Examining the focal mechanism of the 2009 Samoa Earthquakes by means of Tsunami Observation and Simulation

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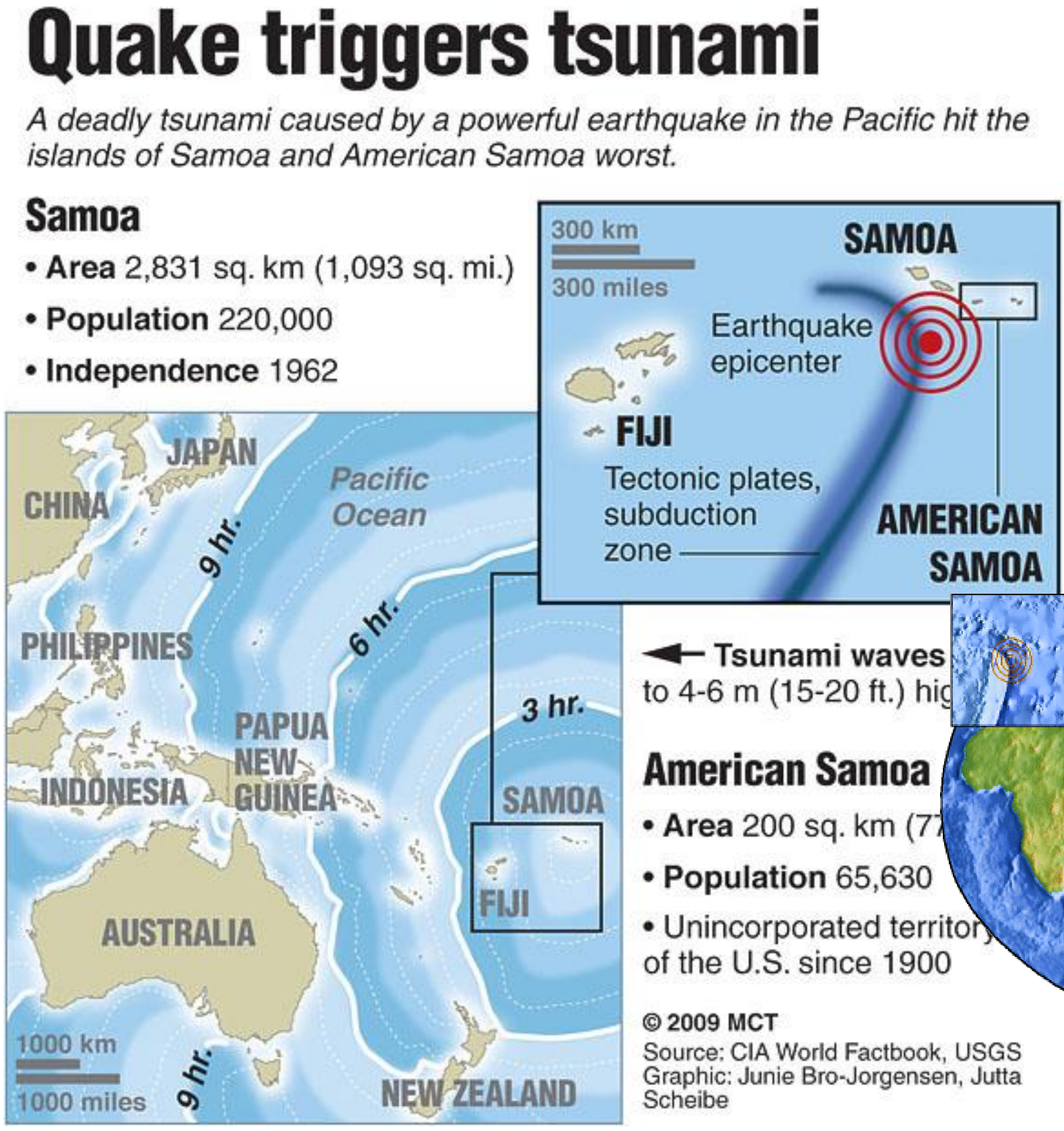
2009 Samoa Earthquake, a doublet or even a triplet

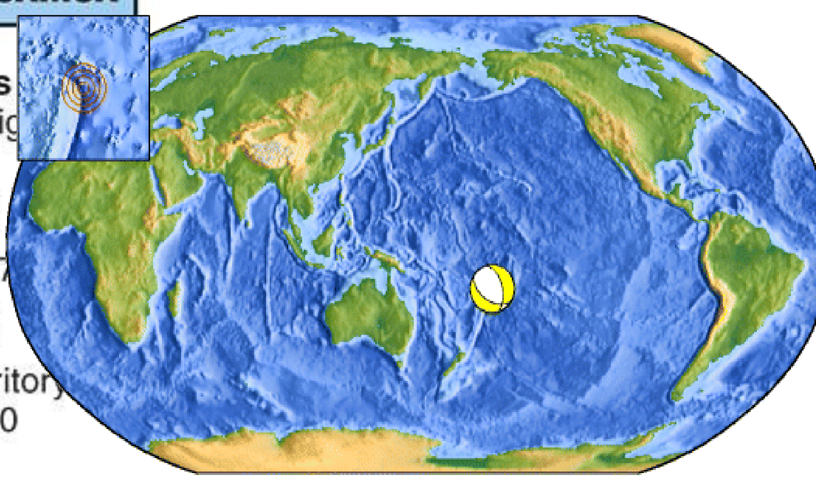


Tonga subduction zone

- large convergent rate
- few large interpolate earthquakes

USGS preliminary solution: an outer-rise normal fault Mw 8.1

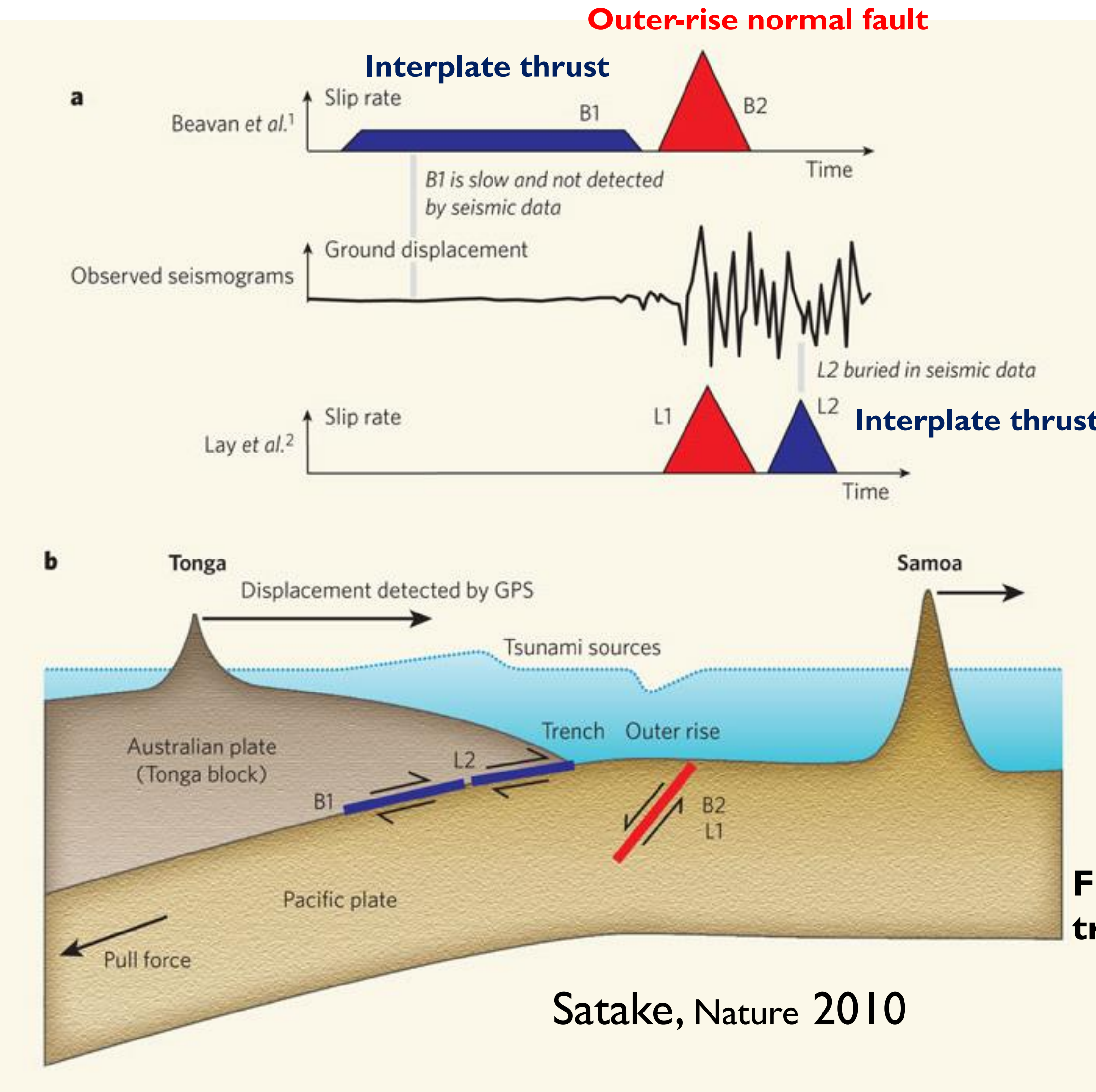
SAMOA ISLANDS REGION
Mw 8.0
USGS Centroid Moment Tensor Solution



Date: 29 SEP 2009
Time: 17:48:10.57
Epicenter: -15.418 -172.005
Depth: 10 km

Debate for the seismic triggering in subduction zone

2009/09/29 17:48:10 UTC Magnitude: M_w 8.1



Satake, Nature 2010

What/how about the interplate thrusting?

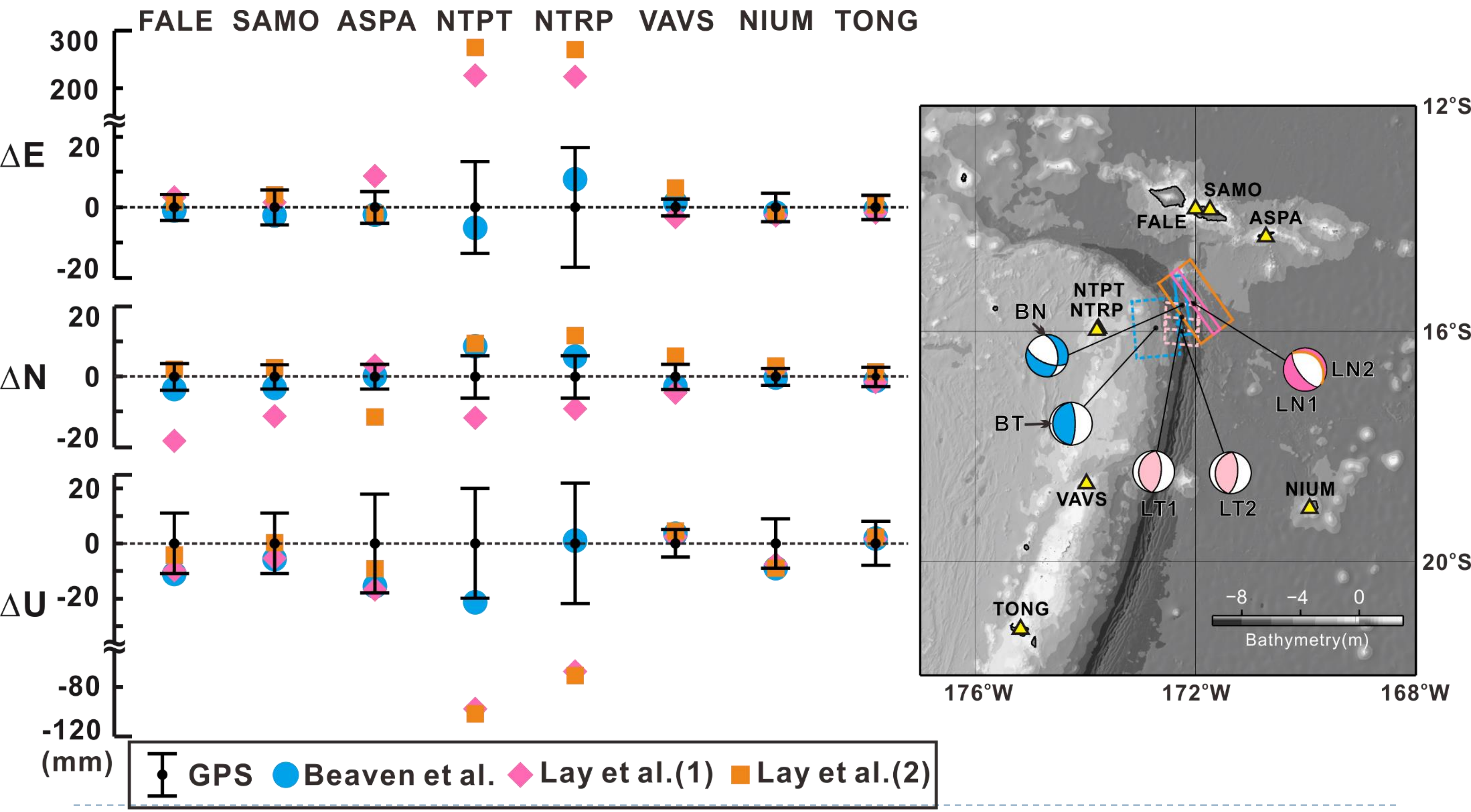
Beaven et al., (B) , Nature 2010
GPS dislocation modelling
tsunami-wave simulation

Lay et al. (L), Nature 2010
teleseismic waveform simulation

come to different conclusion about the seismic sources /stress transfer

Figure 1 | interpretations of the two Tonga-trench earthquakes of 29 September 2009.

Coseismic motions recorded at daily GPS time series
- observations vs modellings from two seismic models



Our strategy : studying the nearby tsunami waveforms

The tsunami wave simulation is taken to,

(1) examine the seismic models which are provided by Beaven et al and Lay et al.

(2) verify which is the exact fault planes acting in the 2009 Samoa earthquake.

(3) discuss the occurrence orders of the interplate thrust and the outer-rise normal fault, which relates to different scenarios of tectonic stress transferring.

Tsunami-wave Simulation

Used package: COMCOT (*Liu, P. L.-F. et al.*, 1998)

Governing Equation: shallow water equation (SWE) in spherical coordinates.

Numerical Scheme: An explicit Leap-frog Finite Differencing Method (FDM) is adopted in COMCOT to solve Shallow Water Equations.

$$\frac{\partial P}{\partial t}+\frac{1}{R\cos\varphi}\frac{\partial}{\partial\psi}\left(\frac{P^2}{H}\right)+\frac{1}{R}\frac{\partial}{\partial\varphi}\left(\frac{PQ}{H}\right)+\frac{gH}{R\cos\varphi}\frac{\partial\zeta}{\partial\psi}-fQ+\tau_x H=0 \qquad \tau_x=\frac{gn^2}{H^{10/3}}P\left(P^2+Q^2\right)^{1/2}$$

$$\frac{\partial Q}{\partial t}+\frac{1}{R\cos\varphi}\frac{\partial}{\partial\psi}\left(\frac{PQ}{H}\right)+\frac{1}{R}\frac{\partial}{\partial\varphi}\left(\frac{Q^2}{H}\right)+\frac{gH}{R}\frac{\partial\zeta}{\partial\varphi}+fQ+\tau_y H=0 \qquad \tau_y=\frac{gn^2}{H^{10/3}}Q\left(P^2+Q^2\right)^{1/2}$$

$$\frac{\partial\zeta}{\partial t}+\frac{1}{R\cos\varphi}\left[\frac{\partial P}{\partial\psi}+\frac{\partial}{\partial\varphi}\left(\cos\varphi Q\right)\right]=-\frac{\partial h}{\partial t}$$

P, *Q* are the volume fluxes in X (East-West) and Y (North-South) direction, respectively

g: the gravitational acceleration

ζ: the free surface elevation in meters

H: the total water depth; including *h* (water depth), and ζ (wave height) meters

ψ , φ: longitude and latitude of the Earth

n: Manning's relative roughness coefficient; an empirical constant depending on the fluid and material of the ground

R: the radius of the Earth

f: the Coriolis force coefficient due to the rotation of the Earth

COMCOT website http://ceeserver.cee.cornell.edu/pll-group/comcot.htm

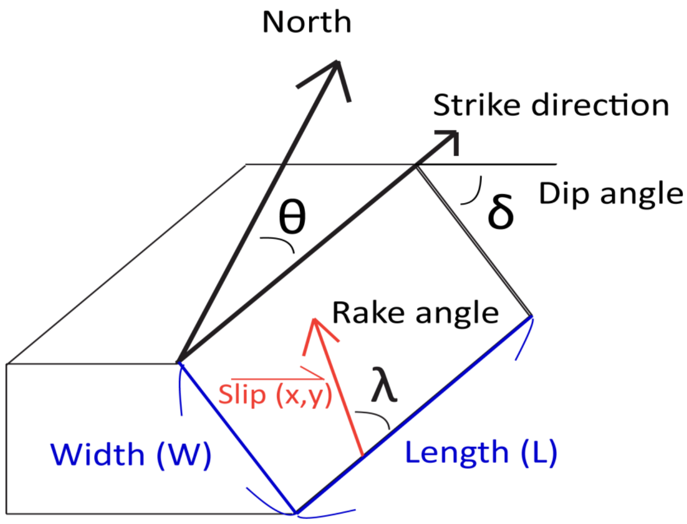
Tsunami-wave Simulation

Initial condition of tsunami waves

- the sea surface run-up corresponding to the seismic rupture

converted from the half-space coseismic dislocation modeling

Wang et al, PSGRN/PSCMP, 2006
viscoelastic-gravitational dislocation theory



Parameters – fault plane solution

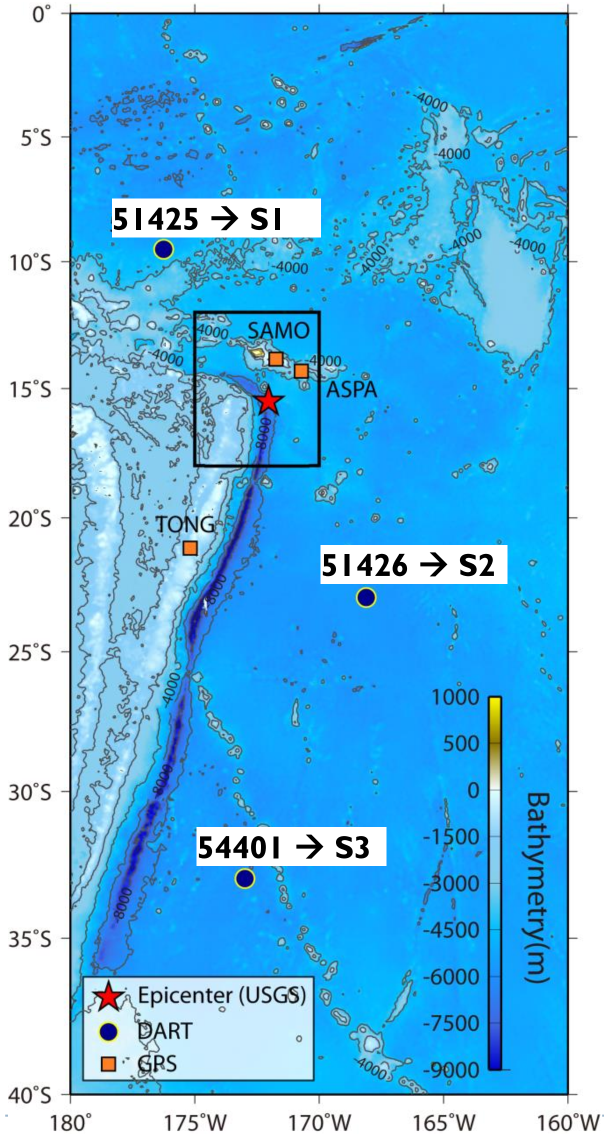
- hypocenter (longitude, latitude, and depth)
- Fault Geometry & rupture dimension

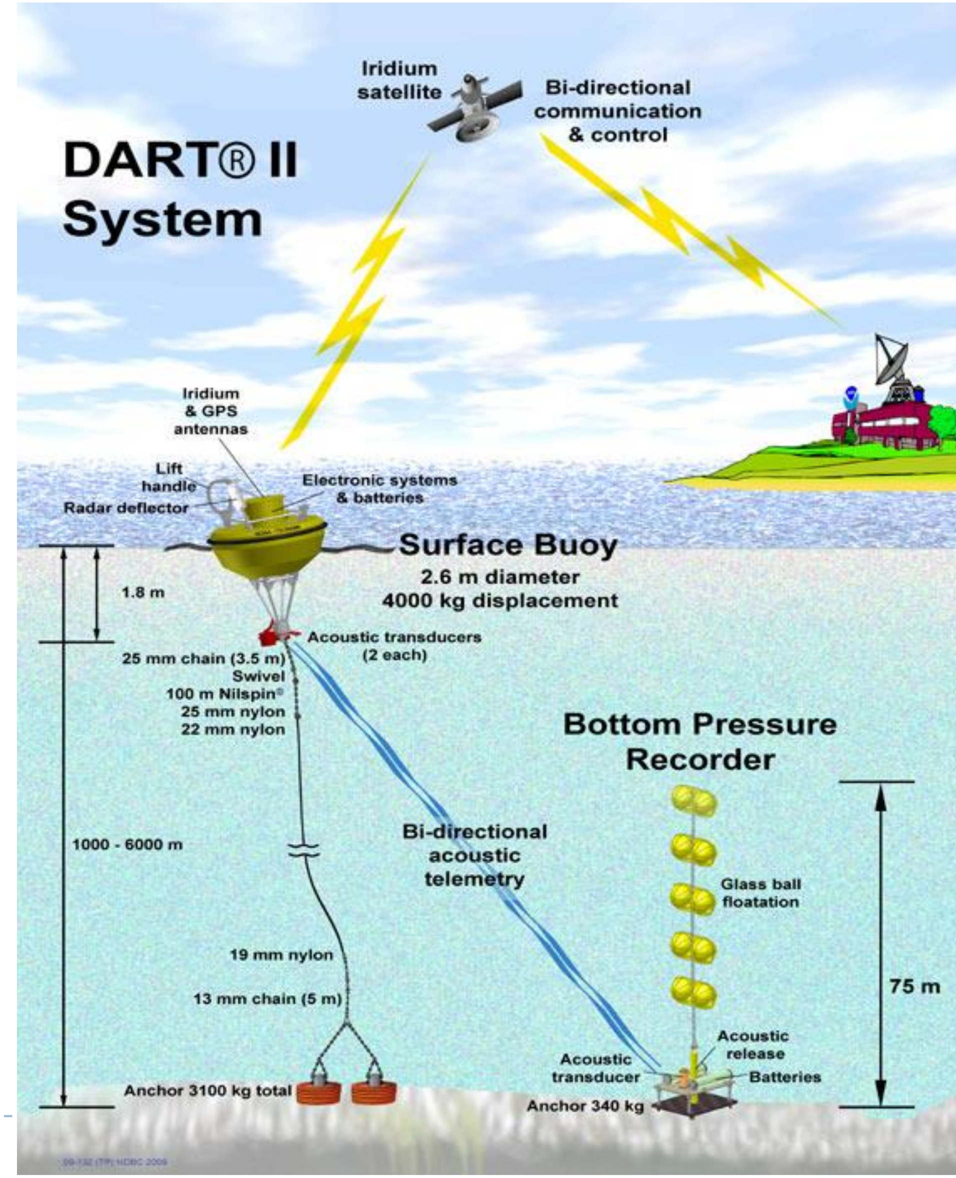
  (strike, dip and rake), (length, width, slip)
- Time of Rupture

$$u_i = \int_{\Sigma} \Delta u_j \left[\lambda \delta_{jk} \frac{\partial u_i^j}{\partial \xi_k} + \mu \left(\frac{\partial u_i^j}{\partial \xi_k} + \frac{\partial u_i^i}{\partial \xi j} \right) \right] \nu_k dS$$

Observations of Tsunamis, DART

Deep-ocean Assessment and Reporting of **Tsunami,** NOAA/NTHMP





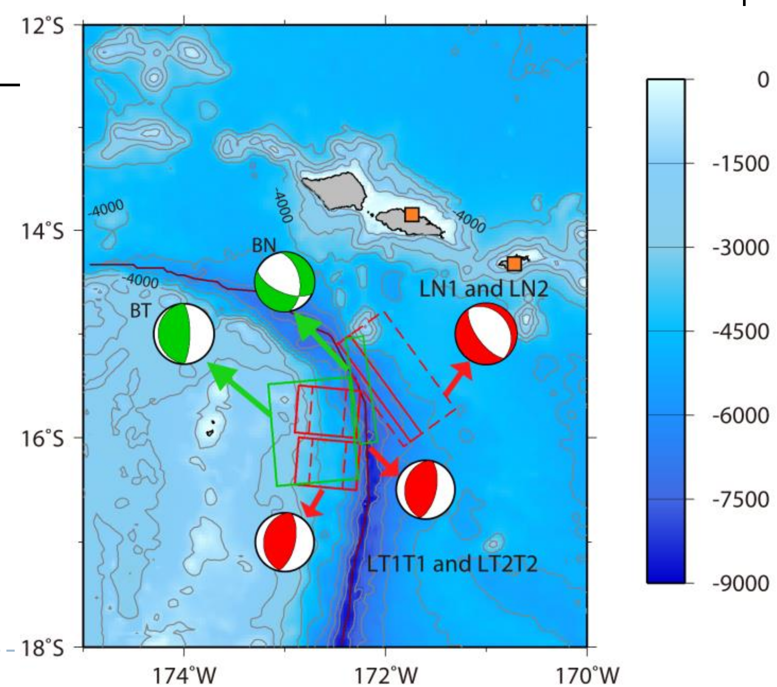
NOAA, National Data Buoy Center

Two seismic models for tsunami simulation

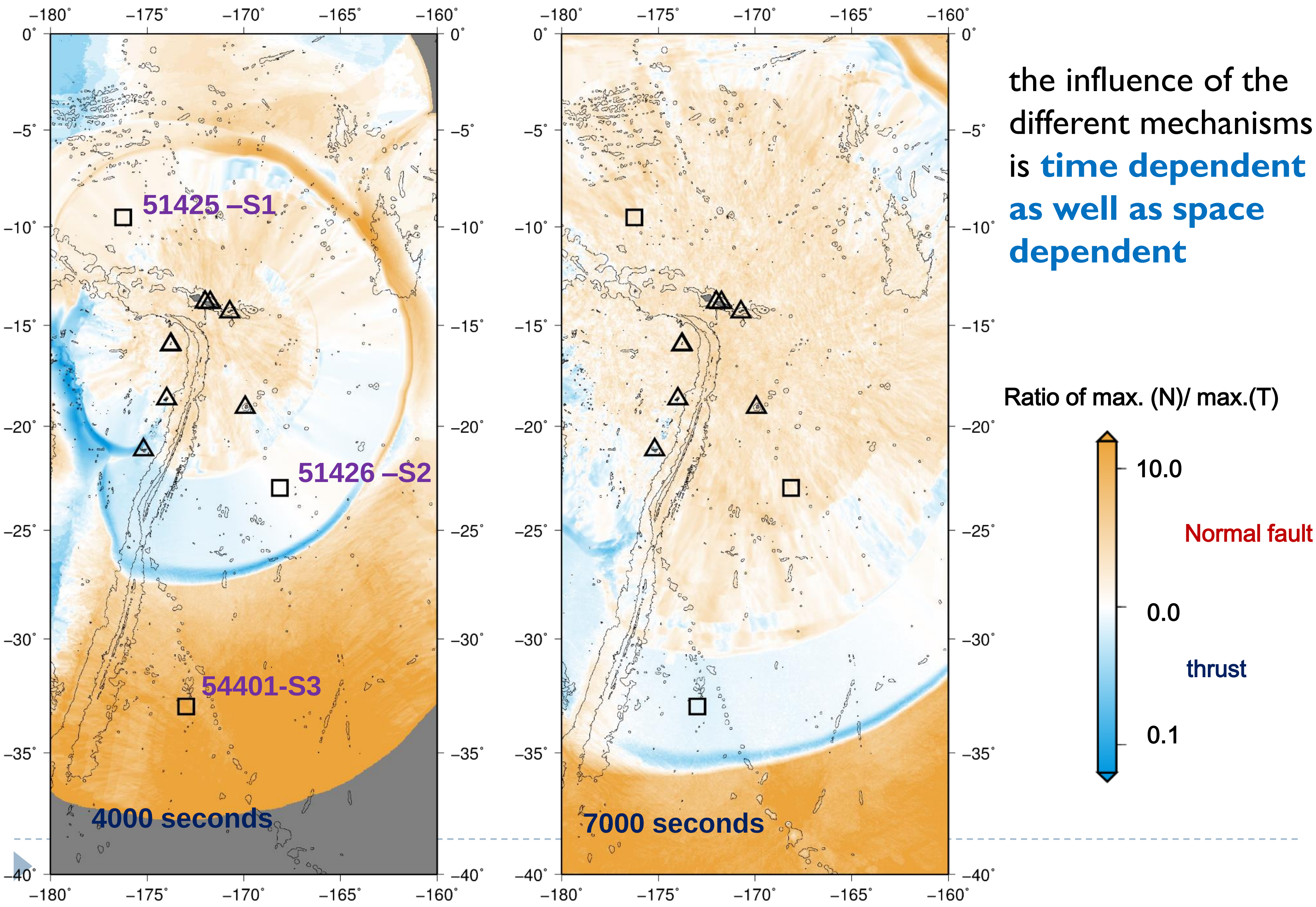
Beaven et. al (2010)			Lay et. al (2010)			
Parameter\Event	BT	BN	LN1	LN2	LT1T1	LT2T2
Longitude	-172.72°	-172.24°	**	**	-172.575°	-172.575°
Latitude	-15.94°	-15.54°	**	**	-15.75° and -16.25°	-15.75° and -16.25°
Focal Depth	18	13	18	18	18 and 18	18 and 18
Strike/Dip/Rake	173°/16°/75°	351°/53°/-32°	144°/65°/*	324°/25°/*	185°/29°/90°	5°/61°/90°
Length/Width (km)	109/90	114/28	3/5/*	3/5/*	50/75	50/75
Slip (m)	4.1	8.6	**	**	4.6 and 4.7	4.6 and 4.7
Occurrence Time*(second)	0	105	70.5	70.5	119.5 and 160.5	119.5 and 160.5

*This is referenced to the mainshock's origin time: 2009-09-29 17:46:59.5
**Each of the patches (subfaults) has varied centers, rakes and slips.

1. The two nodal planes of the normal-fault mechanism solutions are labeled as LN1 and LN2, same for the thrust events labels LT1T1 and LT2T2. LT2 fault plane parameter is conducted from the reported LT1.
2. In Lay et al (2011, personal communication), the two interplate thrusts exhibit the same geometry (strike, dip, rake, and magnitude) but take place separately at different hypocentral locations in a time gap of ~40 sec (the first and second thrusts occur 49 and 90 after the normal fault).

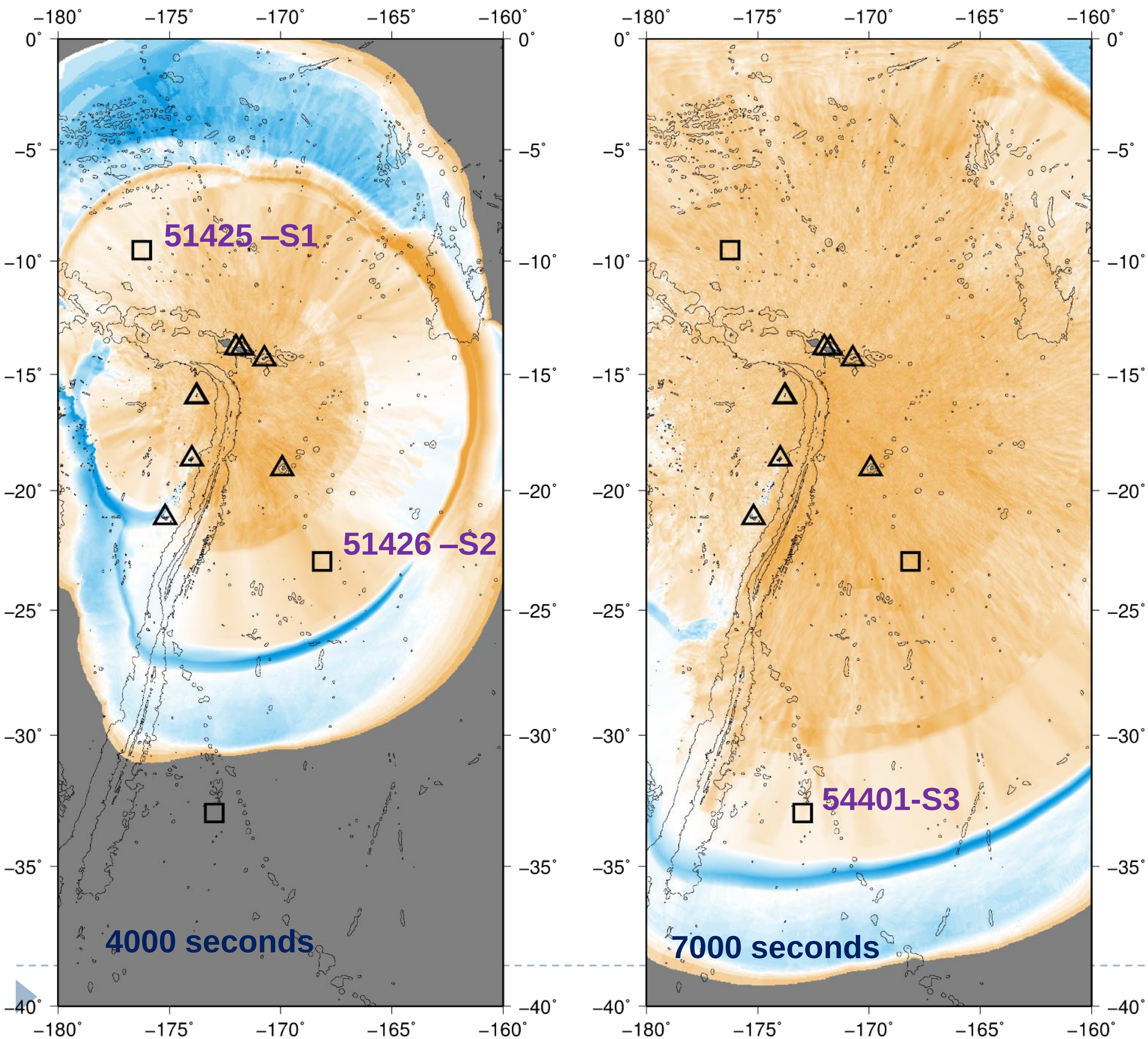


Spatial distribution of domination of the varied mechanisms - modelling from Beaven et al



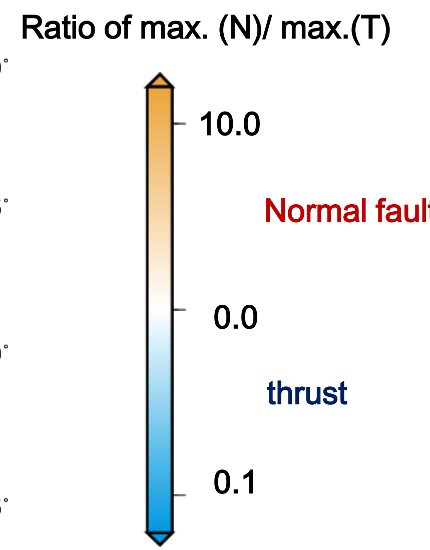
the influence of the different mechanisms is **time dependent as well as space dependent**

Spatial distribution of domination of the varied mechanisms - modelling from Lay et al, LN1

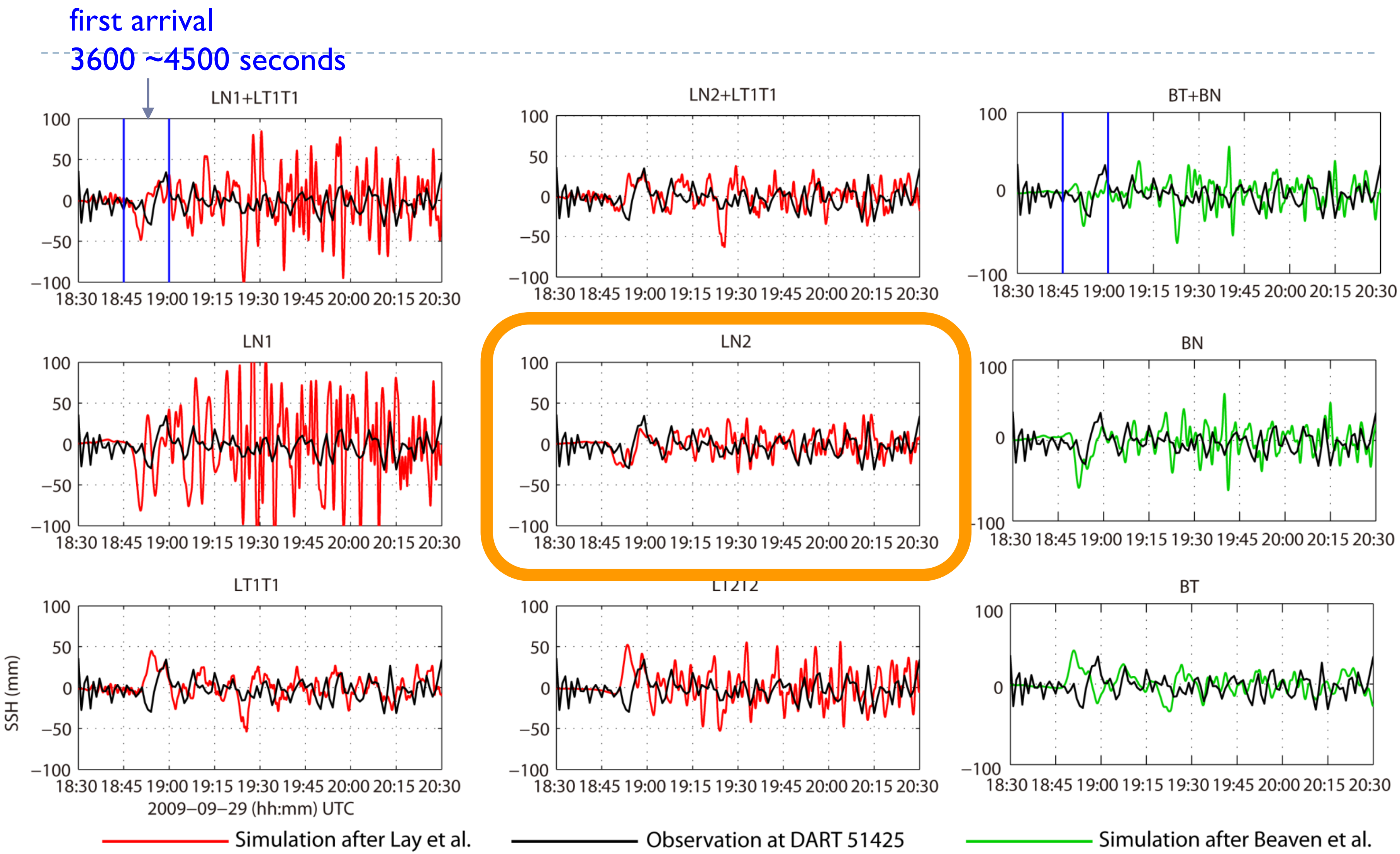


the influence of the different mechanisms is **time dependent as well as space dependent**

strong normal fault

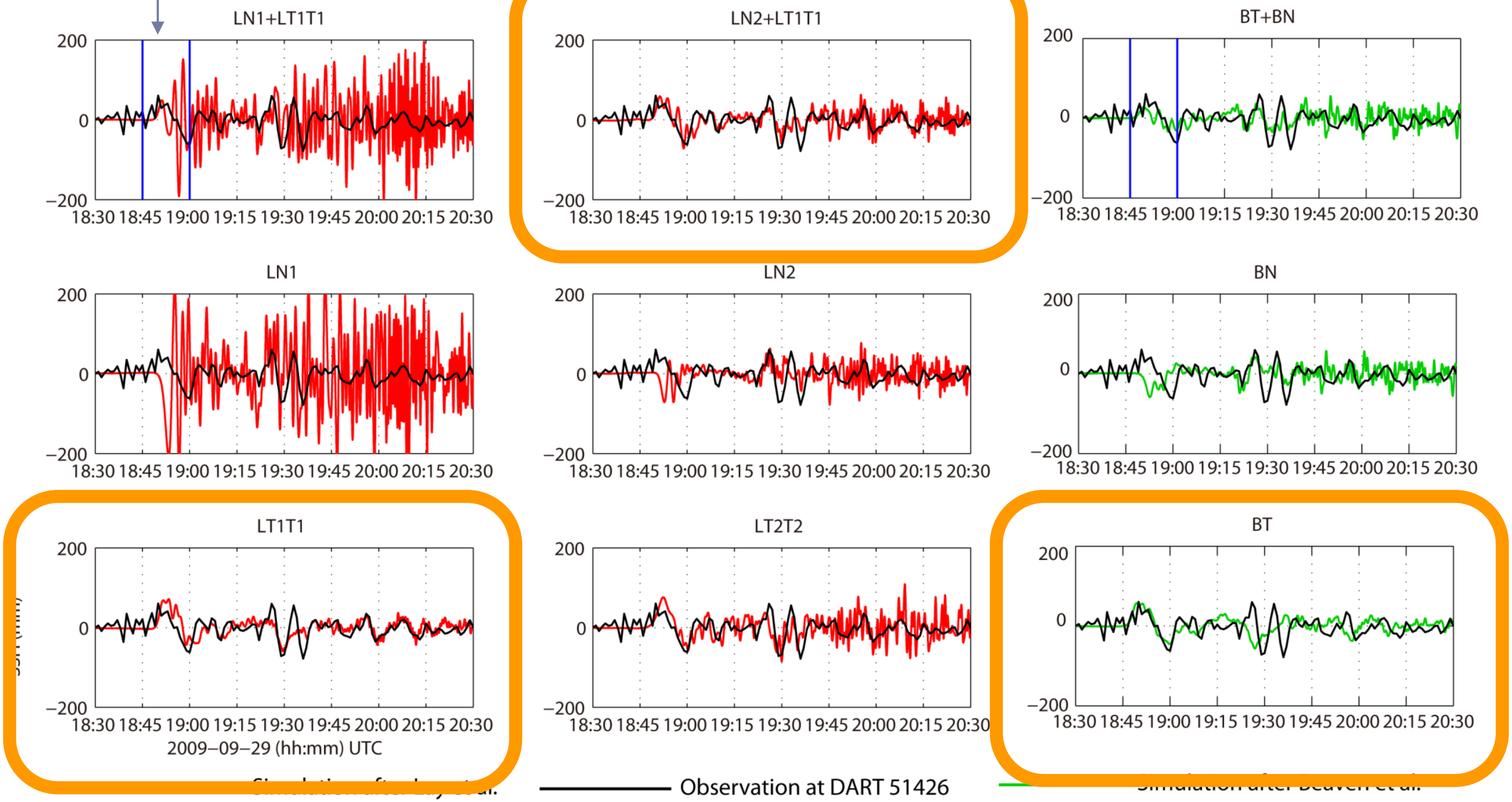


Station 51425 – S1



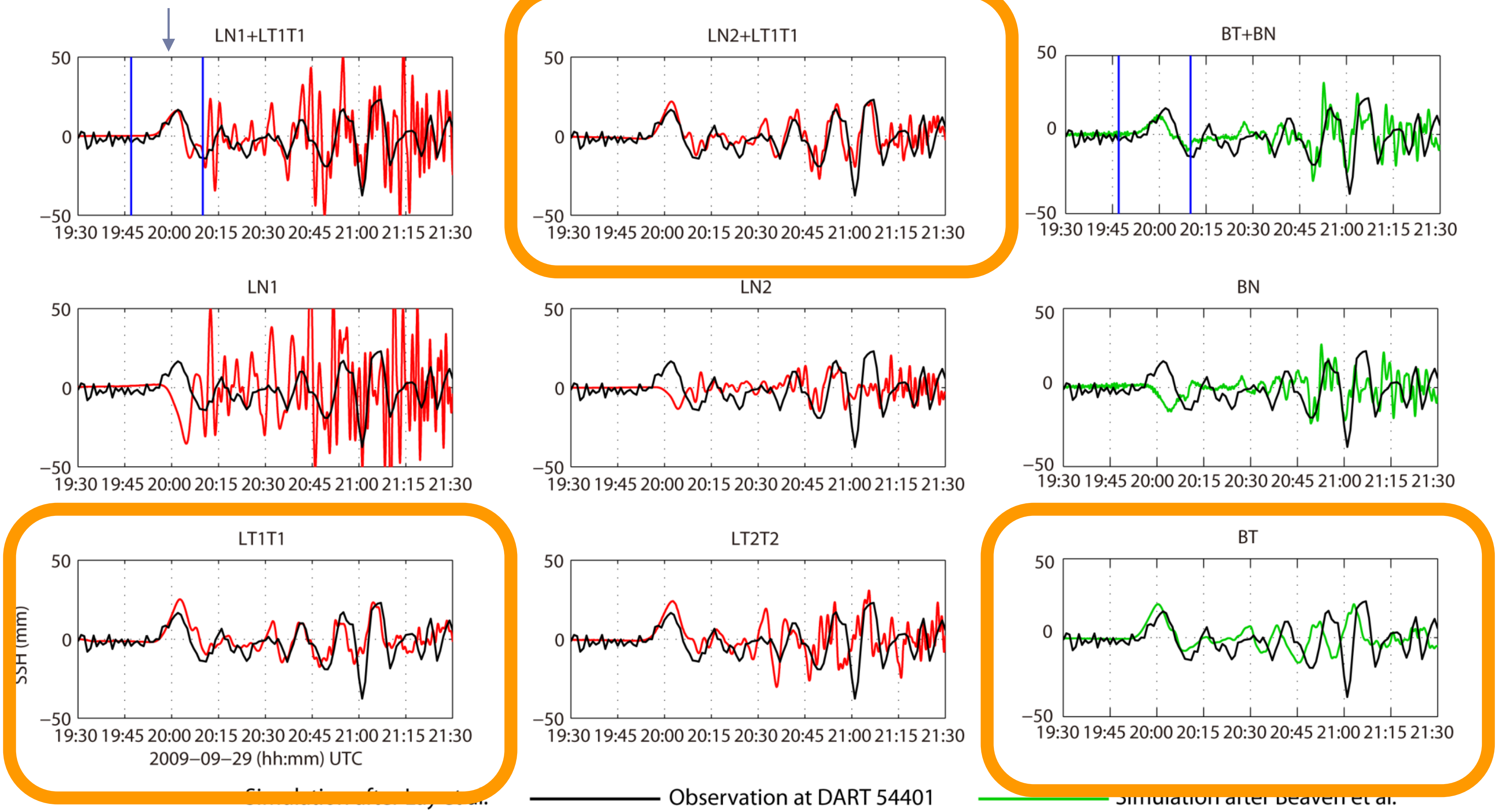
Station 51426 – S2

first arrival
3600 ~4500 seconds



Station 54401 – S3

first arrival
7200 ~9000 seconds



Summery from the comparison btw the DART waveforms and simulations

- For Station 51425, the simulation results seems all not good enough to explain; we suspect the bathymetry between the epicenter to the station is too complex.
- Considering only the normal faulting:

  The interesting thing is: N2 (Lay et al., 2010) dominantly affects the first phase of tsunami at station 51425.
- Considering only the two interface thrusts:

  The first phase of tsunami at station 51426 and 54401 are dominated by the two thrusts.
- Considering all three major events:

  For station 51426 and 54401, the result of simulation are much fitting with the observations.
- From the results, it favors the geometry of the normal fault of dipping to northeast.