Towards a unified and worldwide database of earthquake surface ruptures (SURE)

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

FDHA 2nd Meeting

December 8-9, 2016

Menlo Park, USGS

Stéphane Baize & the SURE Group

Questions posed by present-day « Surface Displacement hazard » practice

- PFDHA – Probabilistic Fault Displacement Hazard estimates are based on:

- A very limited number of data, representing a limited number of tectonic contexts
- Covering a limited range of magnitudes ➔ need to extrapolate when confronted with M<6.5 events
- Different datasets lead to different estimates of the probability of surface rupture : Japan vs USA
- Existing databases do not account for parameters that influence rupture (surface geology, structural complexity)
- New techniques allow the lowering of detection threshold of surface rupture during moderate earthquakes (e.g. M6 2014 Napa - USA, M6 2016 Yualara - Australia)

- Need for updated and unified database of surface rupture

- This objective also serves other approaches (deterministic A-P, scaling relationships, numerical modellers etc)

Paris, Oct 2015: the starting point of SURE dataset

- 1st Workshop: gather experts working in the topic and potentially interested to build a unified DB of surface ruptures.
- Workshop sponsored by IRSN

Objectives

- Present the available data stored in existing databases
- Propose a common database structure
- Elaborate a schedule and define actions

Framework

- INQUA Project + IAEA initiative: shared effort at international scale
- No funding; voluntary-based work

Wide range of seismotectonic contexts' geologists

Attendees from USA; Japan; Europe; South America; New Zealand; Continental Asia; with a large attendance of INQUA community:

- • Tim Dawson (CGS, USA)
- Jim McCalpin (Geo-Haz consulting, USA)
- Makoto Takao (TEPCO, Japan)
- Koji Okumura (U. Hiroshima, Japan)
- Luca Guerrieri (ISPRA, Italy)
- Francesca Cinti (INGV, Italy)
- Pilar Villamor (GNS, New Zealand)
- Carlos Costa (U. San Juan, Argentina)
- Richard Walker (NERC-COMET, UK)
- Yoshi Fukushima (IAEA)
- Stéphane Baize (IRSN, France)
- Oona Scotti (IRSN, France)
- Hervé Jomard (IRSN, France)
- Thomas Chartier (IRSN, France)
- Johann Champenois (CEA, France)
- Jochen Huertgen (University Aachen, Germany)
- Austin Elliott (NERC COMET, UK)
- Eugénie Pérouse (ENS, France)

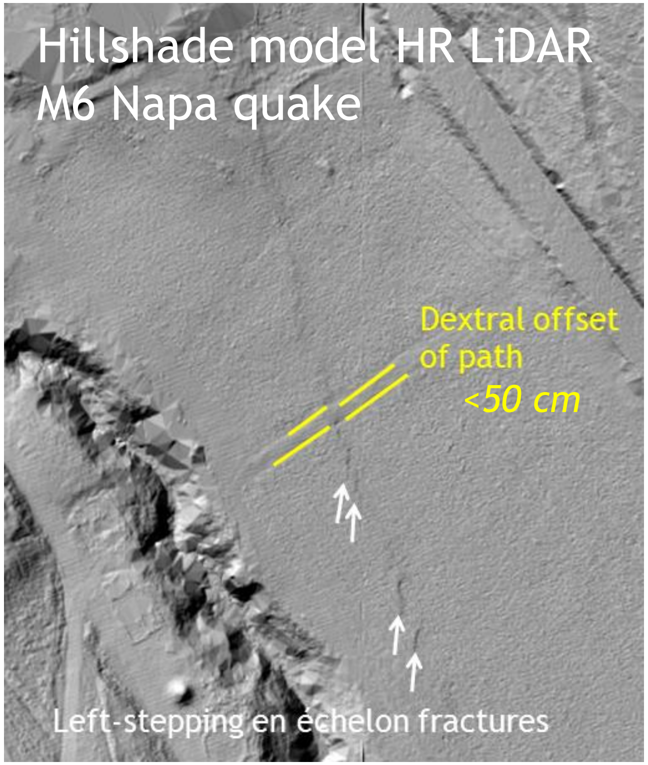
In 3 days, a common agreement was reached

- ❑ Existing data and databases will be implemented in a worldwide database
  - ✓ Japanese database (M. Takao) is ready;
  - ✓ USA databases (T. Dawson and J. McCalpin) need to be checked;
  - ✓ Needs to include other region datasets (Continental Asia, Middle East, New Zeland, etc)
  - ➔ A structure for the new database was agreed upon
    - ➔ Fault maps with primary and distributed ruptures
    - ➔ 3 tables with earthquake info, fault segment description, measurement points' table, including published references

- ❑ A statement: new technologies provide significant improvements for mapping surface ruptures
  - ➔ Enlarge the magnitude range (to low M) and the distributed deformation features
  - → Need to anticipate the incorporation of this type of high-precision data in the DB

Modern techniques

- LiDAR - SfM
  - Accurate elevation model
  - It may be not be available in many countries
  - It may be expensive
- Optical images correlation
  - Only lateral component and low resolution
  - Explore the historical cases
- InSAR
  - Continuously acquiring satellites
  - ALOS2 (low resolution; good penetration in canopy)
  - Sentinel1 (high resolution; low penetration)



Imaging covered regions

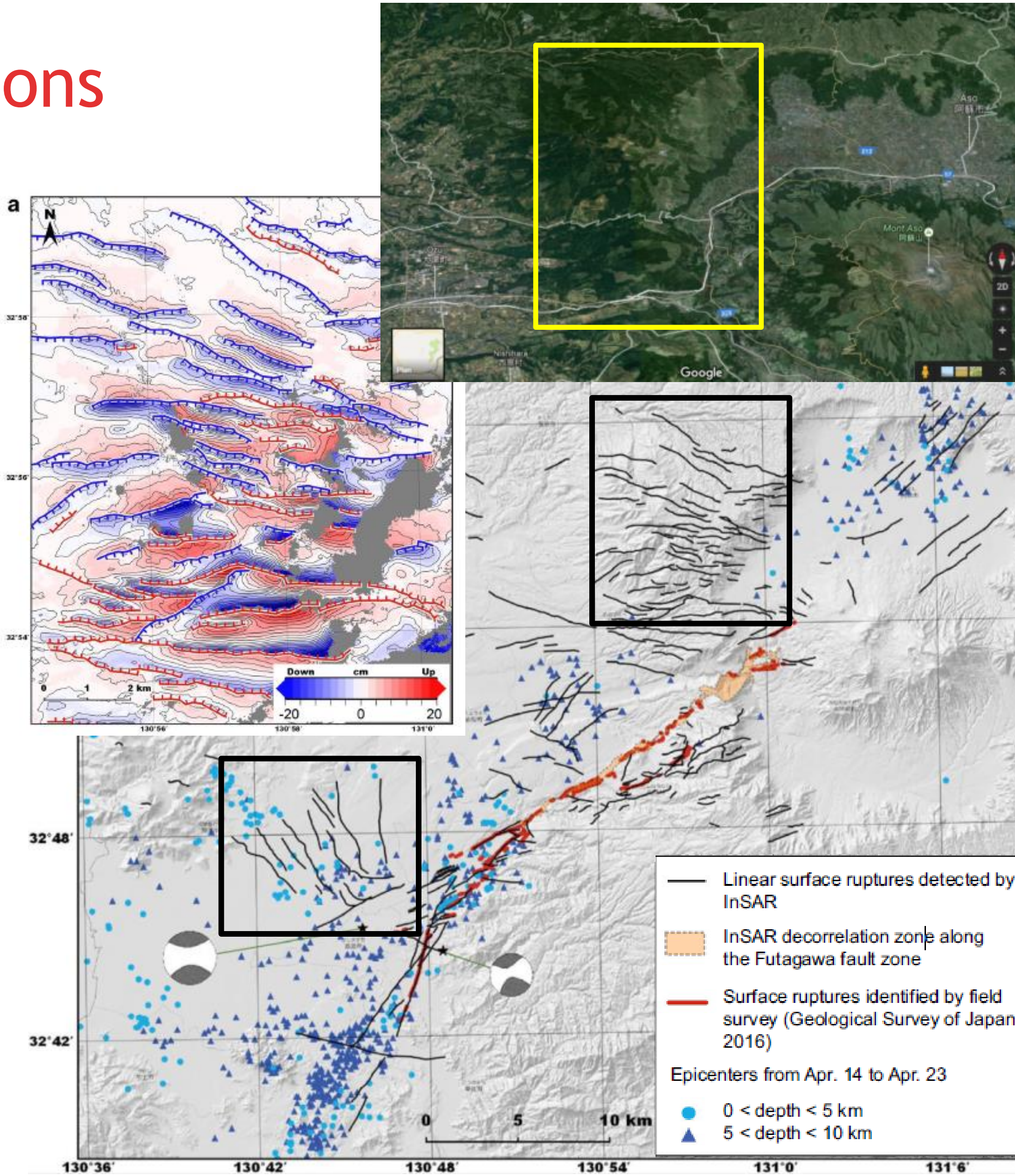
InSAR – ALOS2

- 16 pairs pre/post-quake
- Imaging densely covered regions

Large area with distributed deformation

- Mainly in « hanging wall » block, including Kumamoto city and Aso volcano caldera (offsets: 30 cm)

Fujiwara et al 2016



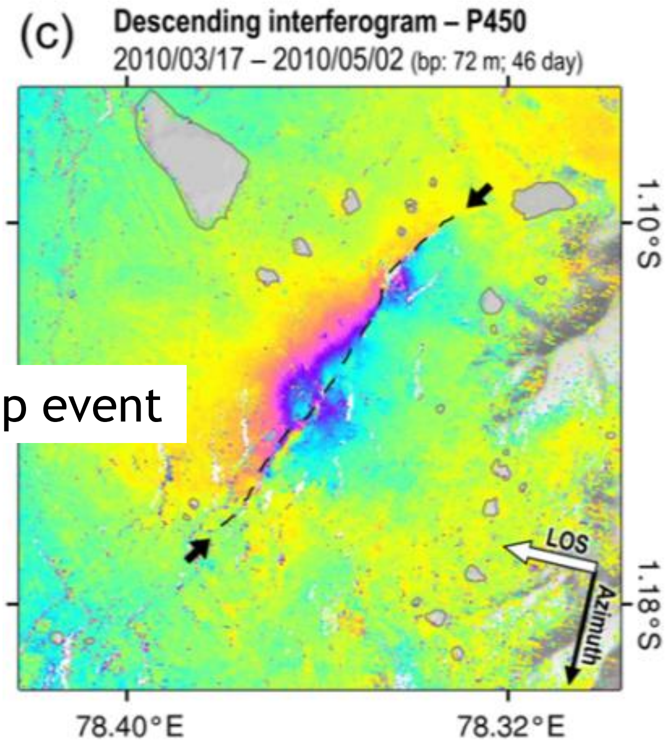
2013: InSAR analysis

Analyzing SAR data to retrieve interseismic loading on the Pallatanga fault over hundreds of km² led to…

Evidencing a shallow slip event along a 9 km long fault

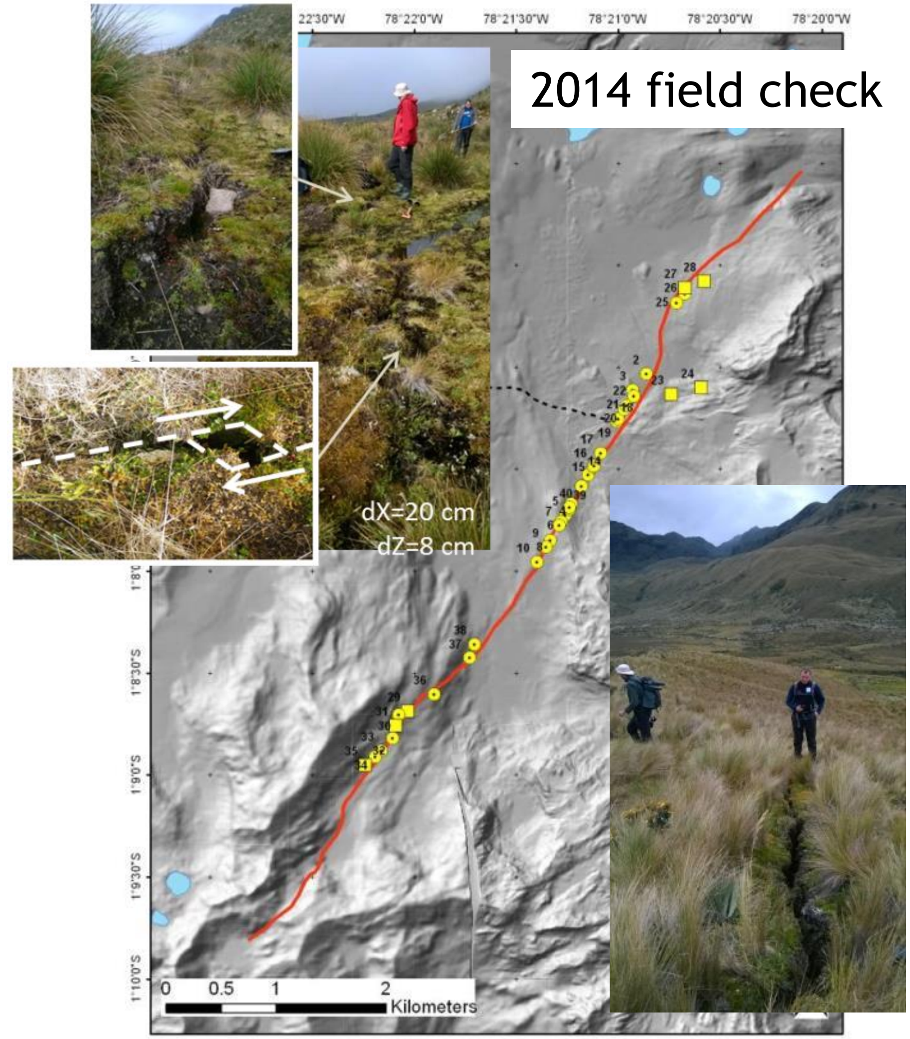
Mw5

2010 slip event

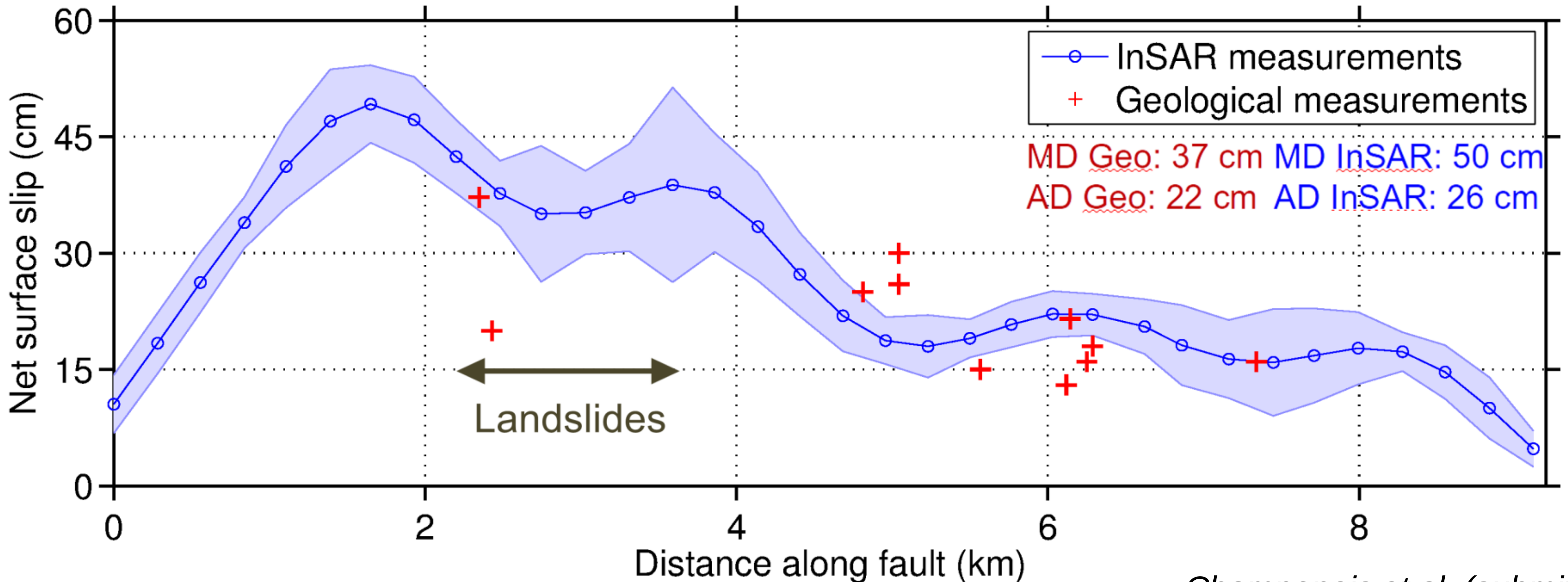


Champenois et al. (submitted)

2014 field check



Comparison Field - SAR



Champenois et al. (submitted)

- **InSAR measurements are in the field range of checked spots**
  - Could be used to complete the slip distribution, especially in remote areas like high mountain ranges

Significant parameters to account for

- Surface geology
- Structural complexity
- …

Surface Geology

- Stanton 2013 sandbox exp.
  - Test two lithologies
  - Test different stiffness
  - Test material state

Figure 44: 12.44 cm of basal displacement beneath loose virgin sand. The dotted line represents the rupture plane. The edges have been cropped for clarity.

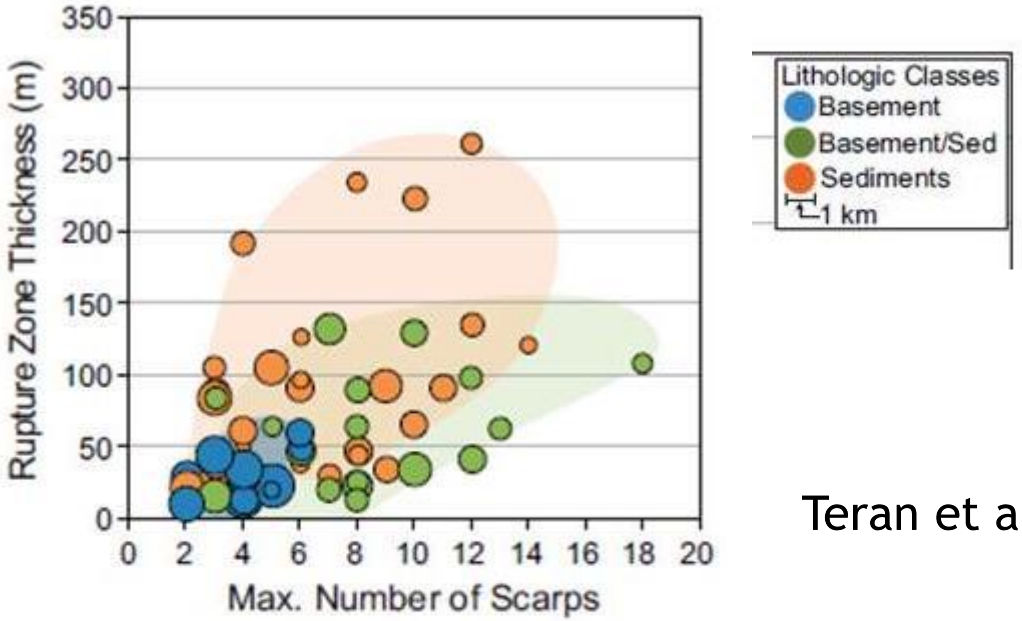
→ Displacement at depth to product surface displacement vary

Table 8: Basal displacement required for surface rupture given material type, relative stiffness, state and shear wave velocity

Run	Material Type	Relative Stiffness	Material State	Shear Wave Velocity (m/s)	Basal Displacement Required for Surface Rupture (cm)	*h/H*
1.0	Sand	Loose	Virgin	77.0	12.44	0.147
1.1	Sand	Loose	Disturbed	77.0	2.19	0.025
2.0	Sand	Dense	Virgin	101.4	4.01	0.047
2.1	Sand	Dense	Disturbed	101.4	0.50	0.0059
3.0	Clay	Stiff	Virgin	41.8	5.73	0.068
3.1	Clay	Stiff	Disturbed	41.8	1.15	0.014
4.0	Clay	Soft	Virgin	23.65	8.37	0.097
4.1	Clay	Soft	Disturbed	23.65	3.76	0.044

Surface Geology

- *M7.2 El Mayor Cucapah earthquake, Mexico, from Teran et al. 2015*
- Loose Quaternary sediments increase the distribution of surface faulting, in terms of distance to primary f and number of scarps



Teran et al. 2015

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Alluvium attenuate slip on distinctive rupture

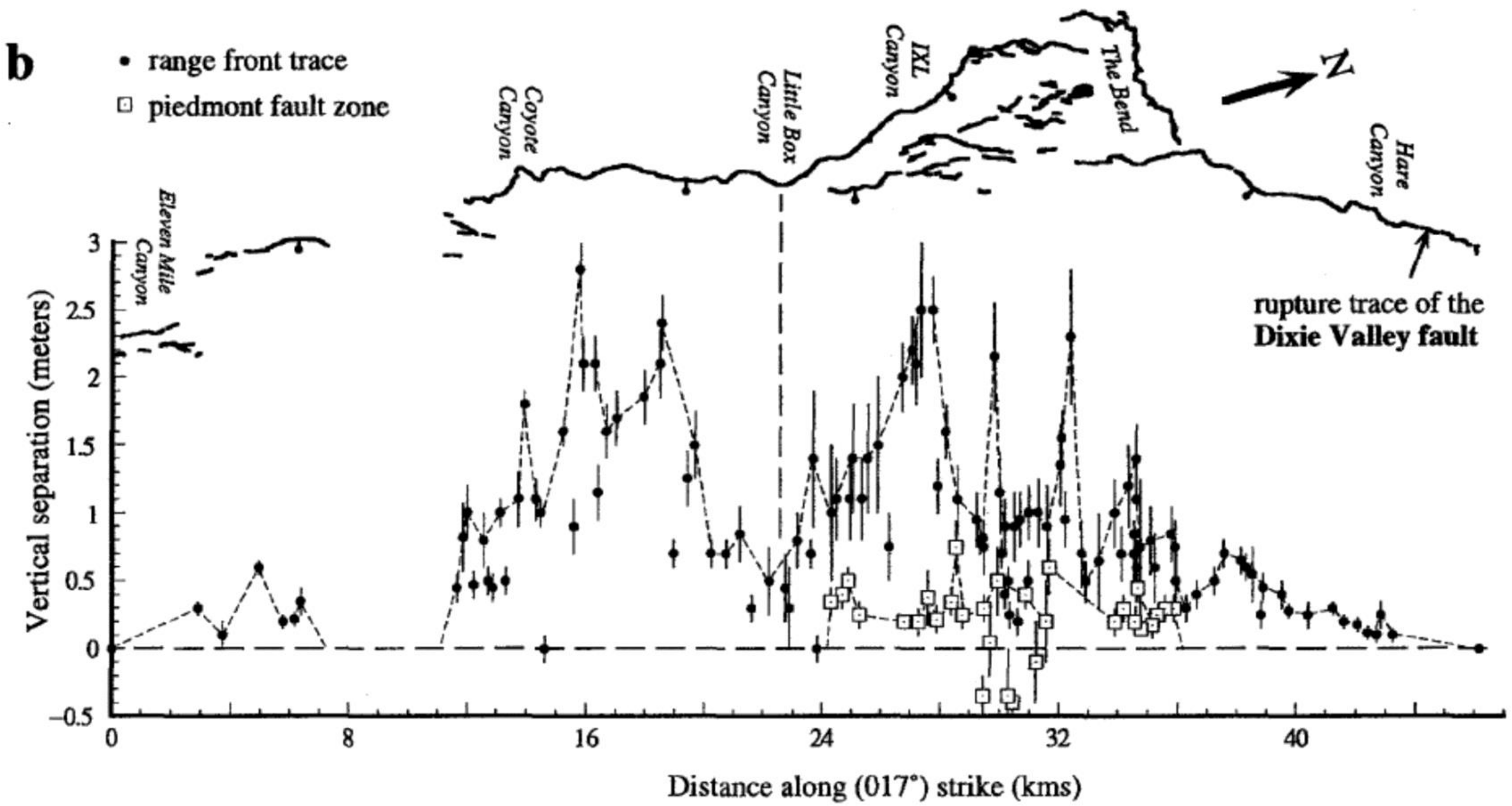
<u>M6.5 Norcia Earthquake, Italy</u>

Structural complexity

- Ruptures of 1954 Dixie Valley, Nevada from Caskey et al 1996 BSSA.

- Note most distributed faults occur in fault bend ("piedmont faults"), a stationary feature that will persist. Elsewhere distributed faults are rare

- Should be included in rupture description



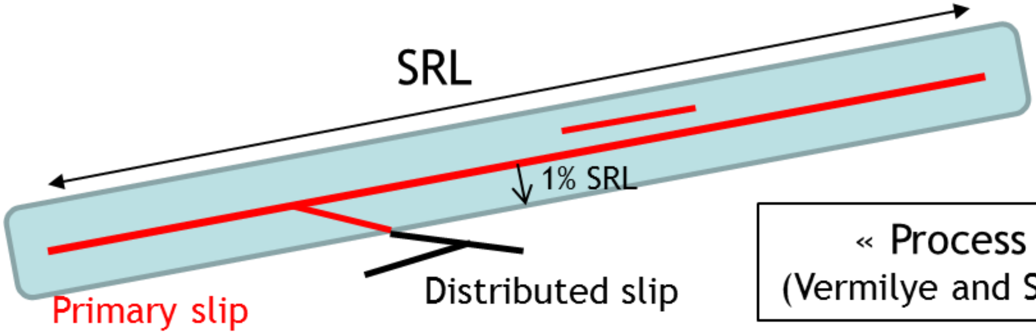
Significant decisions to be taken when database will be implemented

- Assignment of Primary / Distributed / Triggered character to slip observations
- Which Metrics (distances primary/distributed)
- …

Primary / Distributed / Triggered

Primary vs Distributed

- Model approach (Japan)



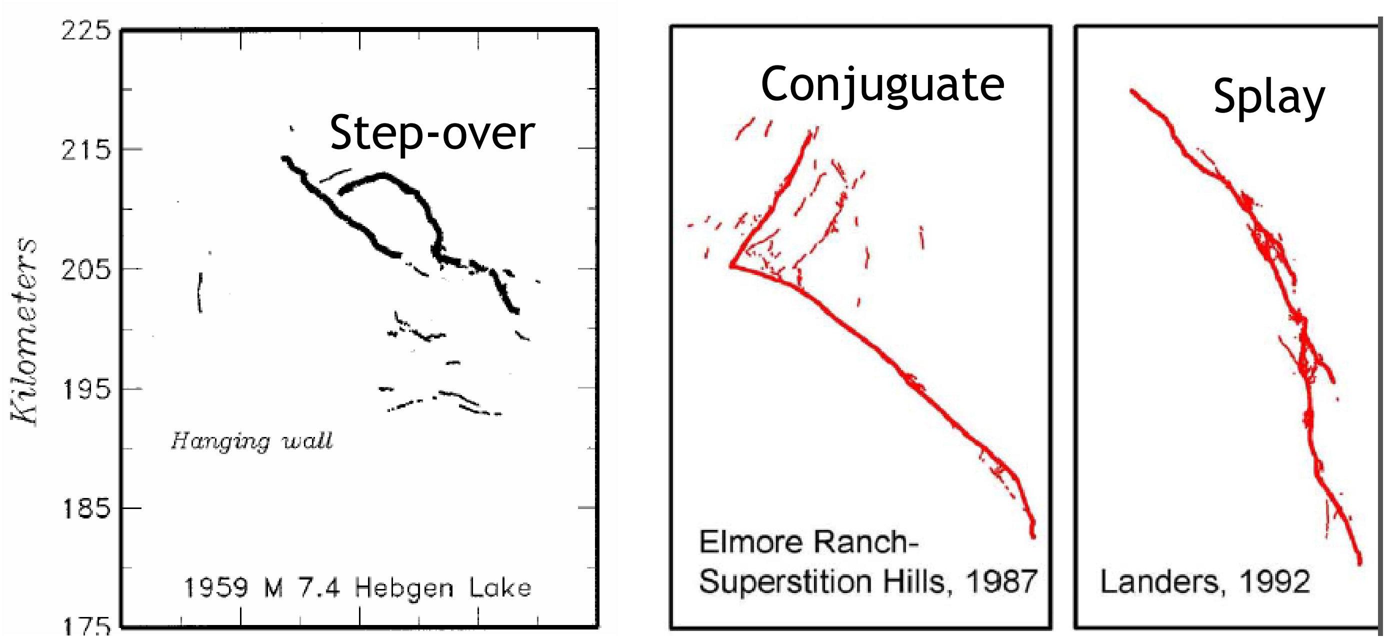
« Process Zone »
(Vermilye and Scholz, 1998)

Takao et al 2013

Primary, Distributed & Triggered

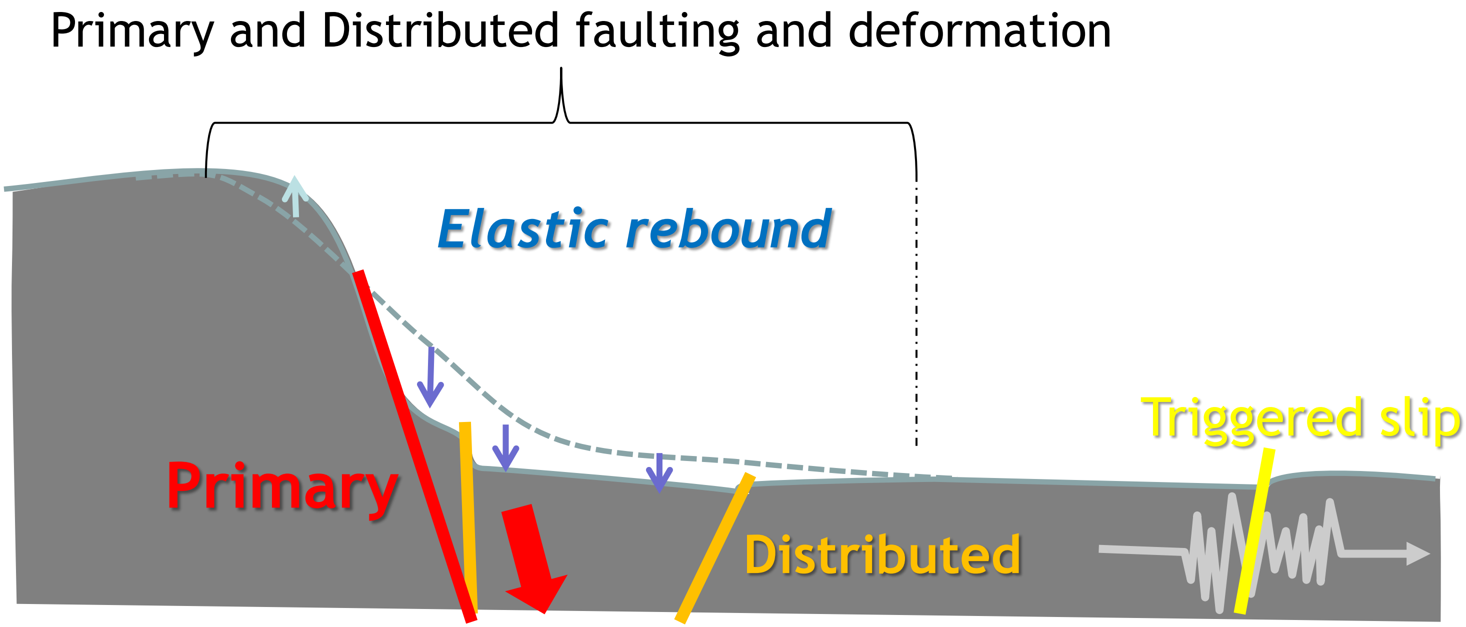
Primary vs Distributed

- Empirical approach (USA)
  - Primary: segment(s) w/ major displacement & length
  - Primary segments have structural relationship (splays, step-overs)



From Youngs et al. (2003) and Dawson (2015)

How to define triggered slip?



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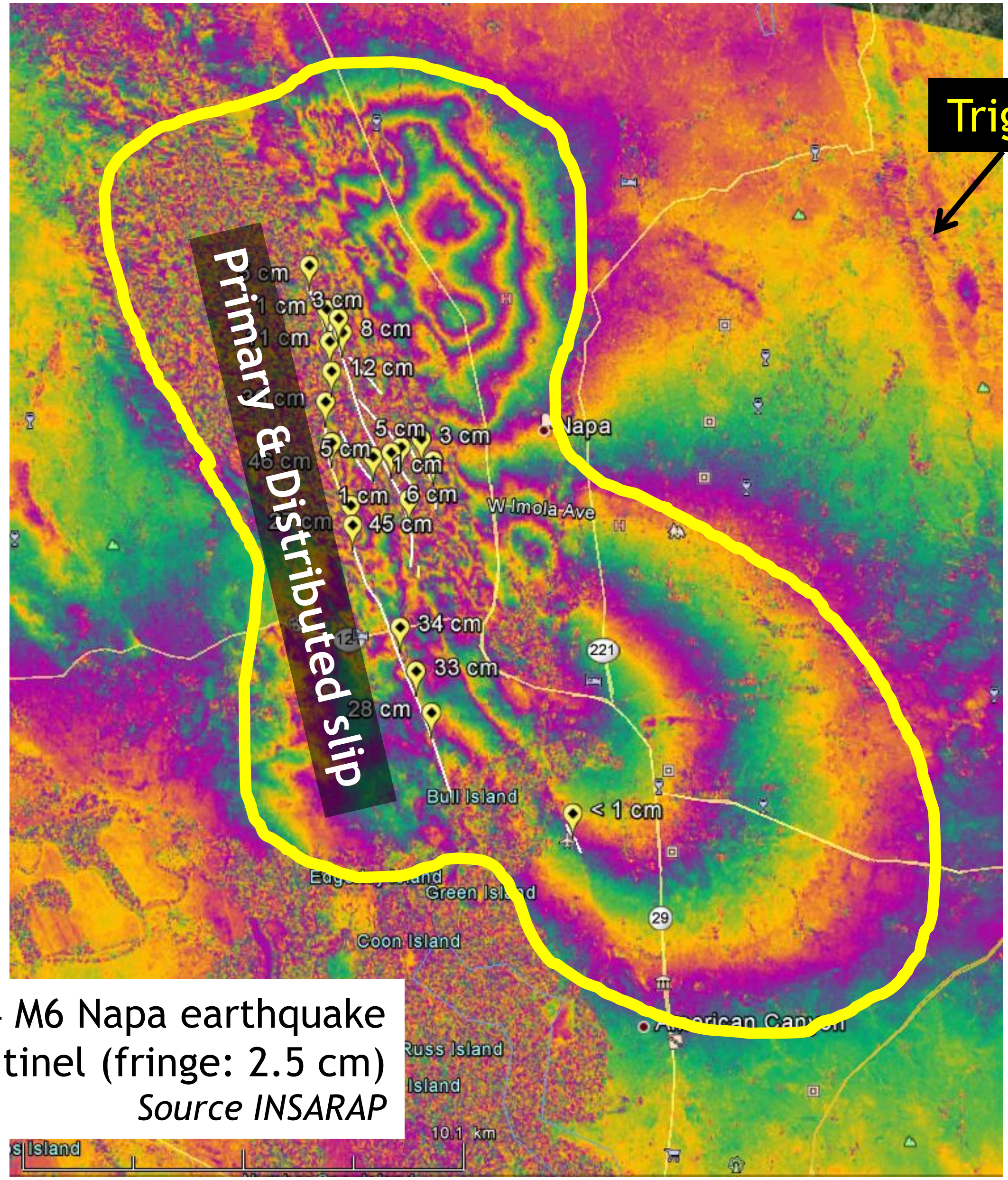
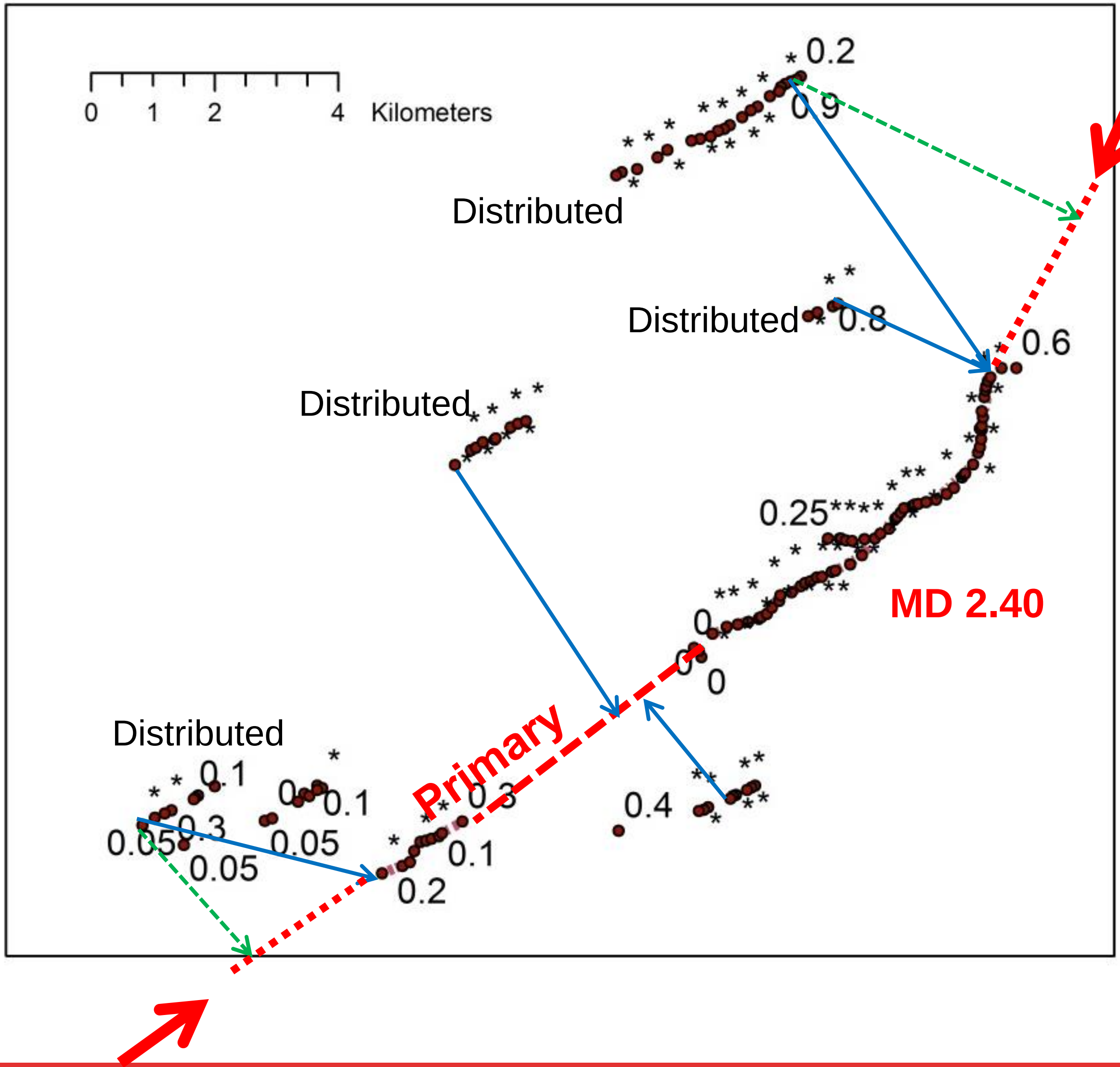
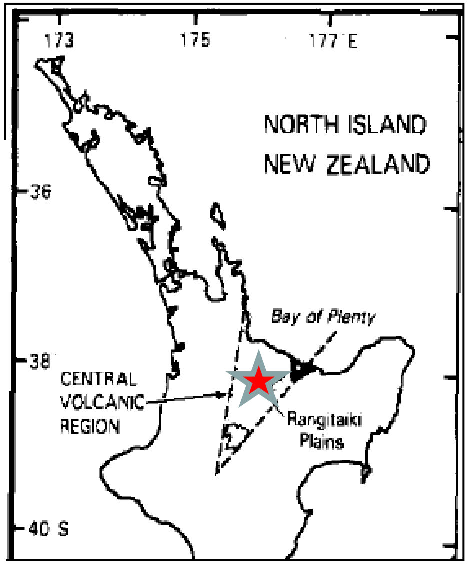


2014 M6 Napa earthquake
Sentinel (fringe: 2.5 cm)
Source INSARAP

Decision on Primary vs Distributed changes Distances

1987 M6.3 Edgecumbe
New Zealand





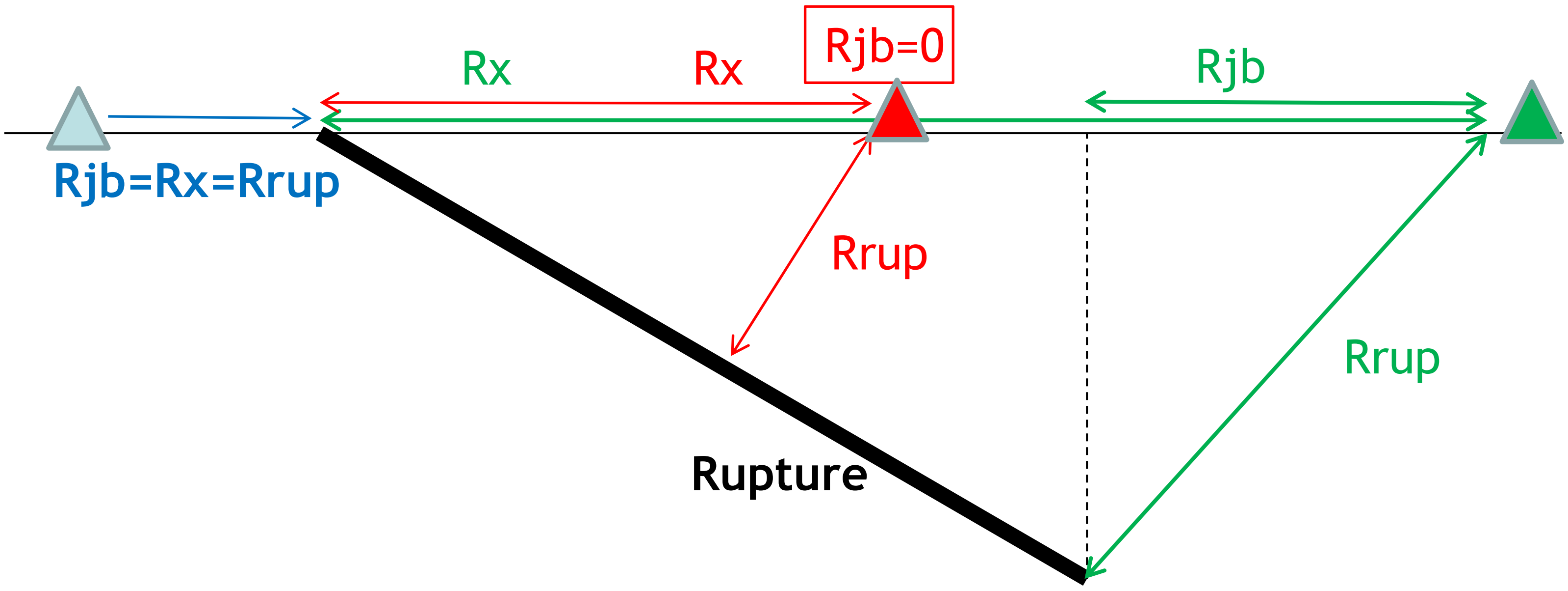
Option 1 of Shortest distance to Primary

Option 2 of Shortest distance to projection of Primary

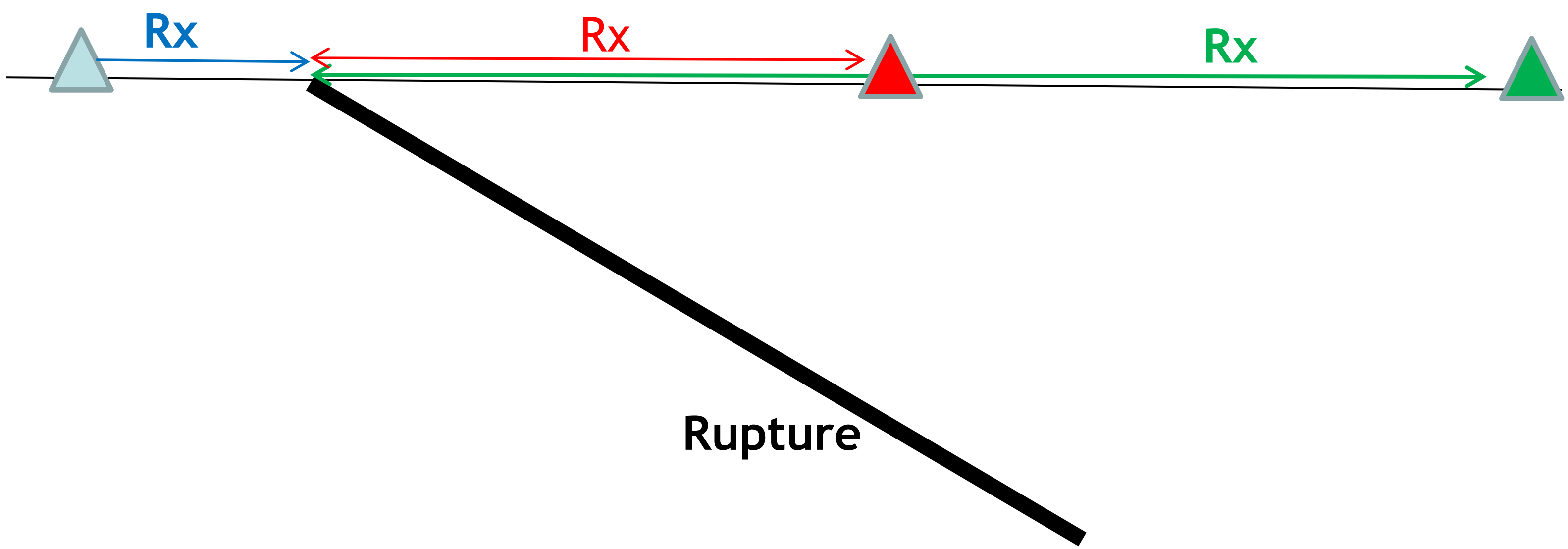
Data from Beanland et al 1989

Ground Motion Prediction Equations

Various distances are used

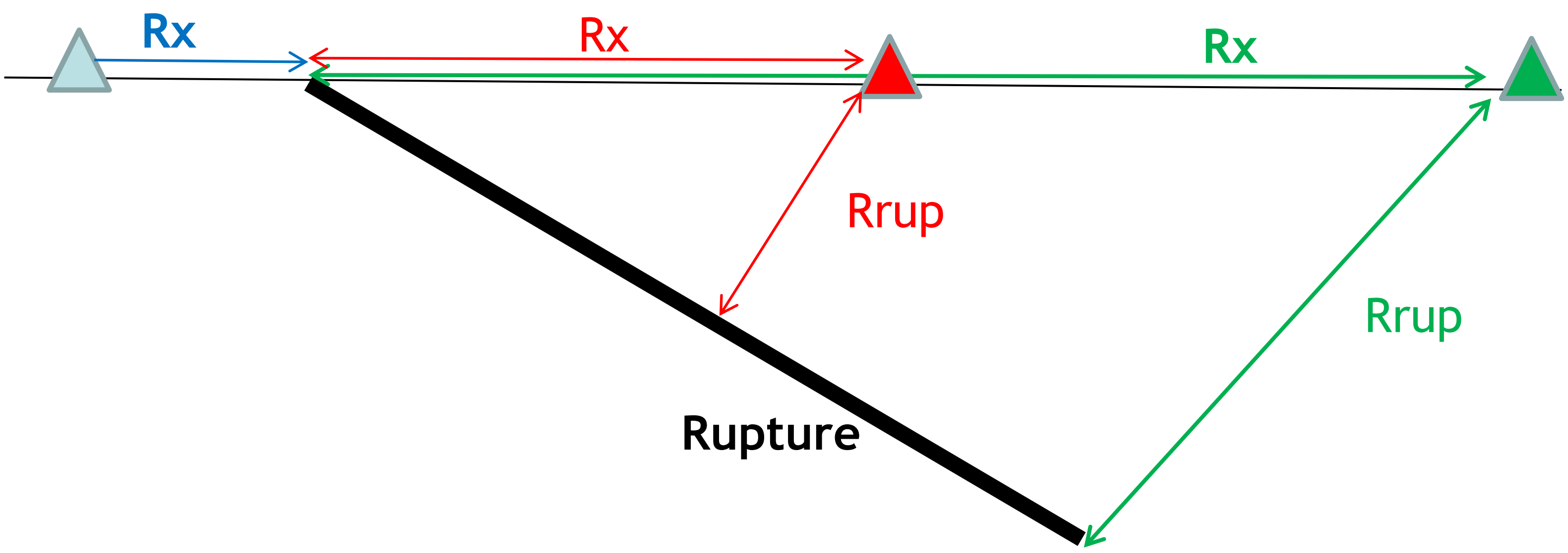


Surface faulting



Which metrics are the most relevant for Surface Faulting?

Question to discuss today



SURE status in 2016/12

- 2016 task after Paris Workshop
  - Each data holder implements case(s) according to the proposed template

- Cases to be implemented first: <u>we are progressing!</u>

  - 1944 San Juan and 1977 Caucete (Argentina), by C. Costa
  - 1987 Edgecumbe and 2010 Darfield (New Zealand), by P. Villamor
  - 1992 Landers, 1995 Kobé and 1999 Hector Mine (California), by T. Dawson
  - 1980 Irpinia, 1997 Colfiorito and 2009 L'Aquila (Italy), by F. Cinti and L.Guerrieri
  - 1968 Dasht-E-Bayaz and another case (Iran), by R. Walker and A. Elliott
  - 1995 Kobé and another case to be defined (Japon), by M. Takao
  - 2014 Nagano (Japan) and 1999 Koaceli (Turkey), by K. Okumura
  - 1959 Hebgen Lake and 1983 Borah Peak (Basin and Range), by J. McCalpin

SURE status in 2016/12

Johann Champenois started in October (IRSN-IPGP, Y. Klinger)
→ SURE implementation & optical correlation to capture deformation

Historical cases

- M6.9 1995 Kobe
  - Fault segments; >300 obs. points (P+D)
- M7.0 1944 La Laja
  - 1 observation point (D)

Work in Progress

- M6.3 2009 L'Aquila
  - >1000 obs. points (P+D+other) and no segment information; additional info to be formatted
- M6.3 1987 Edgecumbe
  - 146 obs. points (P+D) and 2 primary segments; no additional info
- M7.1 1959 Hebgen Lake
  - 62 obs. points (P) and P+D segments; no additional info
- M6.9 1983 Borah Peak
  - 93 obs. points (P+D) and P+D segments; no additional info

Modern cases: List of post-2000 earthquakes

- To update the existing databases w/ recent events that can potentially be (have been) observed w/ modern techniques

- Jim McCalpin (2016) performed this first search in the USGS earthquake database
  - 130 shallow M6+ epicenters onshore between 2000 and 2016
  - Most occurred in China (21), Iran (13), Japan (8), Russia (8), Pakistan (7), Turkey (7), New Zealand (6), Kyrgyzstan (5), USA (5), Chile (5), Nepal (5), Myanmar (4).
  - Very few have surface rupture information reported in literature and there is a need for regional geologists' participation.

- Solicitation of "regional geologists" is one major task of the SURE working group in the next years.

Final remarks

- **Project started as a shared effort**, to rely on the entire community:
  - IAEA and INQUA groups;
- **2016 Menlo Park Meeting is a unique opportunity**
  - To open to other contributors;
  - To discuss the structure and other topics (metrics, primary vs distributed);
- **Implementing SURE** will be time-consuming and might **require sponsorship**:
  - Who? Where? How?
- **SURE, a free, homogenous and downloadable database,**
  - To date, based on published data;
  - Appropriate platform for this will also have to be set up;