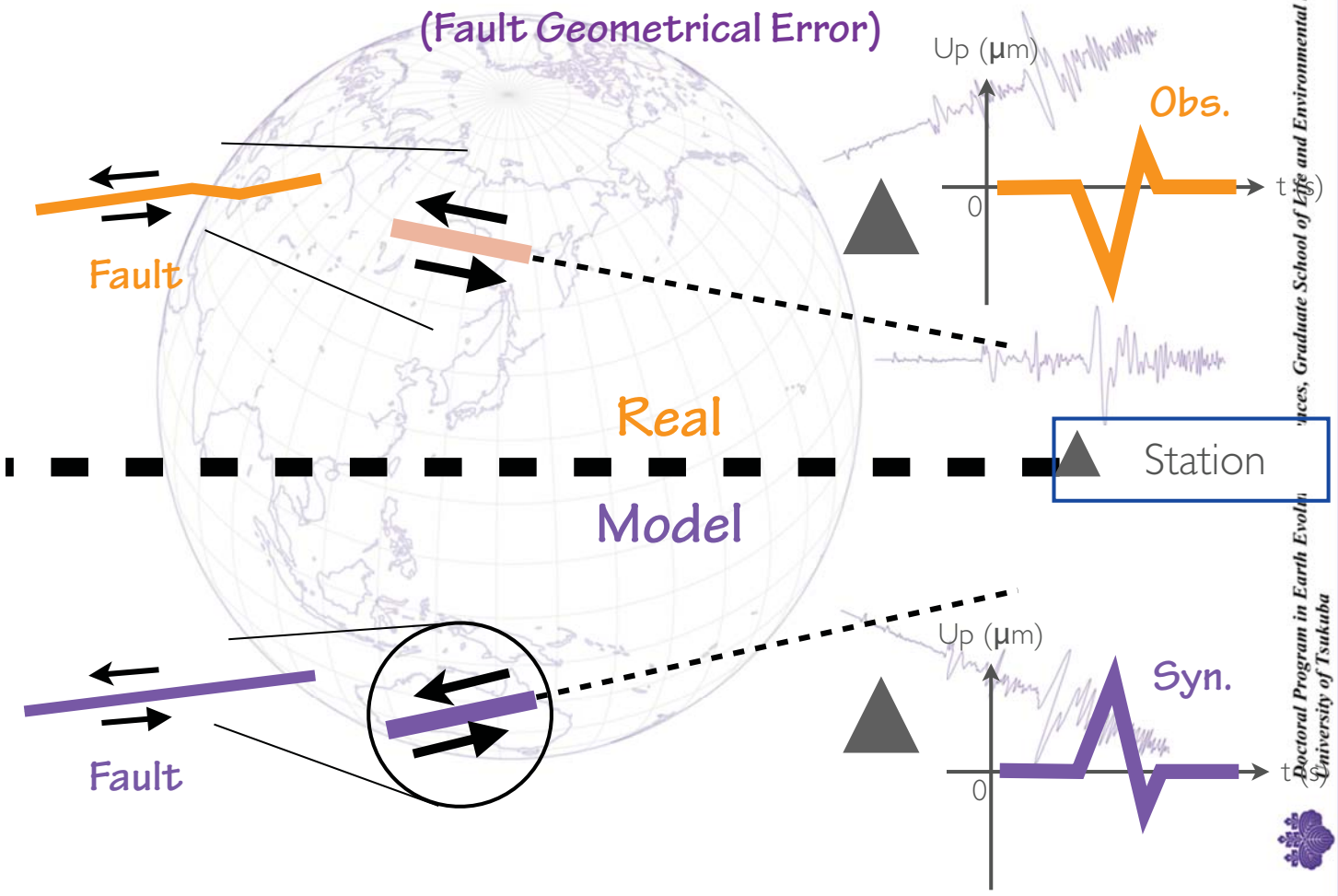
Problem: Modeling Error

(Fault Geometrical Error)



Our Solution !

- Increasing flexibility for moment tensor components of each space knot in the model area.
  - To estimate proper solution, we applied the new formulation of waveform inversion, which considers the data covariance matrix of Green`s function errors and observation errors.

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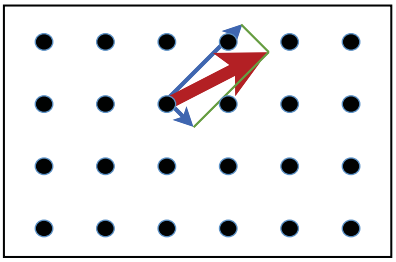
Seismic Source Model

Previous Source Model

$$u_j(t) = \sum_{q=1}^{2} \int_S G^0_{jq}(\boldsymbol{\xi}, t) * \dot{D}^0_q(\boldsymbol{\xi}, t)\, dS + e_{bj}(t)$$

Slip Vector

Green's function

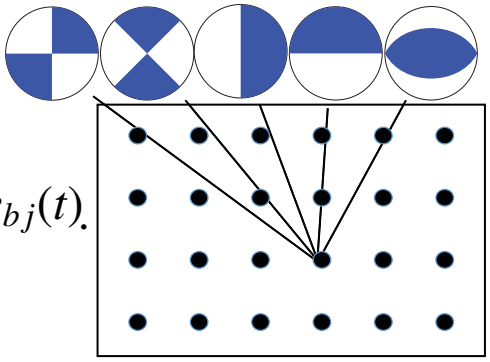


Our Source Model

$$u_j(t) = \sum_{q=1}^{5} \int_V G^0_{jq}(\boldsymbol{\xi}, t) * \dot{m}^0_q(\boldsymbol{\xi}, t)\, dV + e_{bj}(t)$$

Moment tensor

Green's function



Re-construction of observed equation

Yagi & Fukahata, 2010

Problem: We can never obtain the true Green's function !

Solution in Previous studies:
Devoting their efforts to obtain Green's function as precise as possible

Our Solution
Introducing the uncertainty of Green's function for waveform inversion.

$$\mathbf{u}(\mathbf{x},t) = \sum_{q=1}^{5} \int_\Sigma \mathbf{G}_q(\mathbf{x},\boldsymbol{\xi},t) * \dot{m}_q(\boldsymbol{\xi},t)\, dS + F(t) * \mathbf{e}_0(t)$$

Observed error

$$\mathbf{G}_q(\mathbf{x},\boldsymbol{\xi},t) = P(t) * \left[\hat{\mathbf{g}}_q(\mathbf{x},\boldsymbol{\xi},t) + \delta\mathbf{g}_q(\mathbf{x},\boldsymbol{\xi},t)\right]$$

Green's function Error

$$\mathbf{d} = \mathbf{Ha} + \mathbf{P}(\mathbf{a})\delta\mathbf{g} + \mathbf{Fe}_0$$

Data covariance matrix

$$\mathbf{C}_d\left(\mathbf{a}, \sigma_g^2, \chi^2\right) = \sigma_g^2\left[\mathbf{P}(\mathbf{a})\mathbf{P}^t(\mathbf{a}) + \chi^2\mathbf{F}\mathbf{F}^t\right]$$

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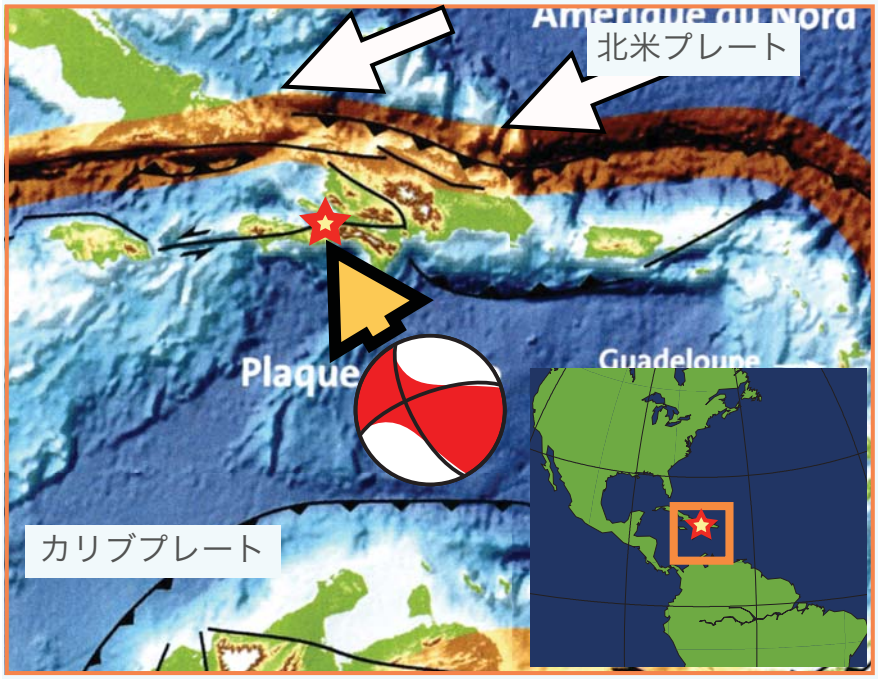
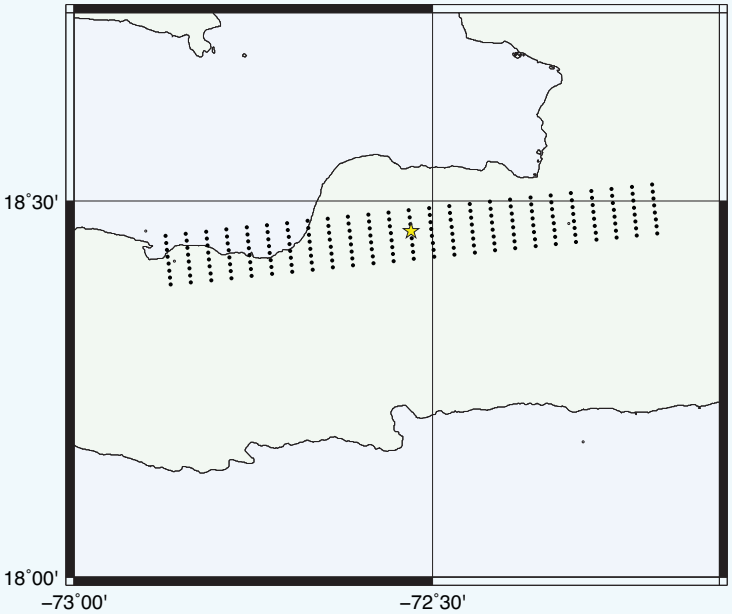
2010 HAITI EARTHQUAKE



- 2010/01/12
  - Lat 18.457°
  - Lon -72.533°
  - depth 13 km

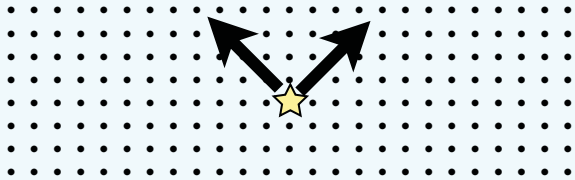
After brgm poster
CMT: Global CMT Catalog
hypocenter: USGS/EERI（2010）

Source Model



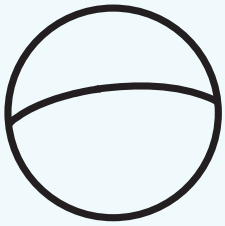
72.53W, 18.46N, 13 km

Rupture Velocity: 2.8 km/s

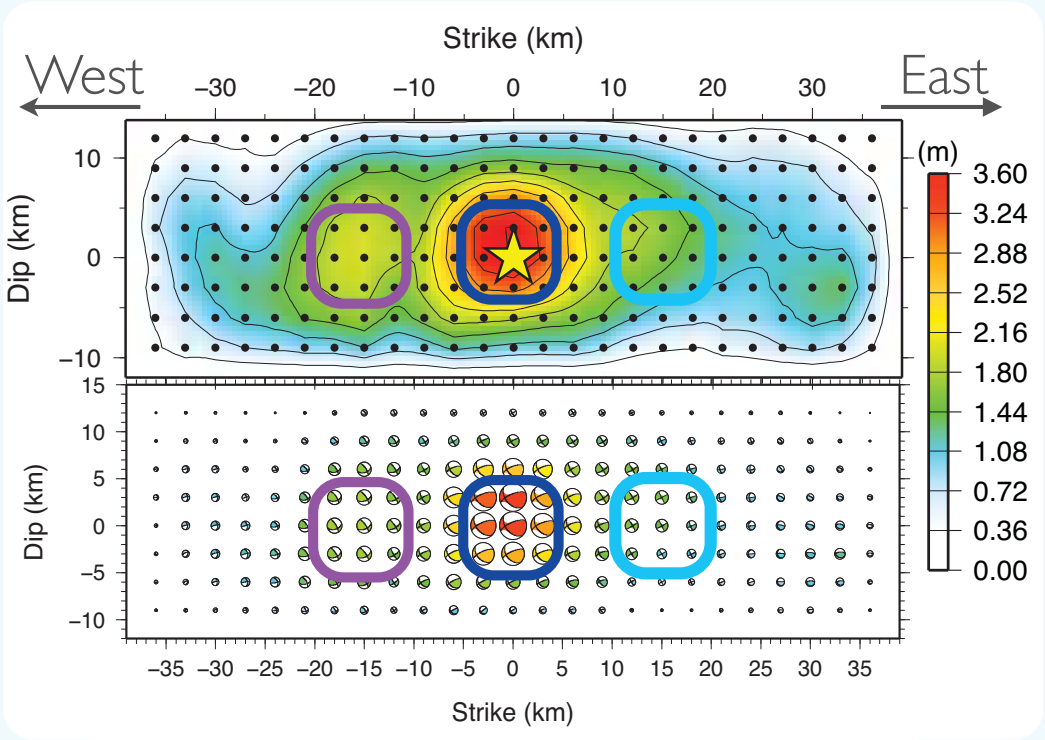


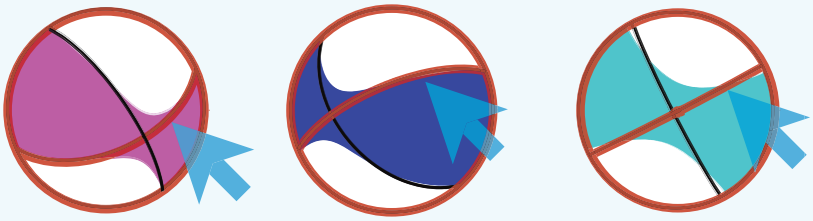
Interval of Space Knot : 3 km

Strike: 264° Dip: 70°



Moment Release

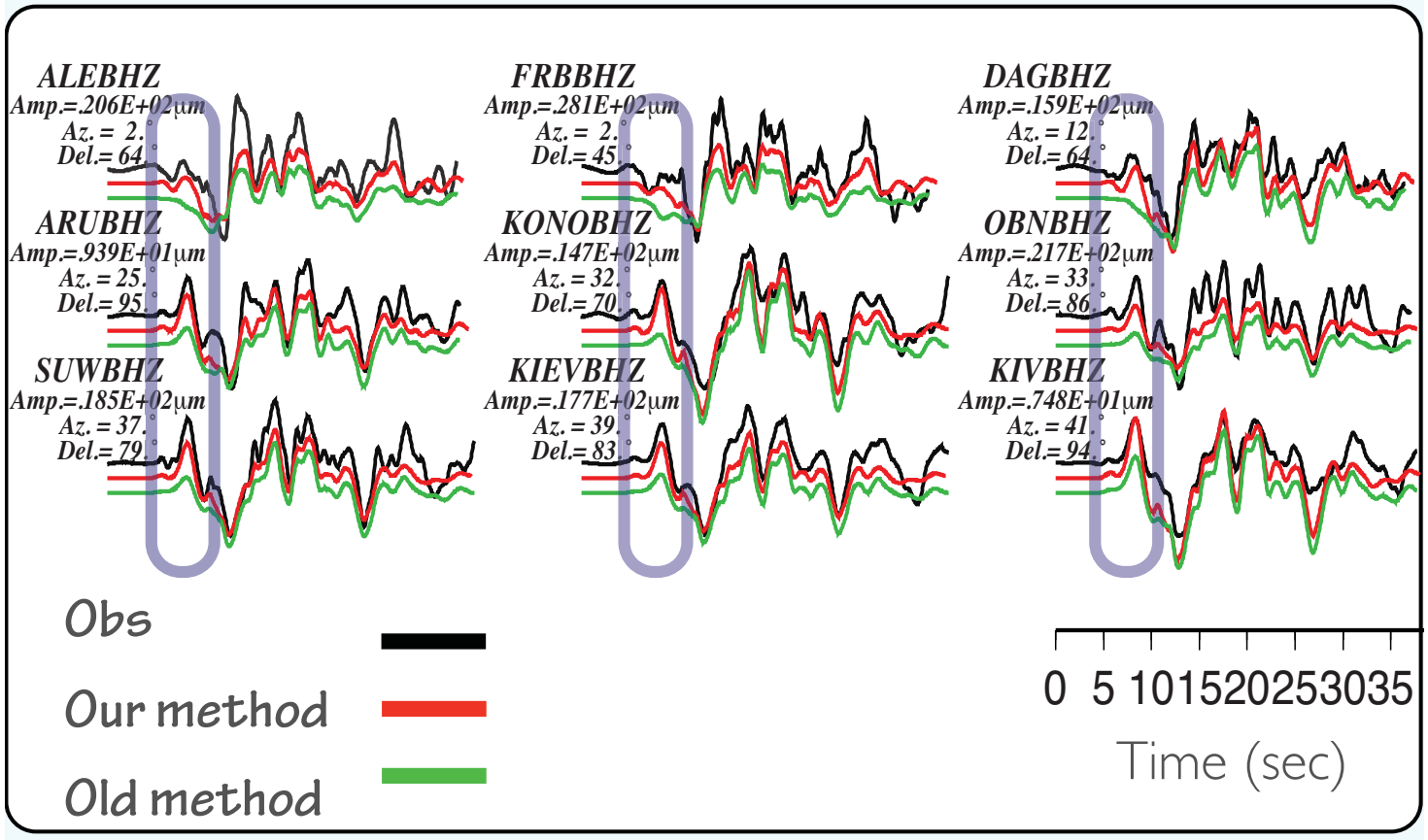




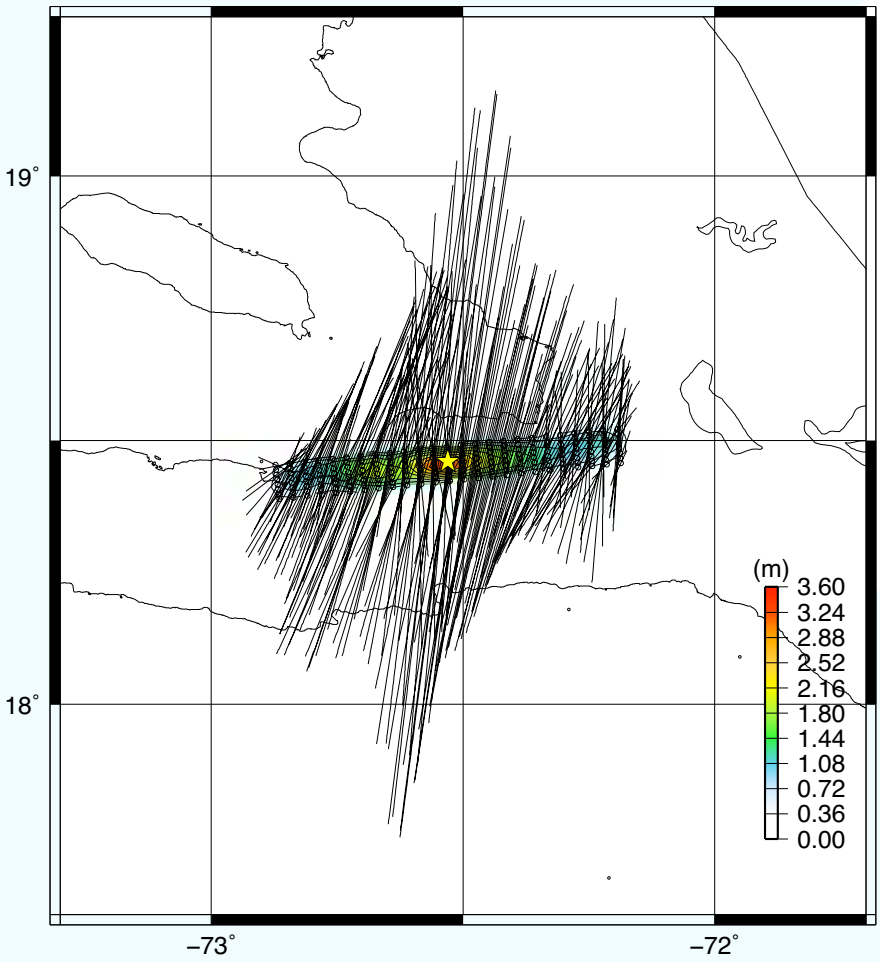
The 2010 Haiti earthquake ruptured three major rupture zones having different focal mechanisms:

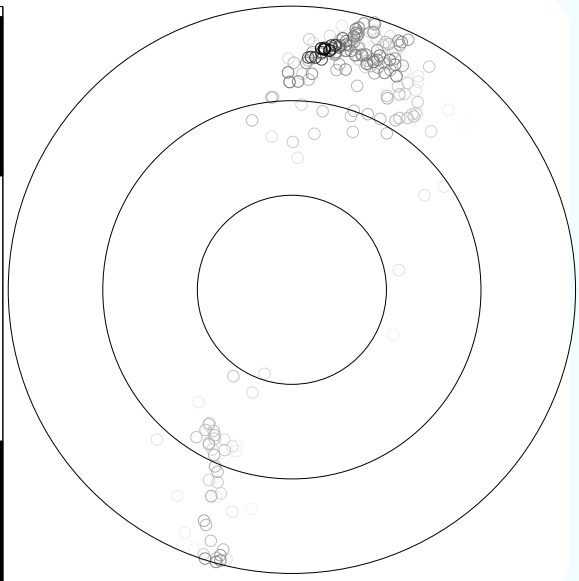
Center Patch,
East Patch,
West Path.

Waveform



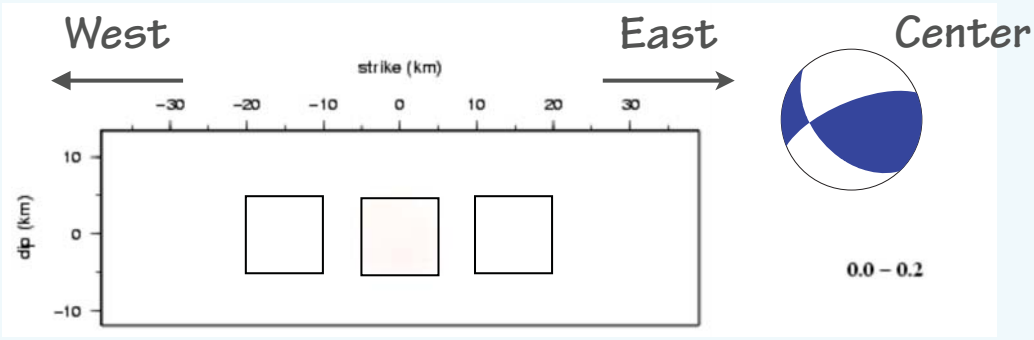
P-axis

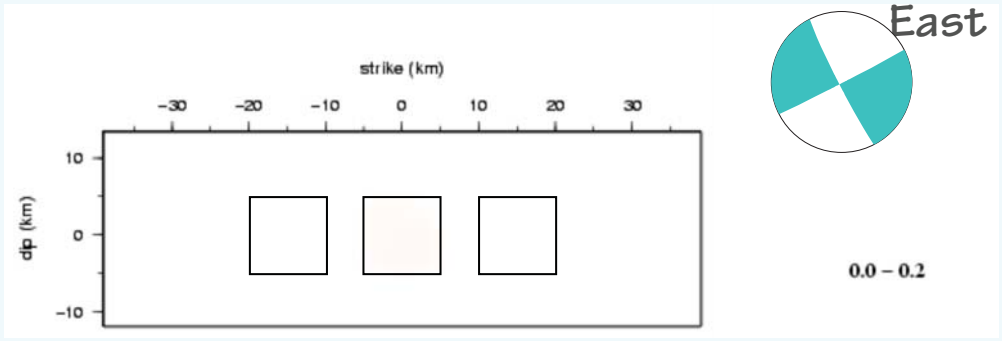


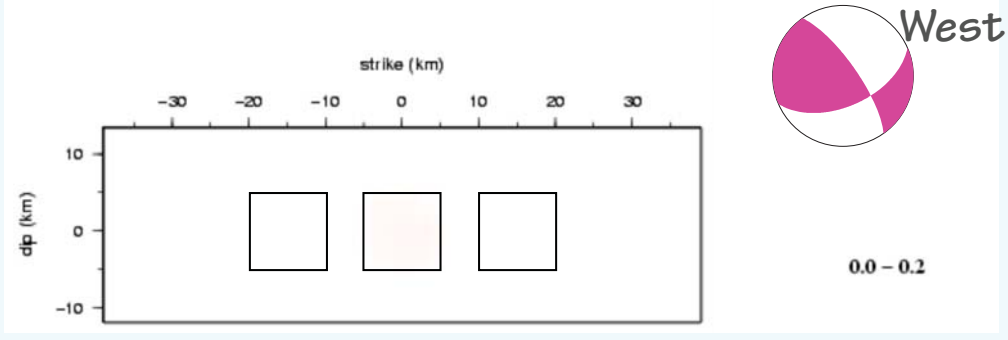


Although we never constrained direction of P-axes, estimated distribution of P-axes is well consistent with the regional stress field.

Rupture Propagation

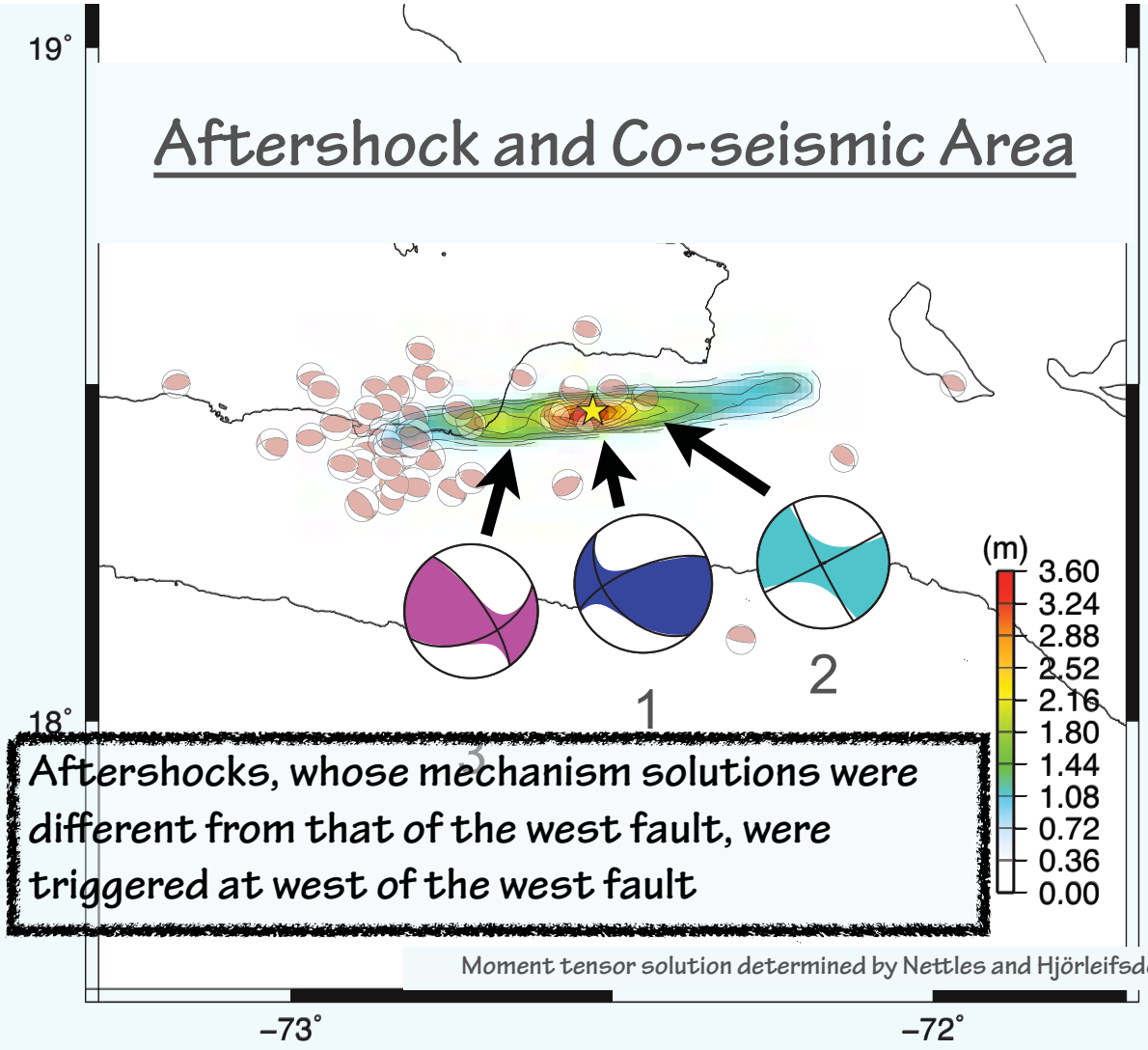






The rupture in east and west patches was started from shallow part, which is weaker than deep part.

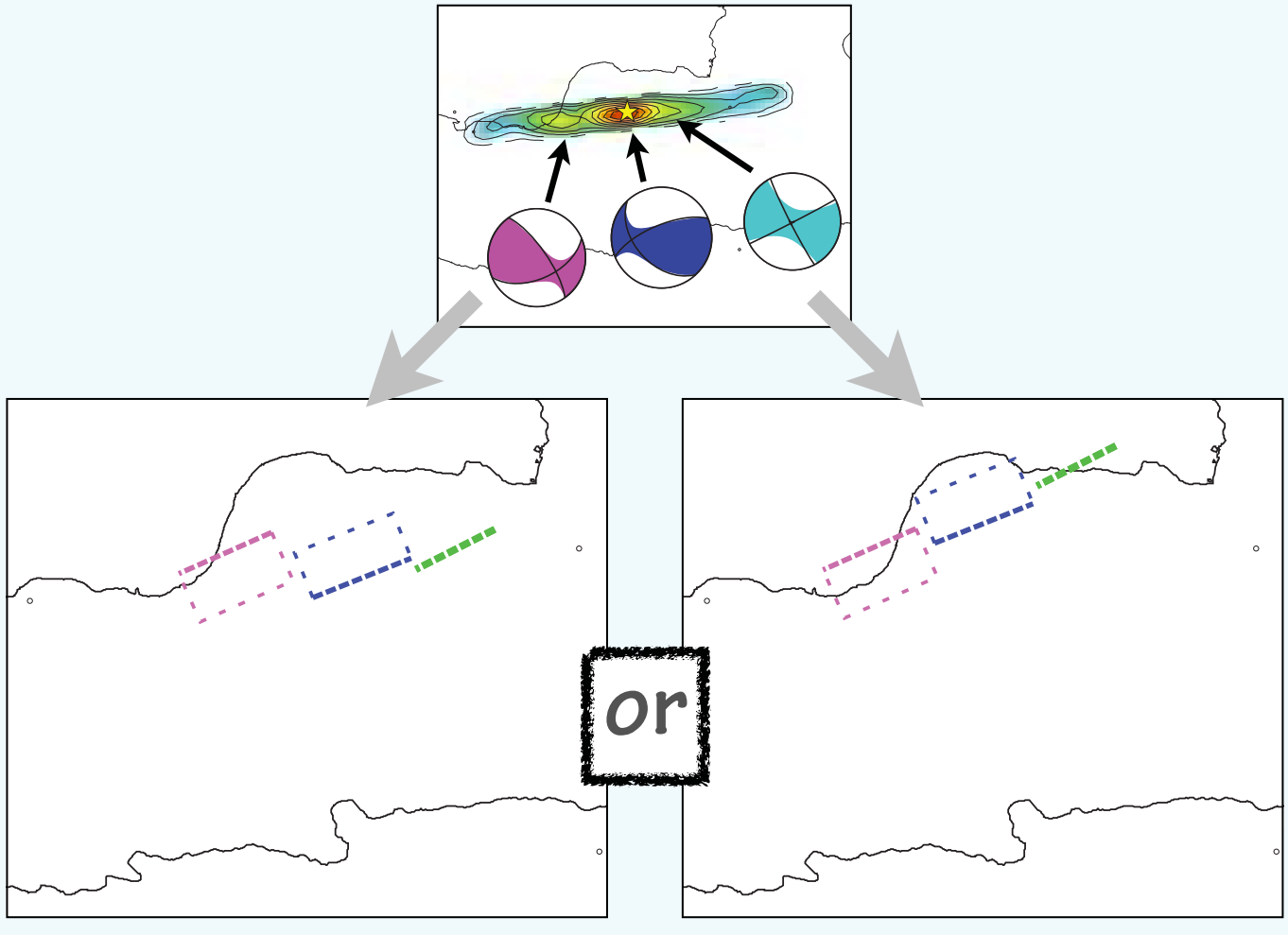
Aftershock and Co-seismic Area



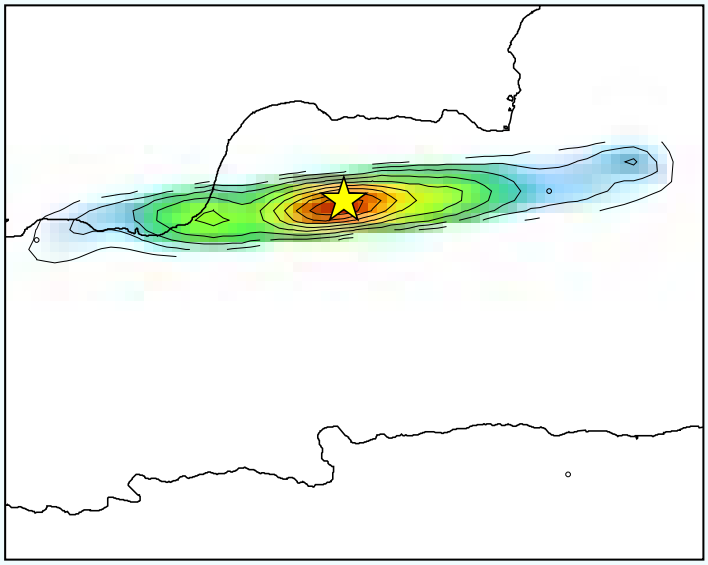
Aftershocks, whose mechanism solutions were different from that of the west fault, were triggered at west of the west fault

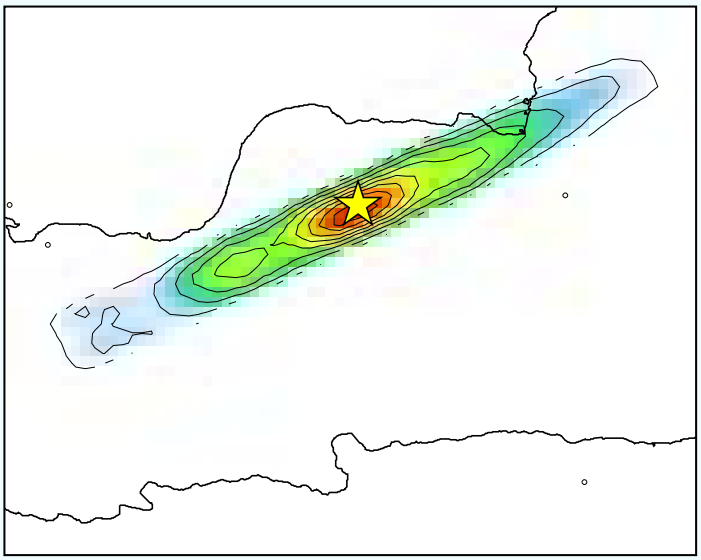
Moment tensor solution determined by Nettles and Hjörleifsdóttir (2010)

Interpretation of focal mechanism



We cannot resolve from Tele-seismic



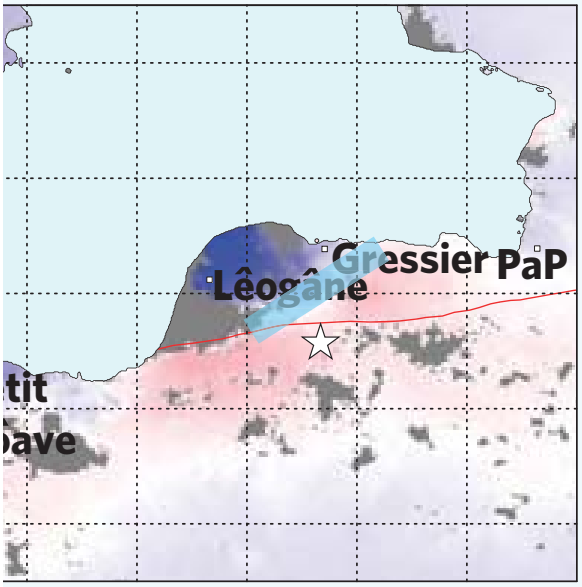


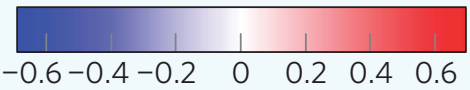
Strike : 264°

Strike : 244.9°

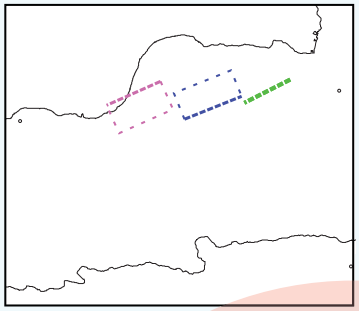
Tow model can explain data!

Interpretation with InSAR





Hayes et al., 2010



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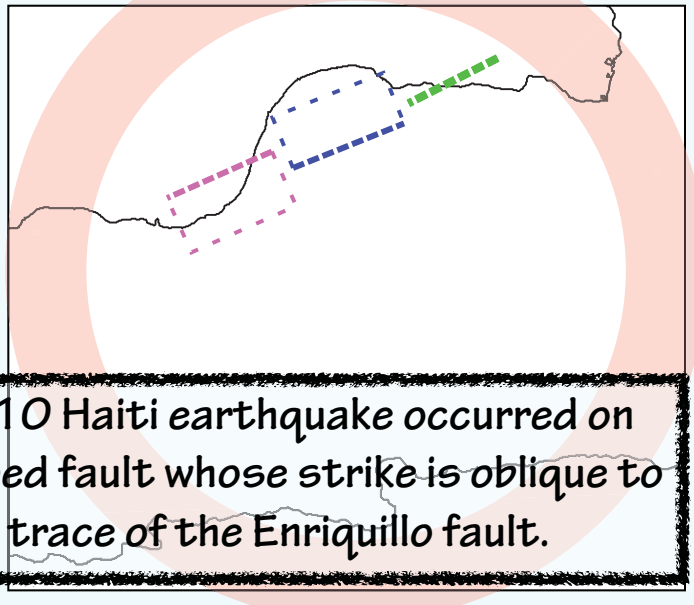
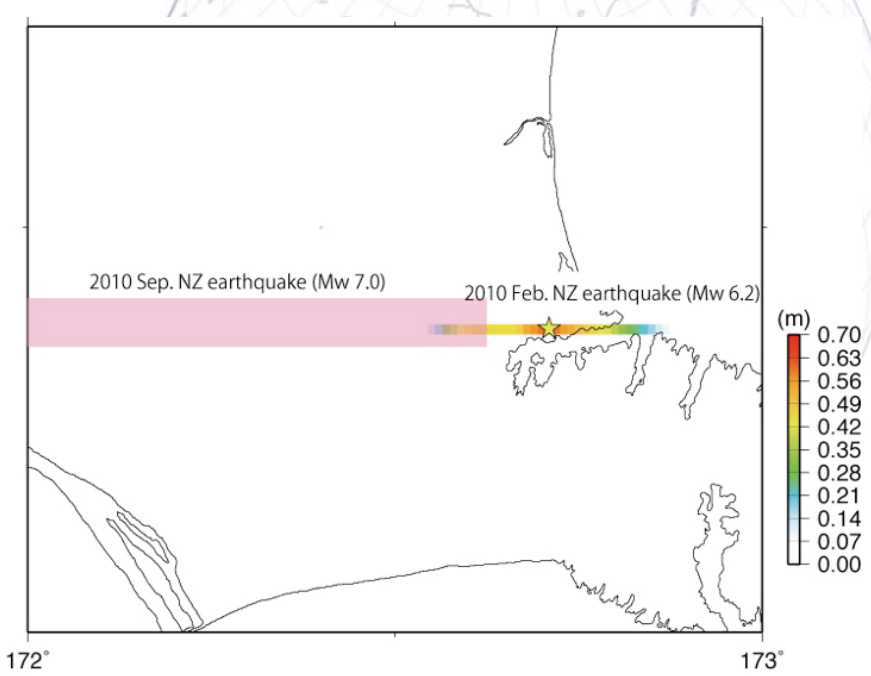


The 2010 Haiti earthquake occurred on unmapped fault whose strike is oblique to surface trace of the Enriquillo fault.

Feb. 21, 2011
New Zealand Earthquake



Destructive earthquake has struck Christchurch, New Zealand, on Feb. 21, 2010 (UTC).
Hypocenter of this earthquake was located in west side of seismic source area of the Sep. 3, 2010, Mw7.1 earthquake (by USGS).

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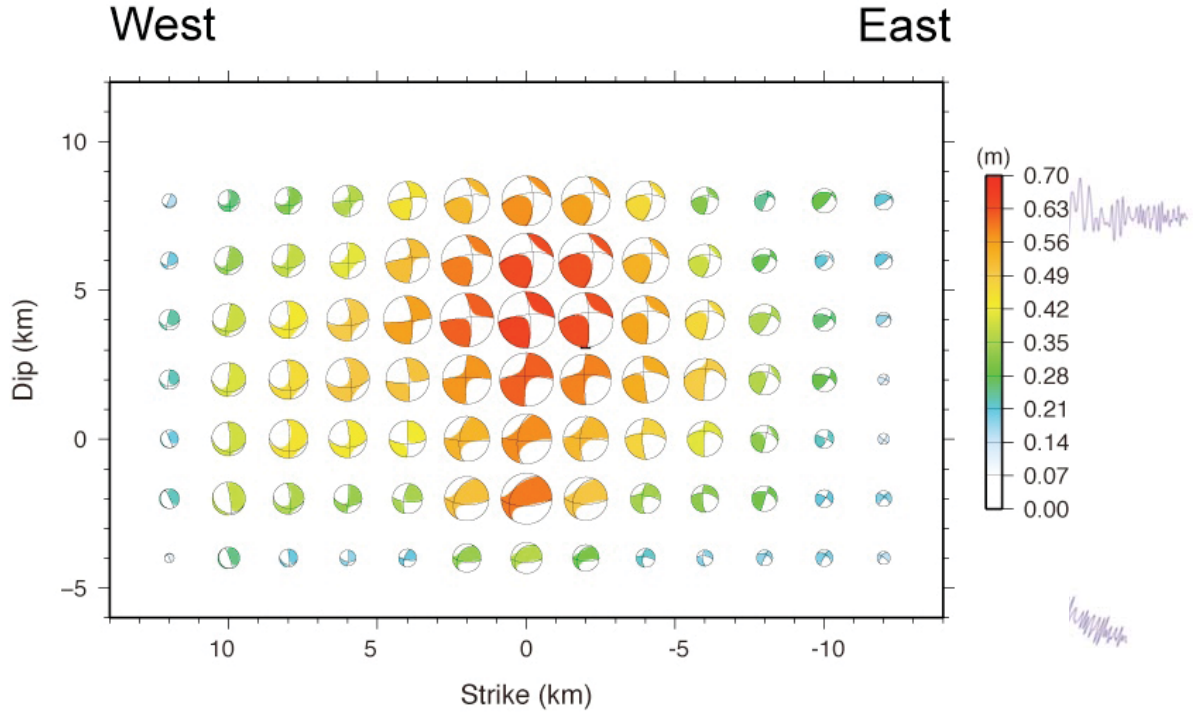
Focal Mechanism



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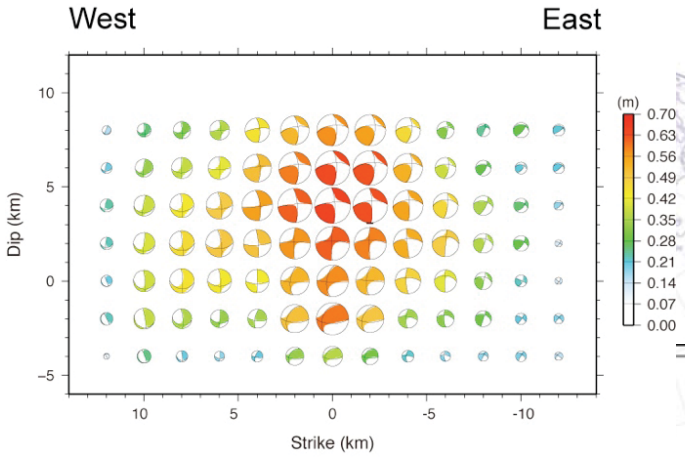
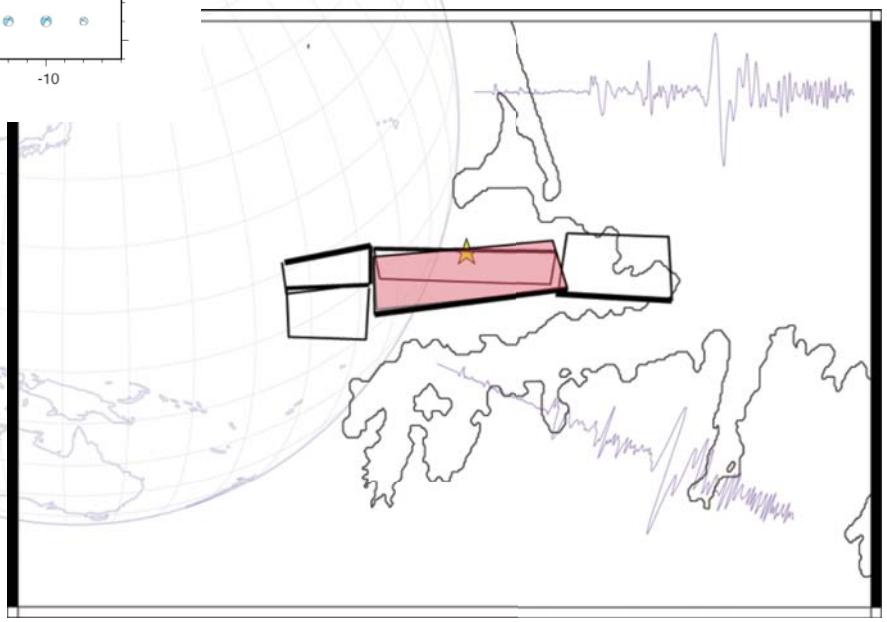
Interpretation





Sumarry

- We developed a waveform inversion method to estimate a spatio-temporal moment tensor distribution from teleseismic body wave (P-wave),
  - which is able to describe a complex seismic source model that reflects the complexity of seismic rupture process
- 2010 Haiti Earthquake
  - The 2010 Haiti earthquake ruptured three major rupture zones having different focal mechanisms.
  - The 2010 Haiti earthquake occurred on unmapped fault whose strike is oblique to surface trace of the Enriquillo fault.
  - The complex fault geometries controls rupture propagation manner.
- 2011 New Zealand Earthquake
  - Complex fault geometry
  - Rupture in shallow part and the complex rupture process might have increased high frequency components of strong ground motion, and hence damages.

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