Last 10 yrs - 18 great earthquakes: rate 1.8/yr; rate over preceding century 0.7/yr

Great (Mw ≥ 8) events from Dec. 2004-Apr. 2014

[Lay, 2014]
I started grad school at Caltech Seismo Lab after, Ammon et al., SRL, 2010
Resolutions of Joint inversion

Spatial Resolution

Tsunami Waves
InSAR and Static GPS

hr-GPS

Teleseismic body waves

Teleseismic Surface waves

Moment Resolution

Time Resolution
Recent Huge Events With “Surprises”

2004 Sumatra $M_w$ 9.2; ruptures 1300+ km long, massive tsunami
   2005 $M_w$ 8.7, 2007 8.5, 7.9 ‘clustered’ events along Sumatra

2006 Kuril $M_w$ 8.4 thrust; triggers 2007 Kuril $M_w$ 8.1 normal

2007 Peru $M_w$ 8.0 devastates Pisco; triggered by 7.8 initial rupture

2007 Solomon Island $M_w$ 8.2; rupture across triple junction

2008 Wenchuan $M_w$ 7.9; unexpected thrusting

2009 Samoa $M_w$ 8.1 normal faulting; triggers Tonga $M_w$ 8.0 thrust

2010 Chile $M_w$ 8.8 ruptures beyond “Darwin Gap”

2010 Mentawai $M_w$ 7.8 tsunami earthquake updip of 2007 8.5/7.9 Sumatra

2011 Tohoku $M_w$ 9.0 ruptures entire megathrust, slip up to 60 m

2012 Indo-Australia $M_w$ 8.7, 8.2 ruptures 5 fault grid- largest intraplate strike-slip

2013 Sea of Okhotsk $M_w$ 8.3 largest/longest/most energy deep earthquake ever
Sumatra-Sunda

Struck by a ‘cluster’ of great/very large earthquakes since 2004.

Dec. 26, 2004 – ‘unexpected’ northward extension to Andaman Islands. 9.2

March 2005 – adjacent ‘aftershock’. 8.6

July 2006 – Java tsunami earthquake. 7.8

Sept. 2007 – Kepulauan pair. 8.5, 7.9

Oct. 2010 – Mentawai tsunami earthquake. 7.8

Similar to Alaska-Aleutians sequence of 1946, 1957, 1964, 1965

Where will the next one be? - 1797 ‘gap’? Sumatran Fault? Sumba potential?

[Lay, 2014]
2006-2007 Kuril Doublet: Mw 8.1 normal after Mw 8.4 thrust. Trench-slope stress cycled from compressional to extensional to compressional
Kuril Islands Great Doublet

Okhotsk Plate

15 Nov 2006
Mw 8.3

~ 4.3-6.5 meters slip
“Interplate Motion”

~ 4.5-6.7 meters slip
“IntraPlate Deformation”

13 Jan 2007
Mw 8.1

Model main slip rupture depth ~4-33 km

15 Jan 2009
Mw 7.4

Model main slip rupture depth ~35-55 km

Lay et al., JGR (2009)
April 1, 2007 Solomon Islands Earthquake $M_w=8.1$
Rupture Across a Triple Junction

Furlong et al., Science (2009)
Great events along southern Peru megathrust: Ruptures triggering large second rupture with complex expansion.

2001 Peru (M<sub>w</sub> 8.4) – Initial 7.5 triggers rupture of 8.4 on ~Rayleigh wave arrival

2007 Peru (M<sub>w</sub> 8.0) – Initial 7.8 triggers rupture of 8.1 after ~60 s hiatus

Lay, et al., BSSA, 2010
2009 Samoa-Tonga Triggered Doublet (Mw 8.0, 8.0)

Lay et al., Nature (2010)
The Tonga-trench earthquakes of 29 September 2009 offer a unique opportunity to study the sequence of events. B1 and L1 denote which, respectively, the authors consider to have occurred first. But, if the second earthquake (L2) happens soon after the first one, the signal can be buried in seismic records.

Clues to the earthquakes' sequence can also be sought in GPS measurements, such as those made during the 2010 Chilean earthquake, which were not available, however, for the Tonga earthquakes. Continuous GPS measurements before and after the earthquake can indicate the existence of such slow earthquakes, but it is difficult to achieve an accurate measurement on faults hundreds of kilometres from the earthquake source. When two earthquakes occur nearly simultaneously, the signal from the later event may be overwhelmed by the earlier one.

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Beavan et al.1 determined that B1 is slow and not detected by seismic data. Lay et al.2 found that a plate-boundary earthquake (L2) happens soon after the first one, the signal can be buried in seismic records. Lay et al.2 carried out non-routine, detailed and comprehensive analyses of the available seismic data, and succeeded in detecting signals that were not found in tsunami waveforms recorded on bottom-pressure (DART) sensors operated by the US National Oceanic and Atmospheric Administration. Lay et al.2 likewise show that the plate-boundary earthquake really happened later. If the two Tonga earthquakes happened in the same order, and the GPS data suggests that the plate boundary breaks in a great earthquake. A recent paper by Satake et al., published in Nature (2010), discusses the implications of these findings for our understanding of earthquake dynamics.

Satake, Nature, 2010

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The tsunami hazard is produced by the large slip out near the trench. The shaking hazard from the low slip area down-dip on the fault near the coast.

The boxes are regions where strong motions were generated.
Feb. 27, 2010 Chile
M$_w$ 8.8

Filling the 1835 seismic gap?
But it went well beyond that...

Updated From: Lay et al., GRL, 2010
Complementary pattern with the aftershock distribution

[Yue et al. 2014b]
Summary: Recent great ruptures share similar depth-varying frequency-dependence. It has been recognized that upper 15 km depth range had ‘tsunami’ earthquakes, with very low short-period radiation, but central portion of megathrust also has little coherent short-period radiation.

Lay et al., JGR, 2012
Lay et al., 2014

South America Plate

1868 M ~ 8.5-8.8

June 23, 2001
Mw 8.4

Nazca Plate

~65 mm/yr

1877 M ~ 8.7-8.9

April 1, 2014
Mw 8.1

April 3, 2014
Mw 7.7

[Lay et al., 2014]
Great Earthquake Scenarios

A  Trench
   Overriding Plate

Sumatra 2004, 2005
   2007

B  Ridge

Solomon Islands 2007

C  Sediments

Mentawai 2010

D

Tohoku 2011

Chile 2010

E  Overriding Plate
   Trench

Kuril Islands 2006, 2007

F

Samoa 2009a,b

[Lay, 2014]
Implications for Cascadia

Rupture of full seismogenic zone length and width
  – Tohoku 2011, Chile 2010 (Need offshore geodesy to determine slip deficit)

Partial rupture of ‘seismic gap’, up-dip tsunami earthquakes
  – Chile 2014, Mentawai 2010 (Enhanced tsunami hazard)

Cascading rupture growth
  – Peru 2001, 2007 (Challenge for rapid warning)

High frequency radiation from deeper region
  – Tohoku 2011, Chile 2010 (Enhanced shaking hazard)

Triggering of interplate faulting - Outer rise normal faulting

Rupture of bathymetric segment ‘boundaries’
  – Solomon 2007 (Don’t count on segmentation)