A journey to the center of the Earth

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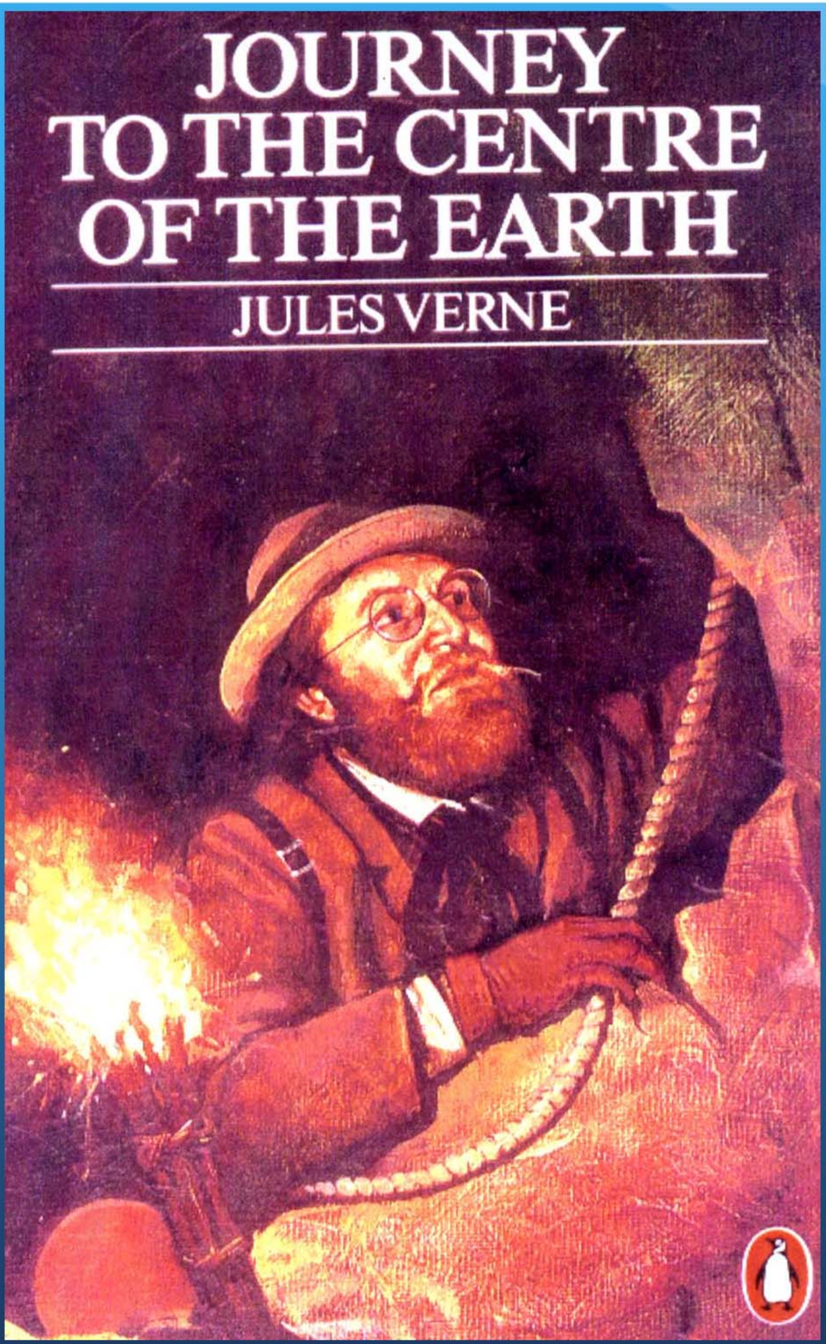
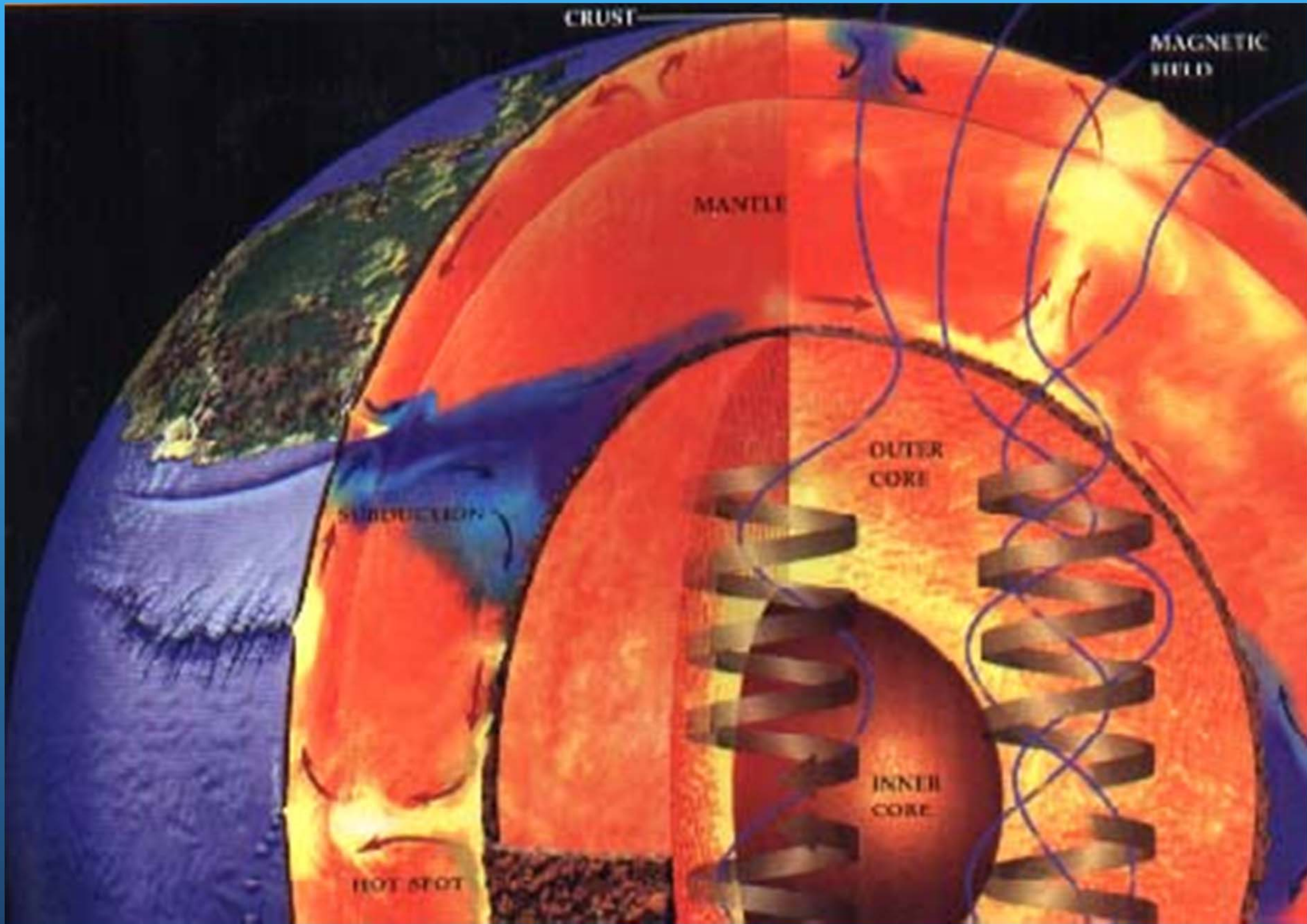
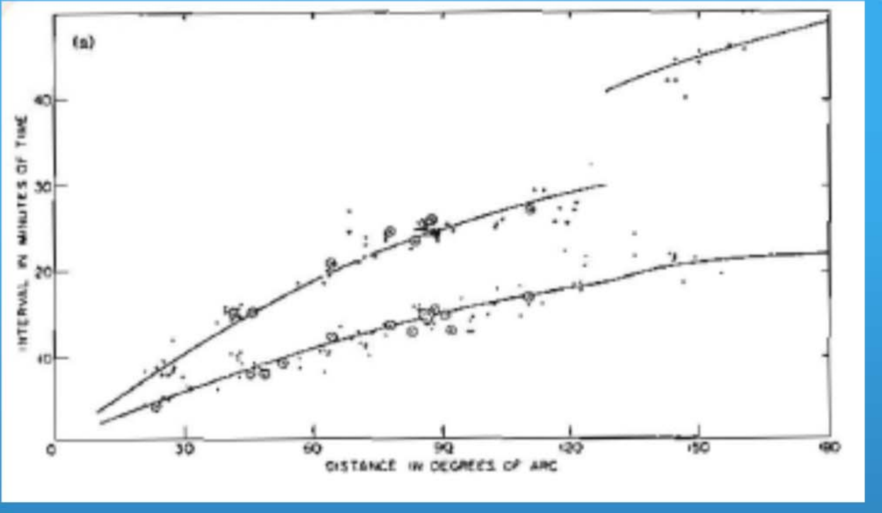
April 30, 2013
National Central University



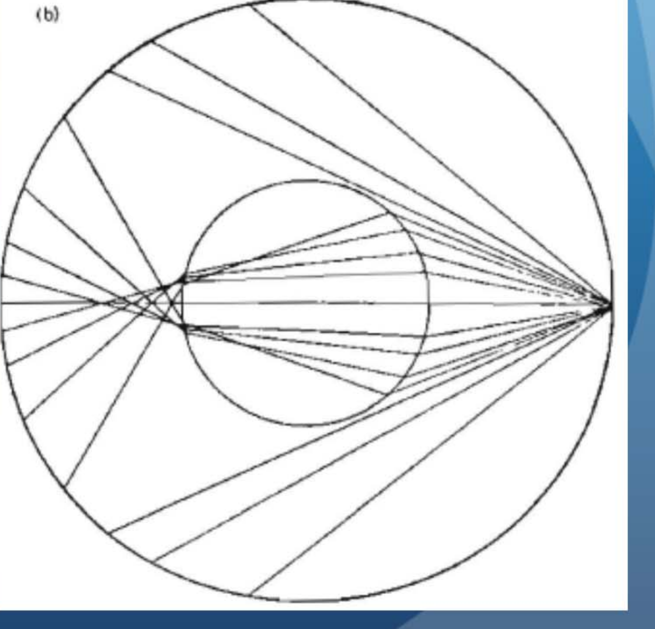
Jules Verne, 1864


CRUST
MAGNETIC FIELD
MANTLE
OUTER CORE
SUBDUCTION
INNER CORE
HOT SPOT

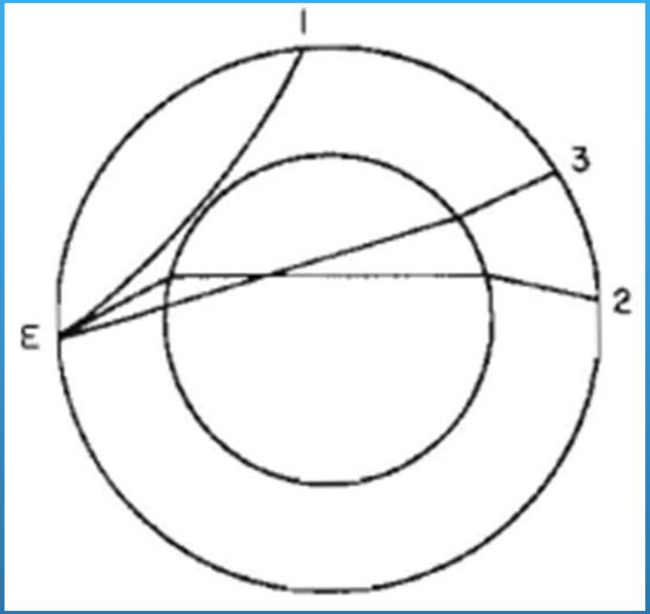


Evidence for a Central Core

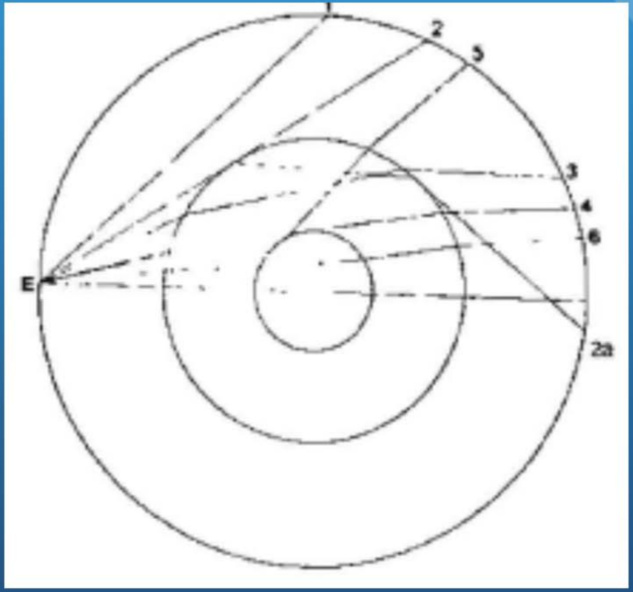
Oldham, R.D., J. Geol. Soc. London, 62, 456, 1906



Interpretation of arrivals in the core “shadow zones”



Rays without an IC



Rays with an IC

Lehmann, I., Publ. Bur. Cent. Seismol. Int. Ser, A., Trav. Sci. 14, 88, 1936

Outline

- Intro: seismic imaging of the Earth’s interior
- Inner core structure
- Inner core rotation and topography
- Ambient noise seismology

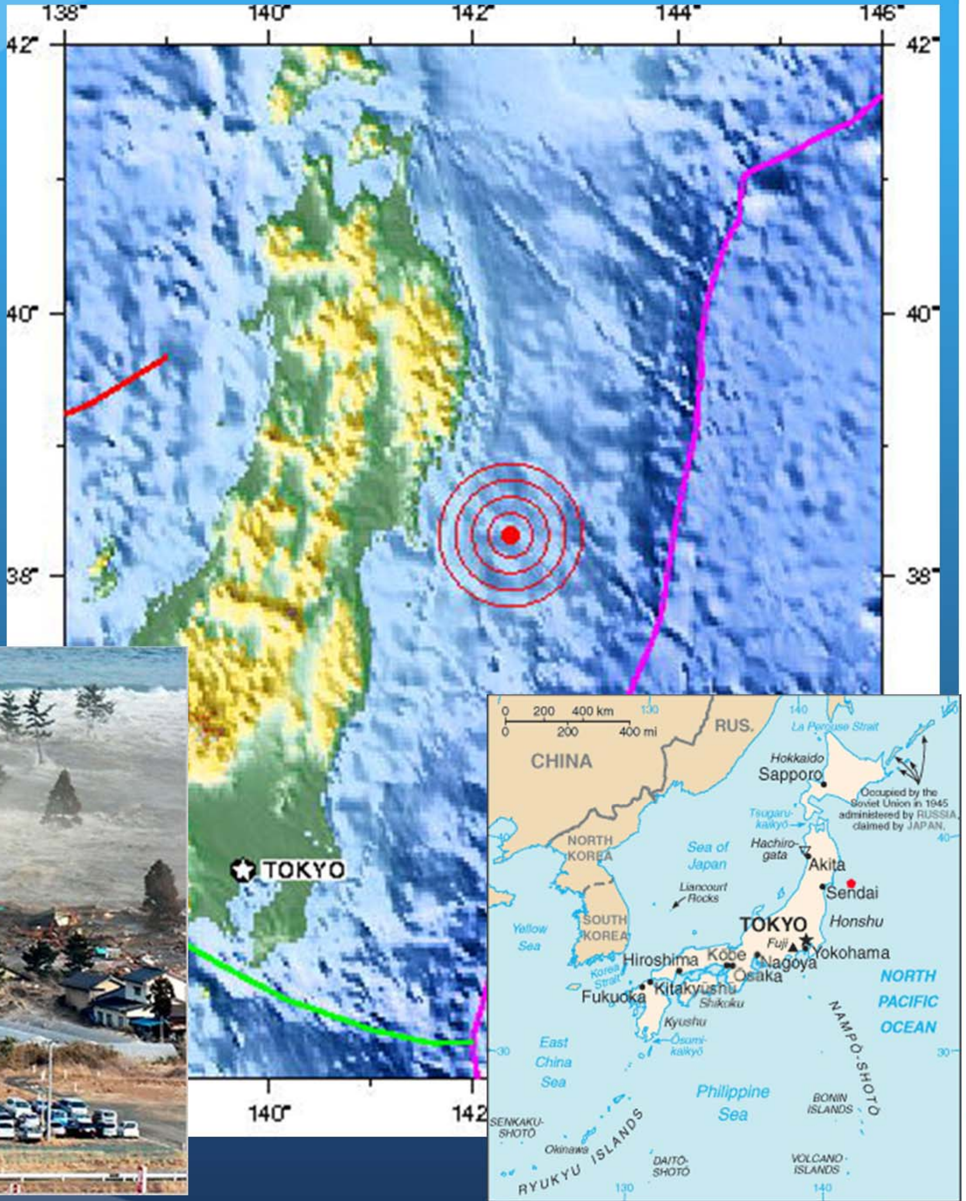
Magnitude 9.0 NEAR THE EAST COAST OF HONSHU, JAPAN
Friday, March 11, 2011 at 05:46:23 UTC

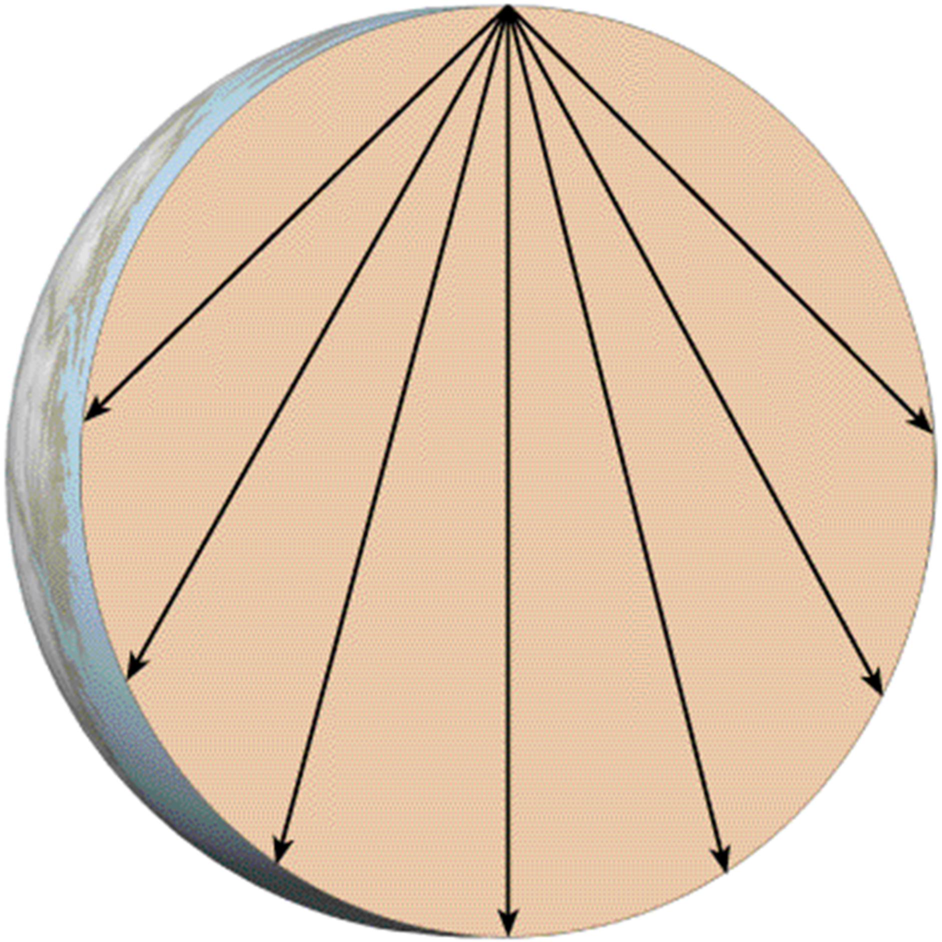
Magnitude: 9.0

Date-Time:
Friday, March 11, 2011 at 05:46:23 UTC
Friday, March 11, 2011 at 02:46:23 PM at epicenter

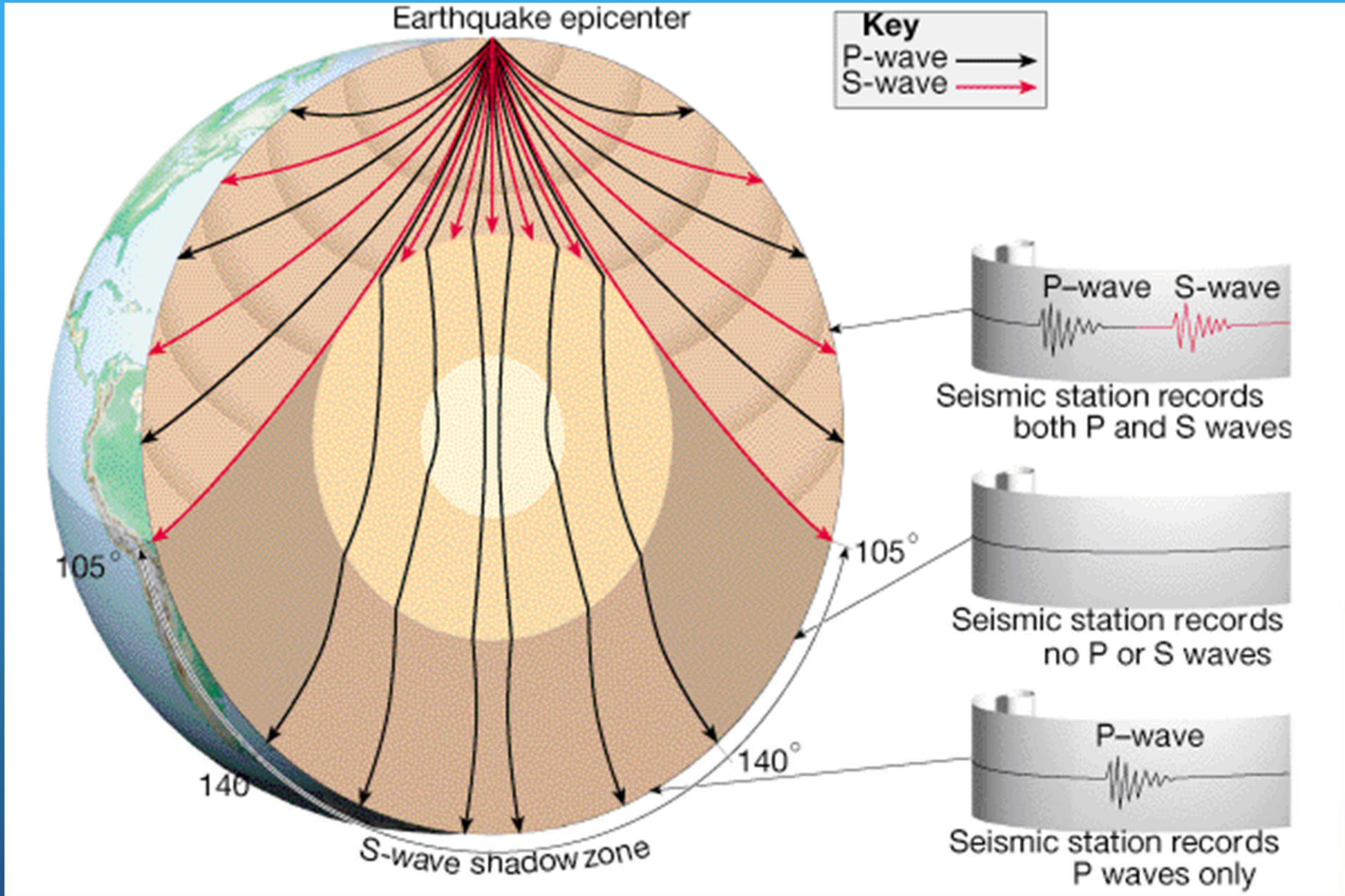
Location:
38.322° N, 142.369° E

Depth: 32 km (19.9 miles)

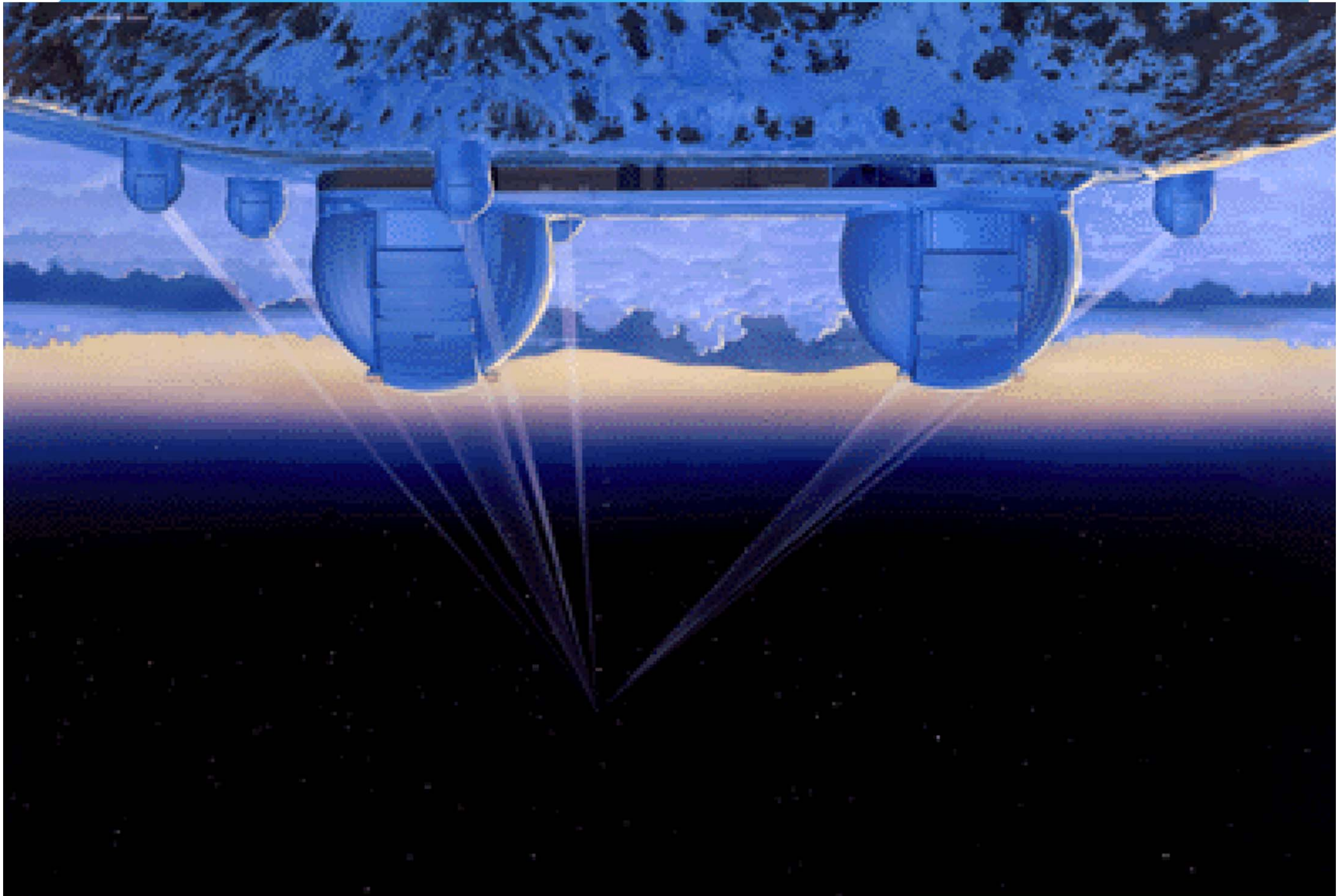




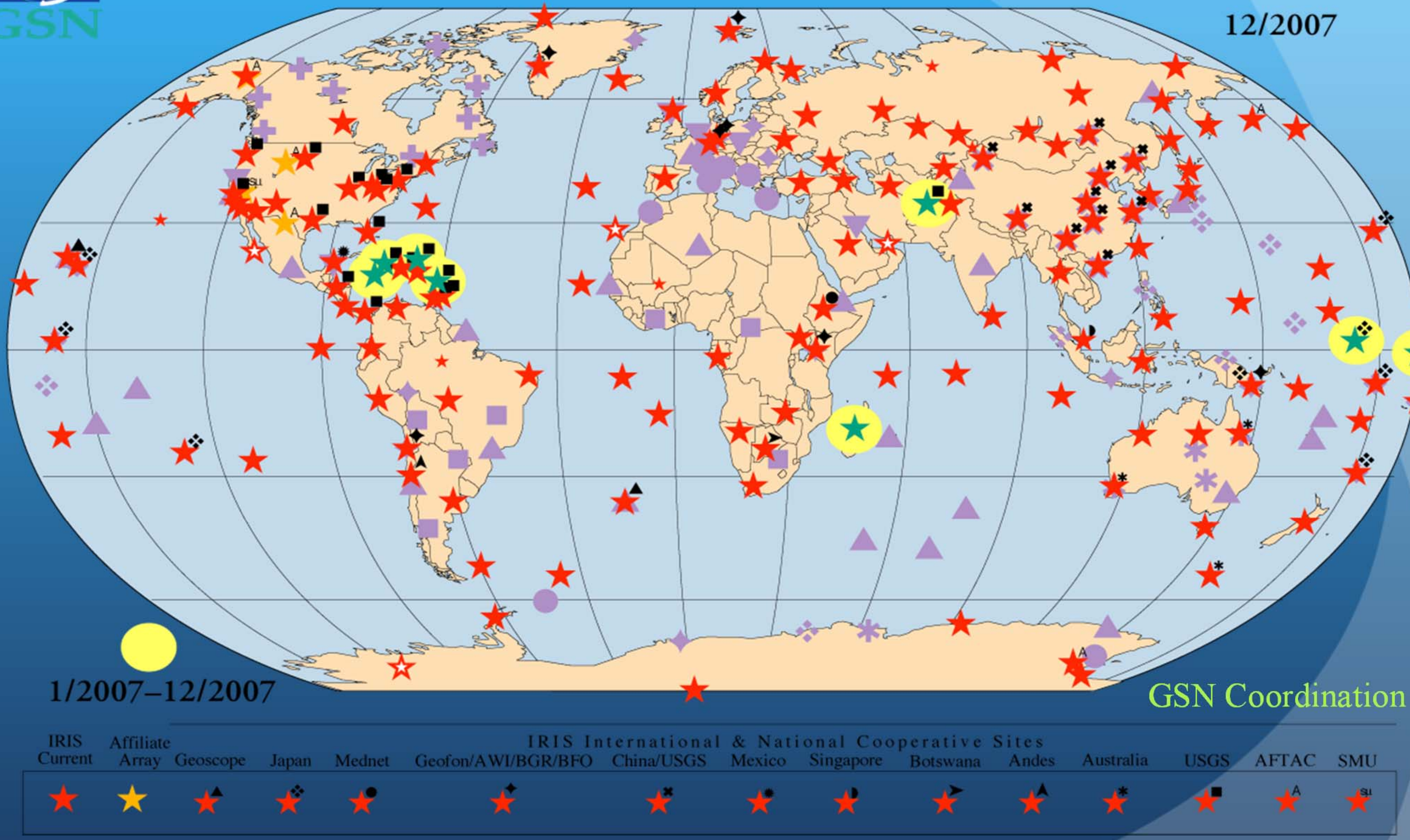
- Seismic rays travel in straight lines in a homogenous sphere. (Tarbuck and Lutgens)



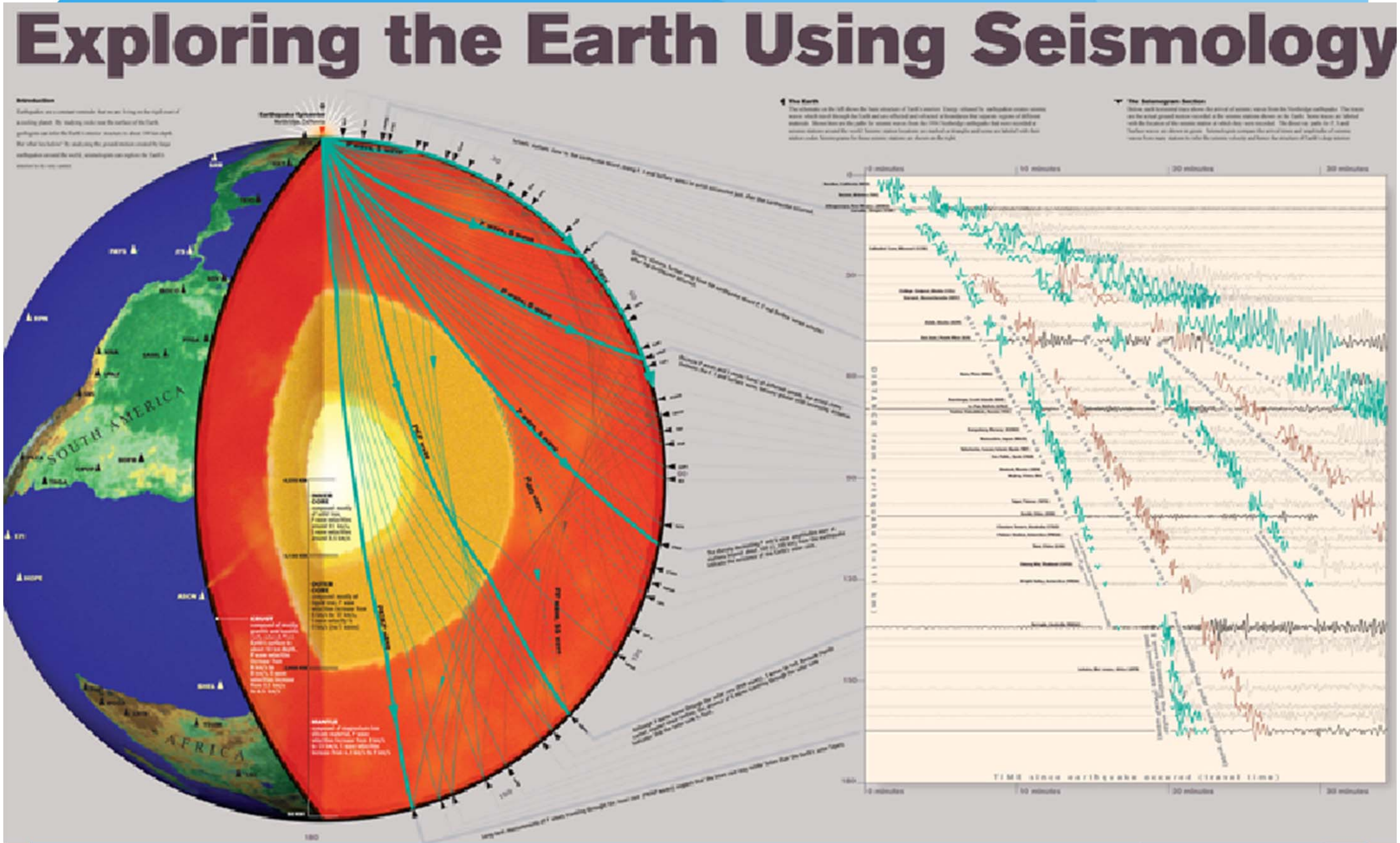
- P and S wave paths through the Earth. No S waves through the core because outer core is liquid.



GLOBAL SEISMOGRAPHIC NETWORK
& INTERNATIONAL FEDERATION OF DIGITAL SEISMOGRAPHIC NETWORKS



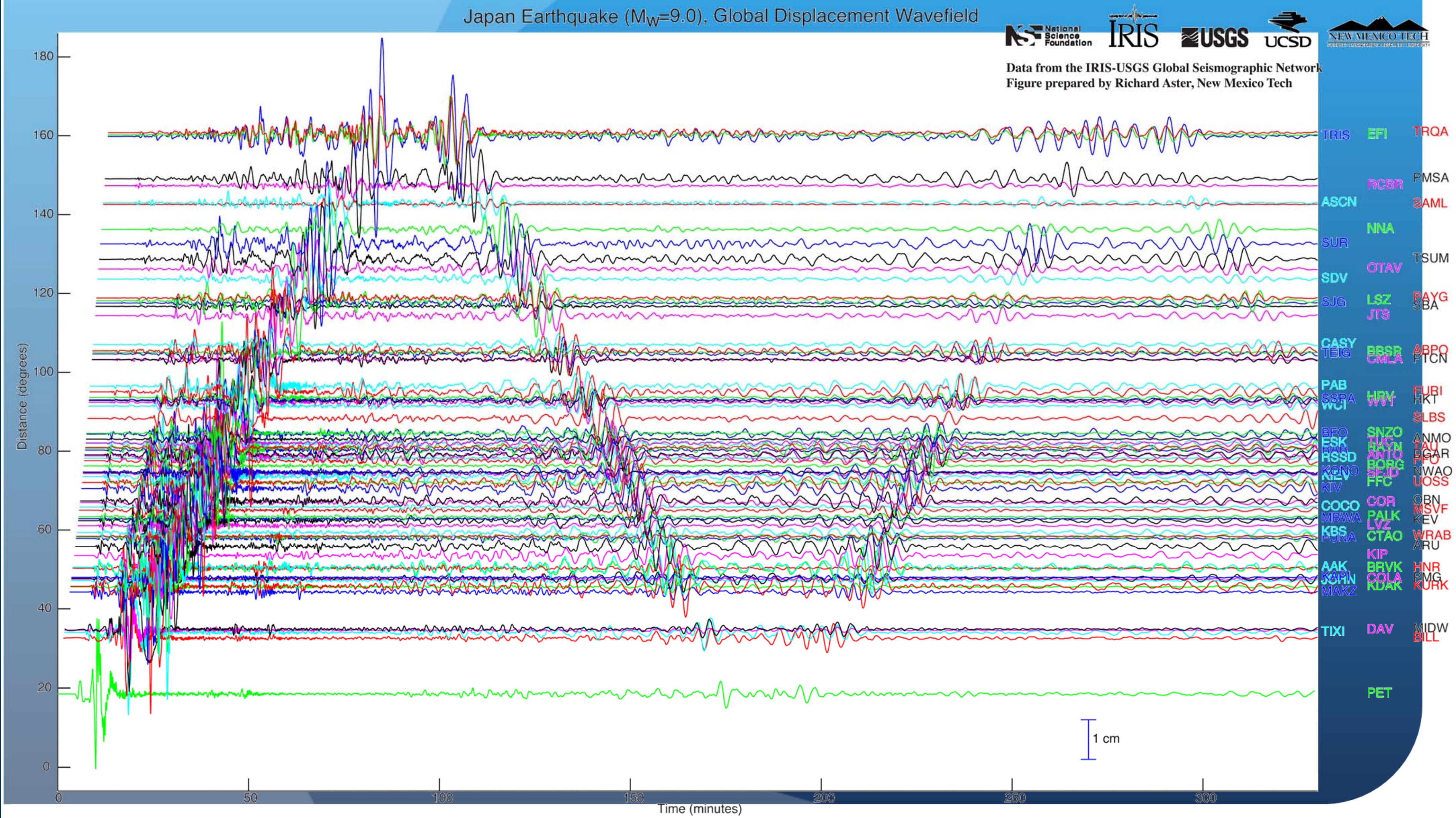
150 Global stations and arrays in 69 Nations • Cornerstone of the FDSN Backbone

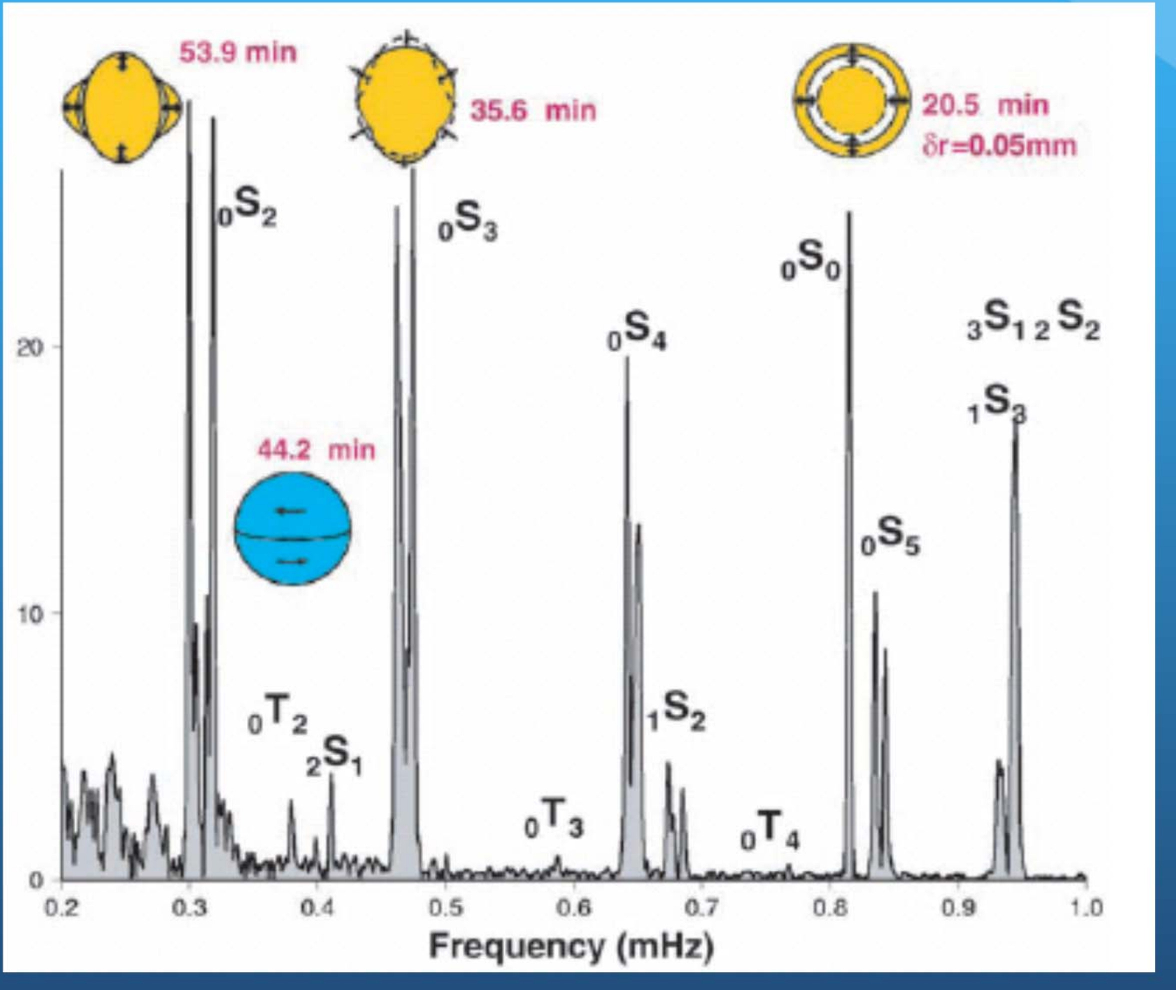


Exploring the Earth Using Seismology
SOUTH AMERICA
AFRICA
TIME since earthquake occurred (travel time)

Magnitude 9.0 NEAR THE EAST COAST OF HONSHU, JAPAN
Friday, March 11, 2011 at 05:46:23 UTC

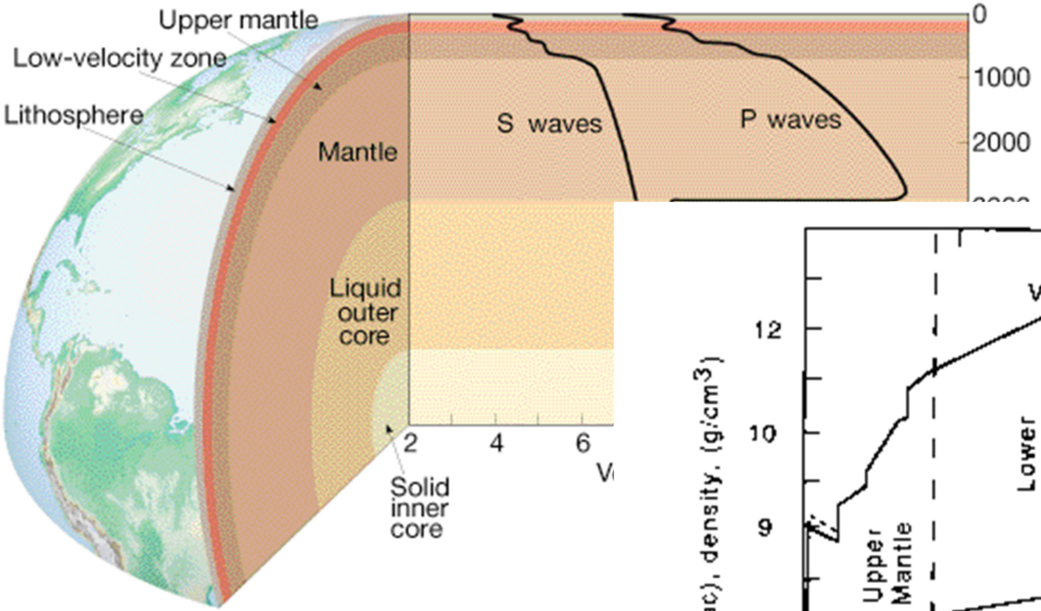
Seismic waves recorded around the world.

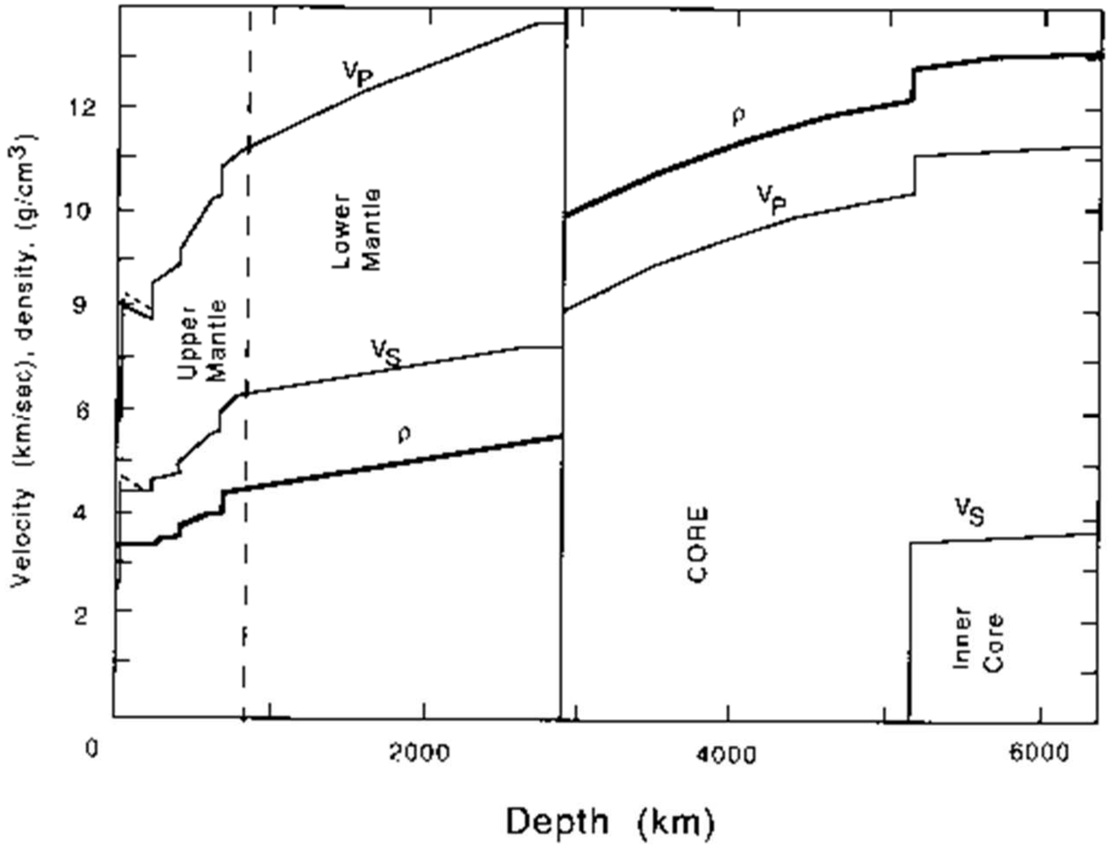




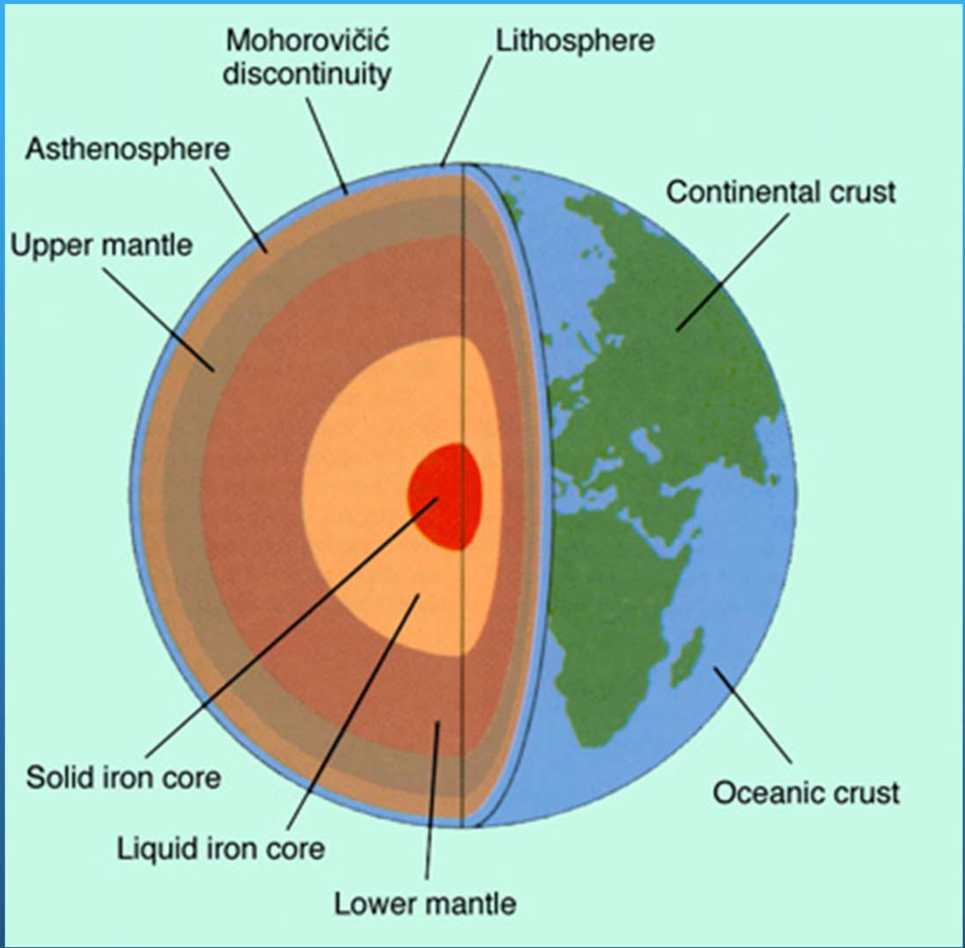
Earth's free oscillations excited by 2004 Great Sumatra earthquake.

PREM model





- P, S velocities and density through the depth of the Earth



Major layers of Earth's Interior:

Crust

Upper mantle

Transition zone

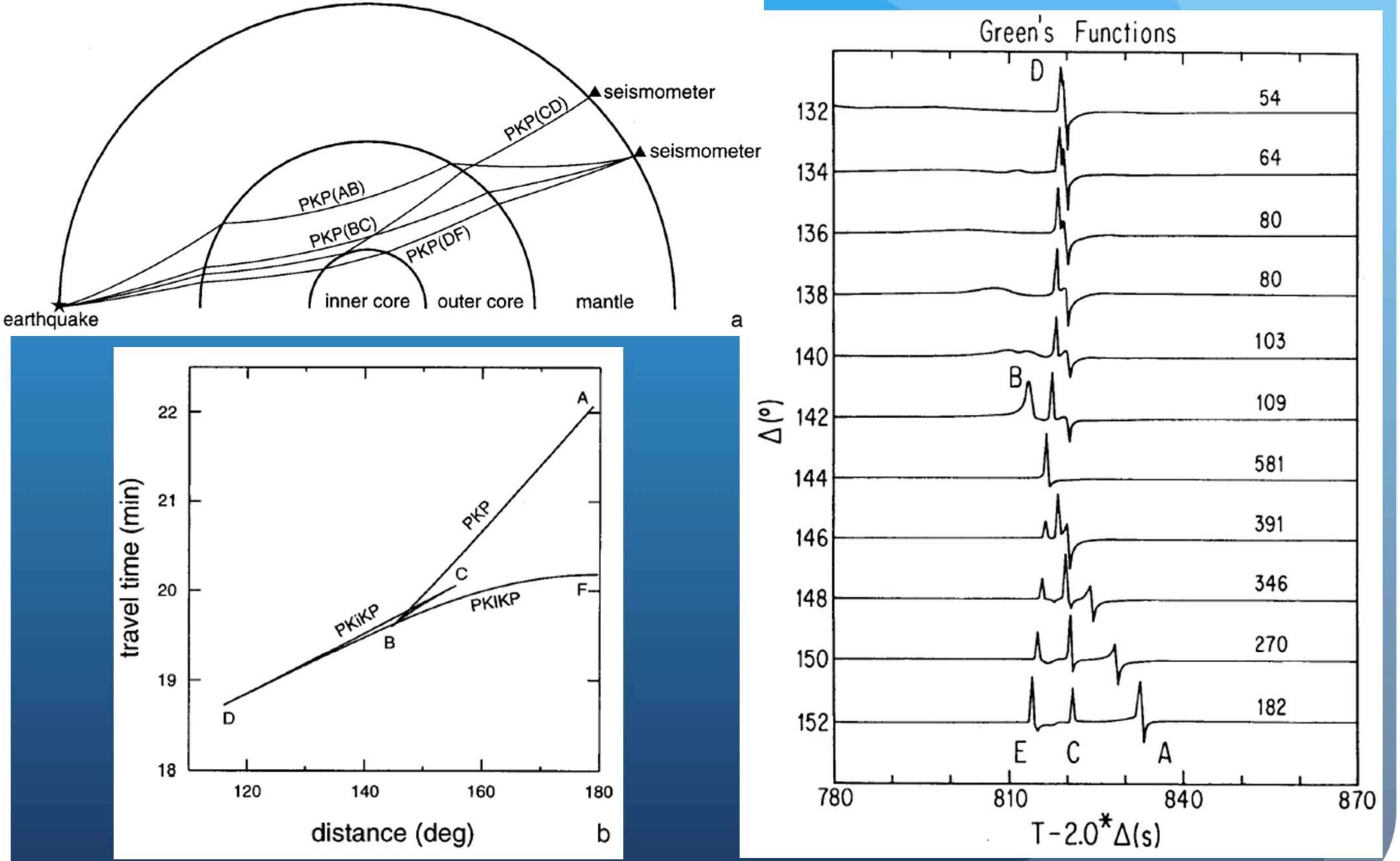
Lower mantle

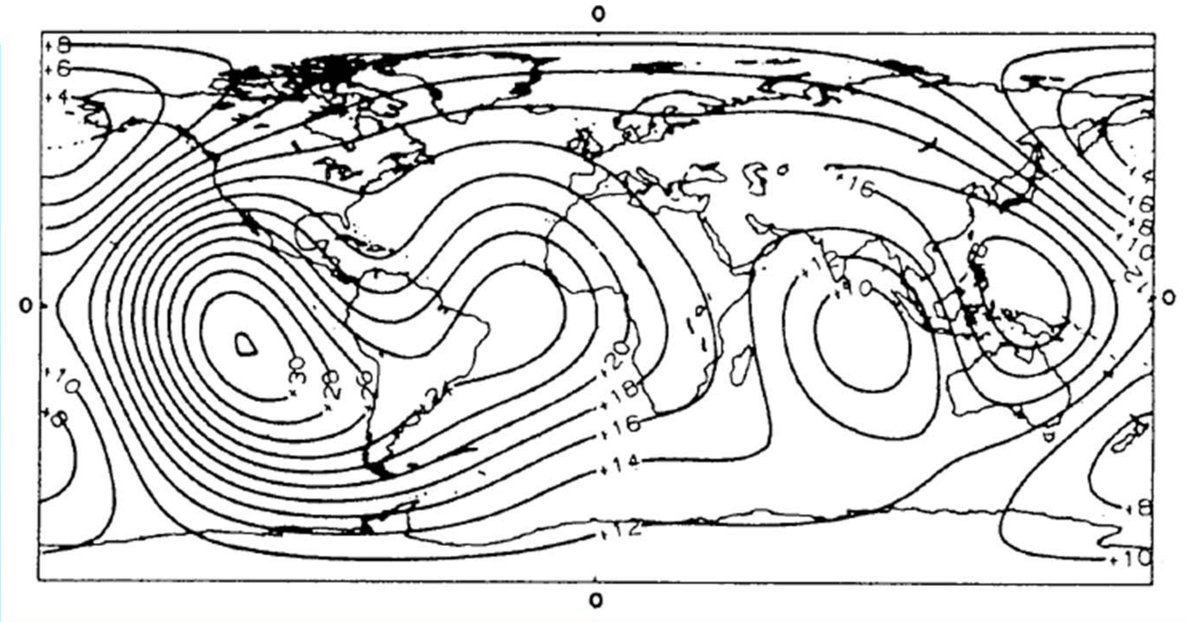
Outer core

Inner core

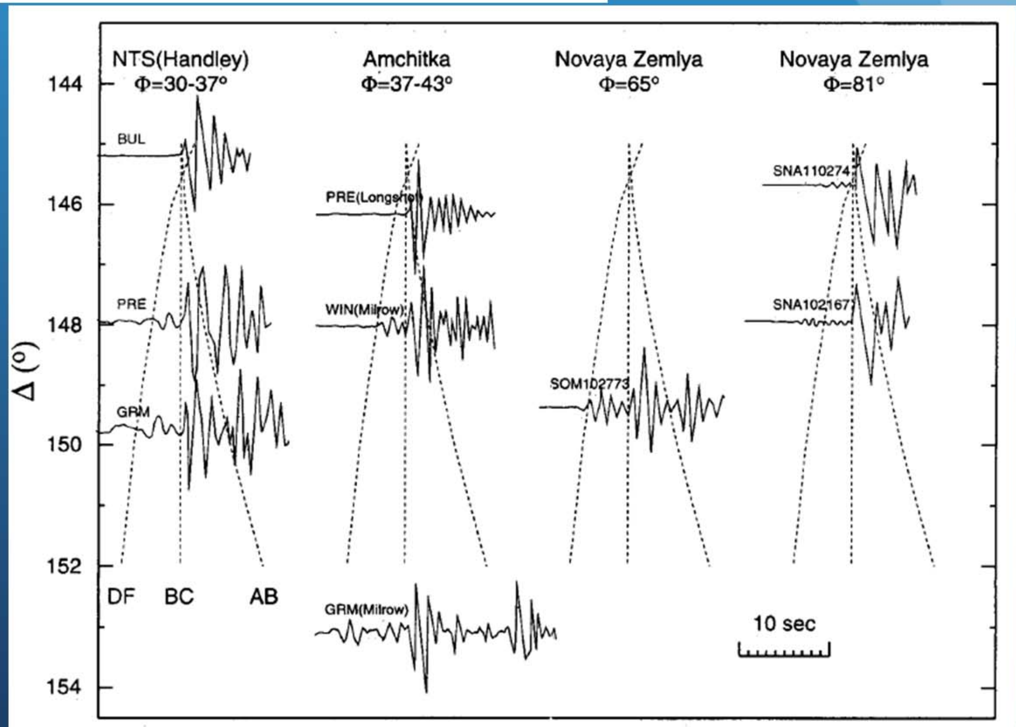
Inner inner core?

PKP ray paths, travel times, and synthetic seismograms

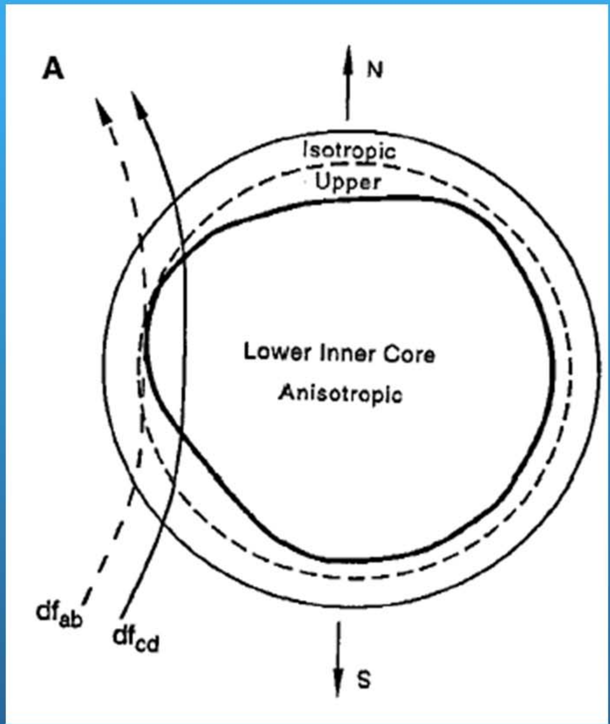


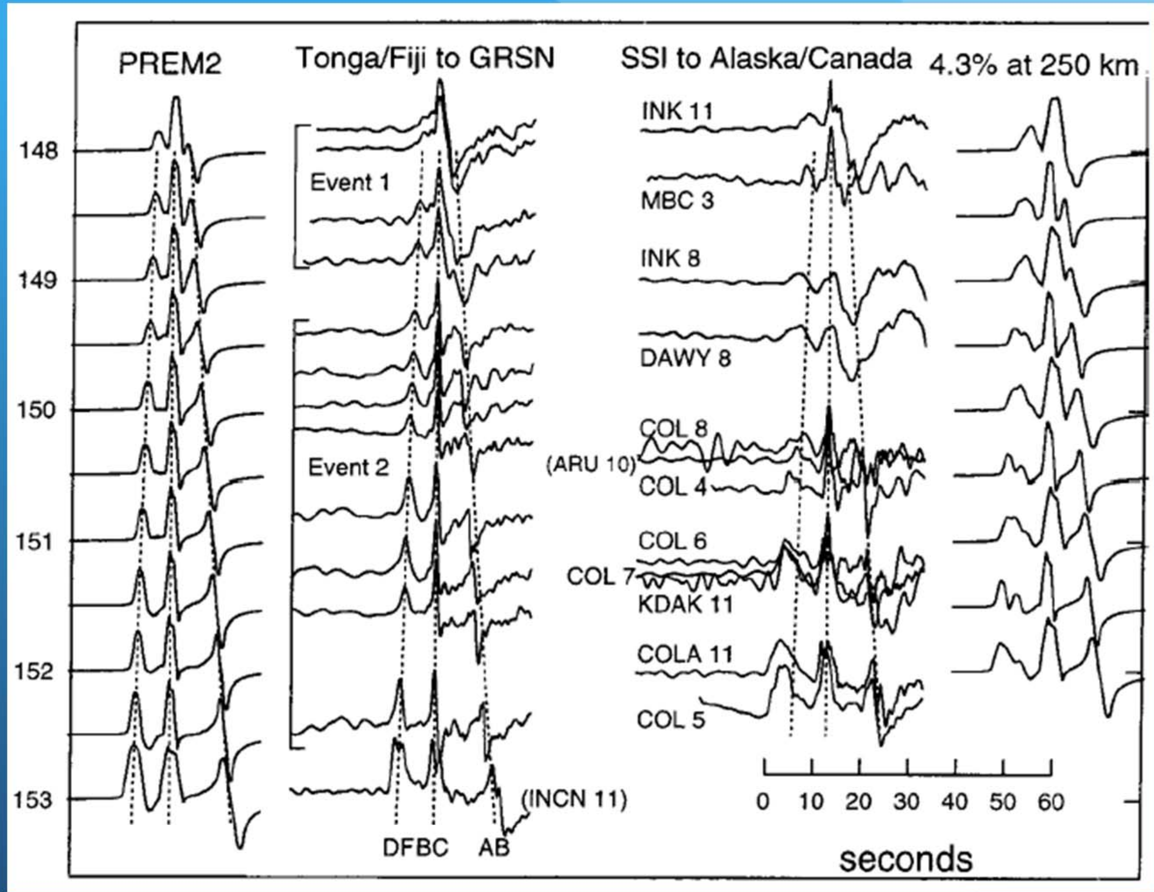


Poupinet et al., Nature, 1983



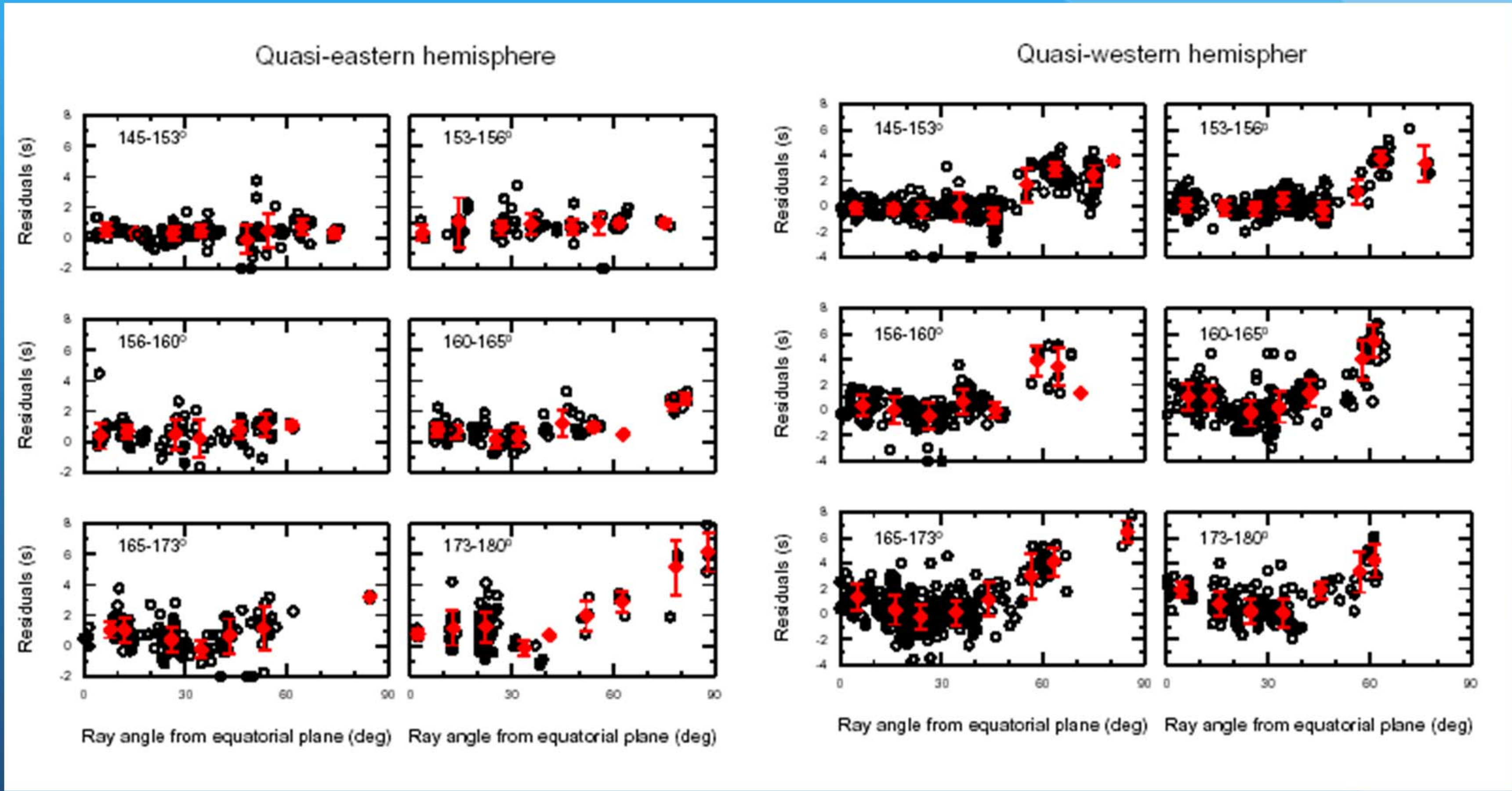
Song and Helmberger, GRL, 1993





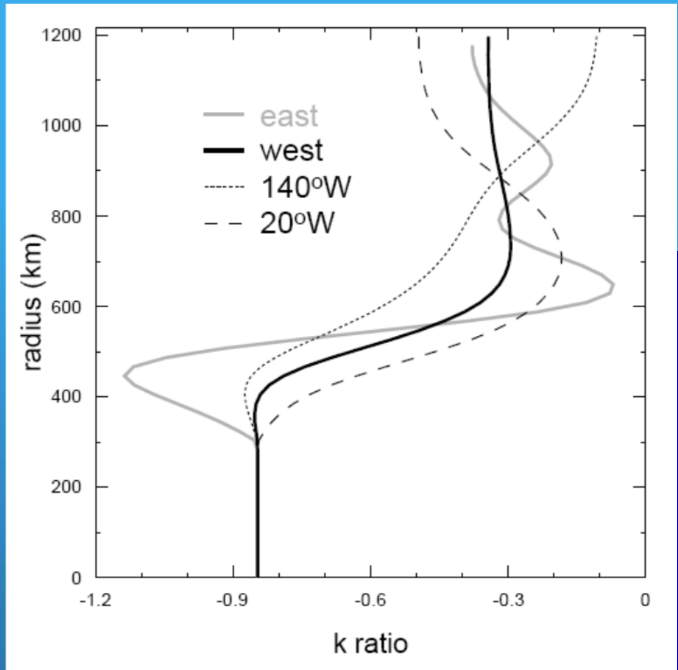
Song and Helmberger, Science, 1998

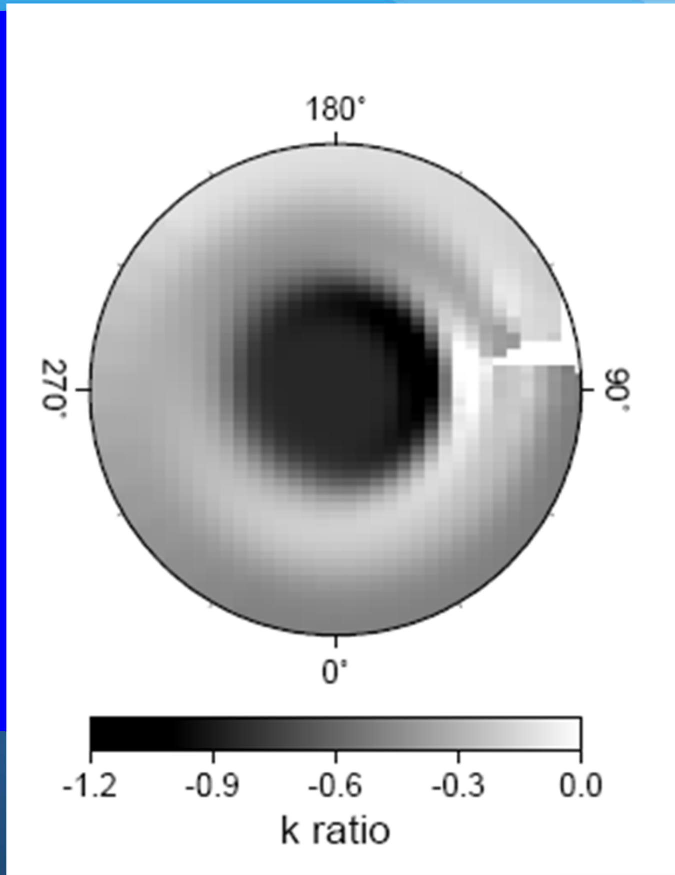
Data variability and 3D model predictions

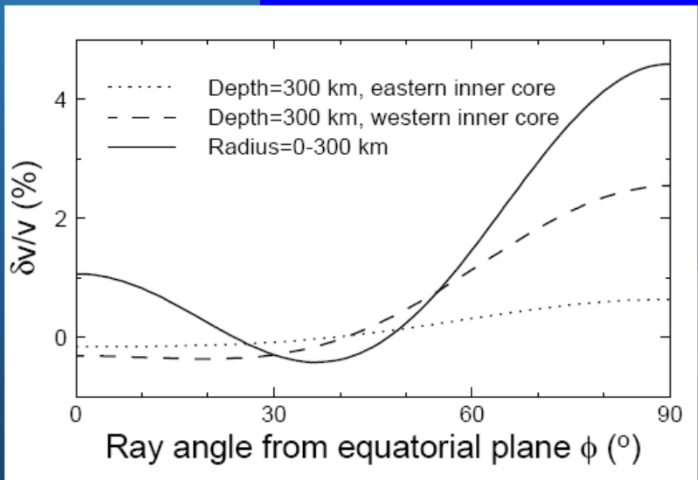


Sun and Song, PEPI, 2008

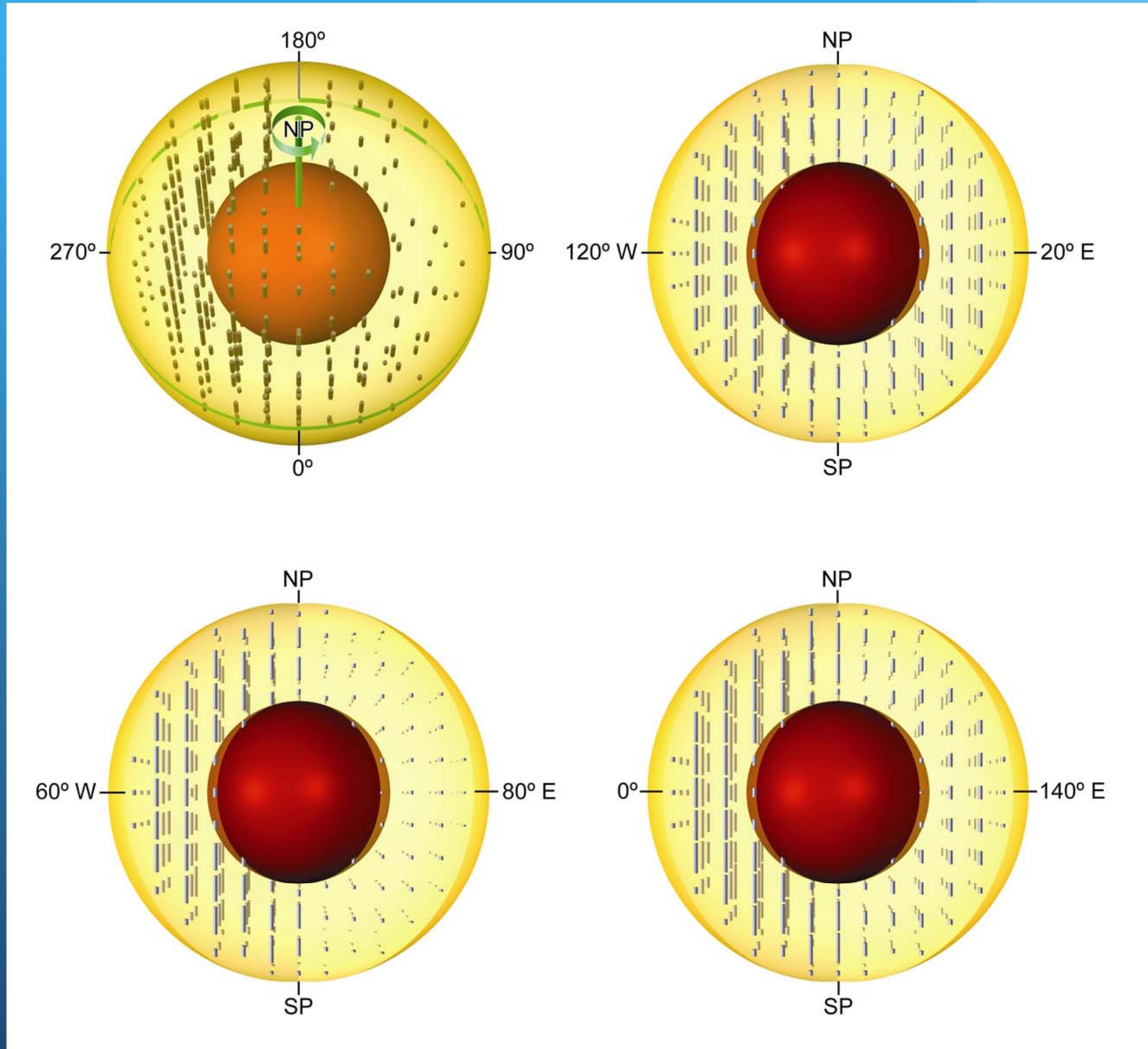
Evidence for an inner inner core







Sun and Song, EPSL, 2008



Cartoons of inner inner core and crystal alignments by mapping inner core anisotropy

Song and Richards, Nature, 1996

ELSEVIER

Physics of the Earth and Planetary Interiors 91 (1995) 63–75

PHYSICS
OF THE EARTH
AND PLANETARY
INTERIORS

A three-dimensional convective dynamo solution with rotating and finitely conducting inner core and mantle

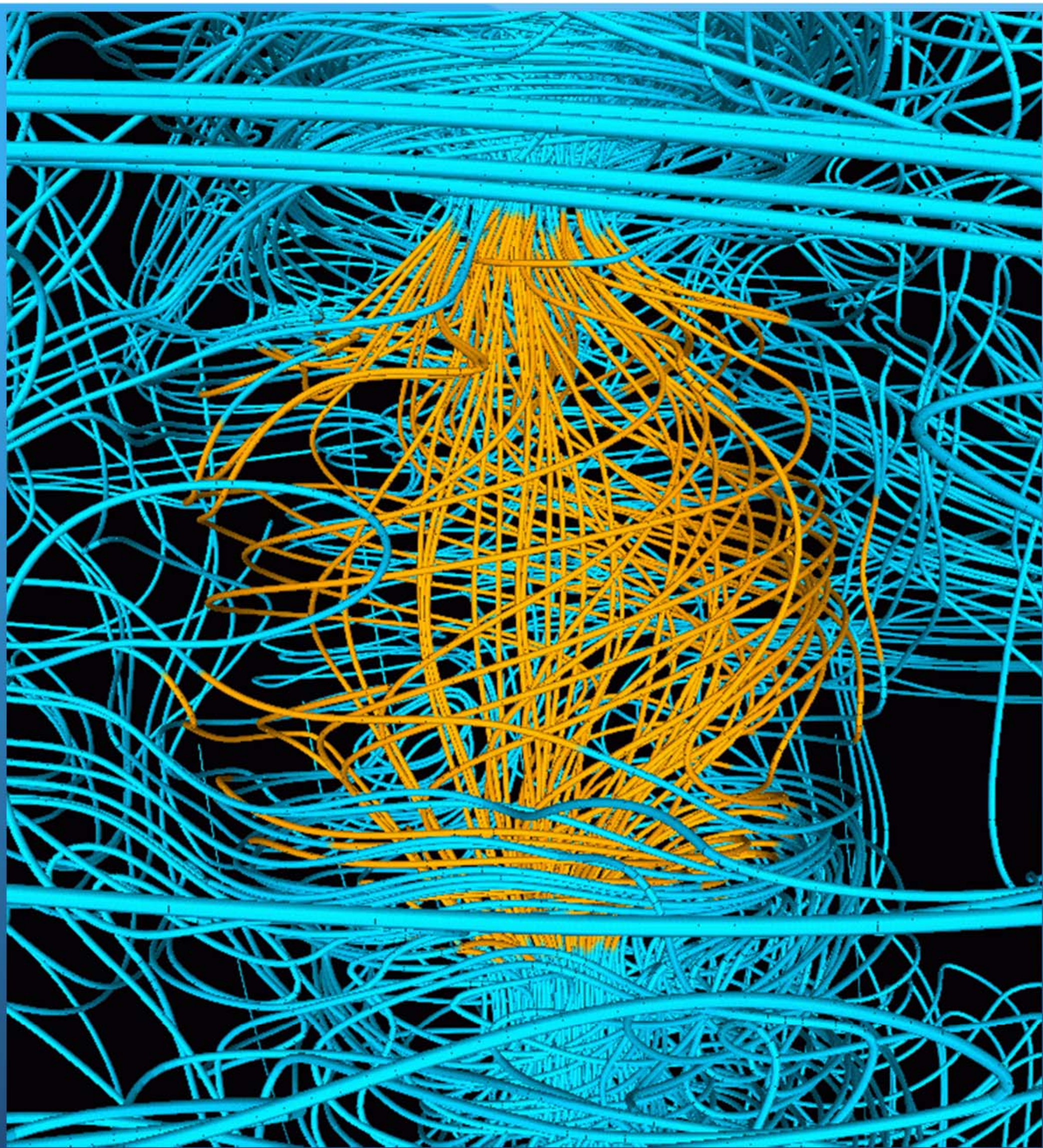
Gary A. Glatzmaier [a,*], Paul H. Roberts [b]

[a] *Institute of Geophysics and Planetary Physics, Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[b] *Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024, USA*

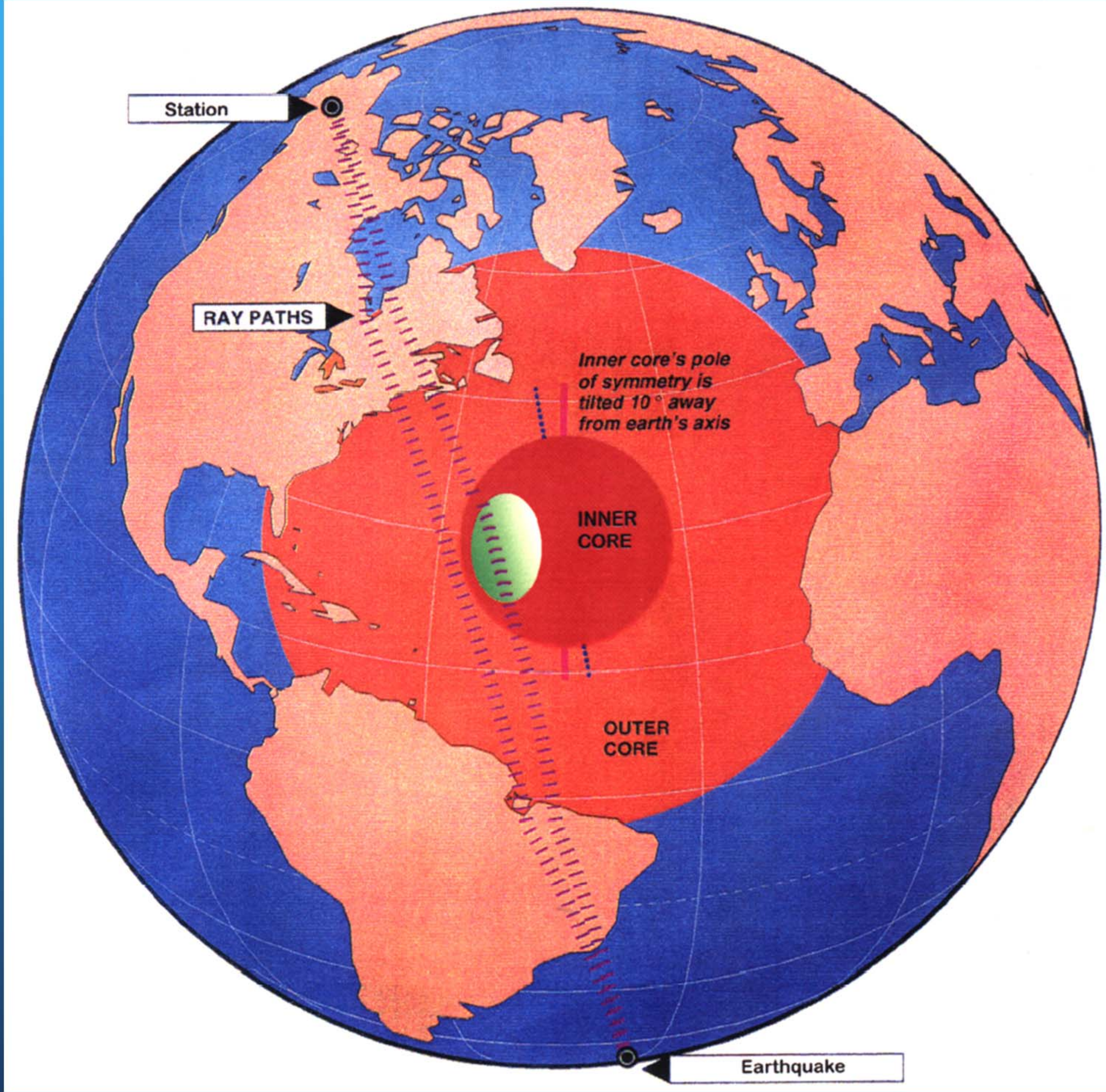
Received 10 November 1994; accepted 3 March 1995

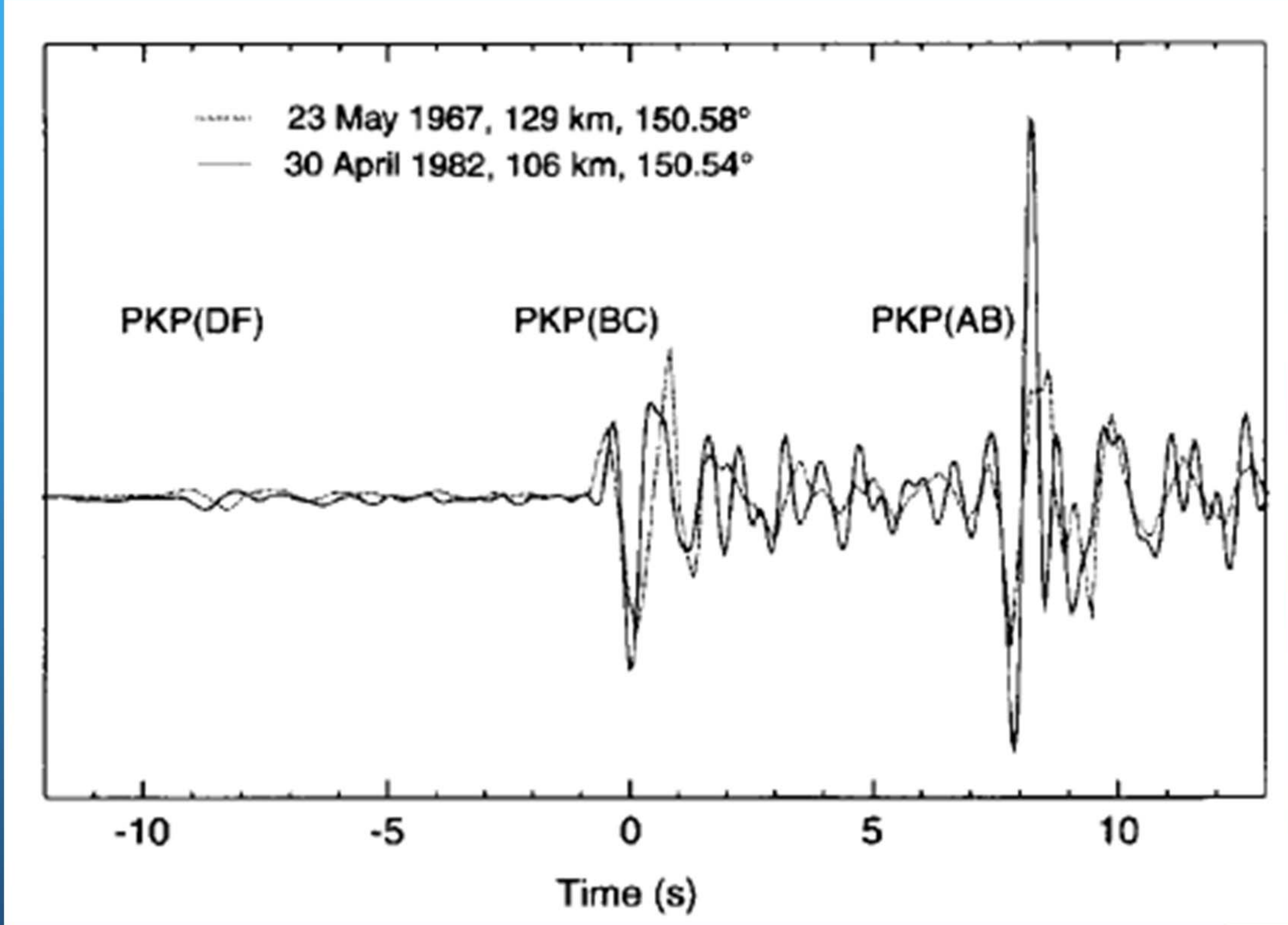
Viscous and magnetic coupling at the ICB and CMB produce time-dependent rotation rates of our inner core and mantle relative to the frame of reference rotating at $\mathbf{\Omega} = \Omega\hat{\mathbf{z}}$. The z-axis rotation rate of the inner core is almost always eastward, i.e. prograde relative to the initial non-convecting state. It can be as large as a few times 10^{-9} rad s^{-1} and changes on a time scale of about 500 years. The off-axis rates change ampli-

10^{-9} rad/s = 1.8 deg/yr

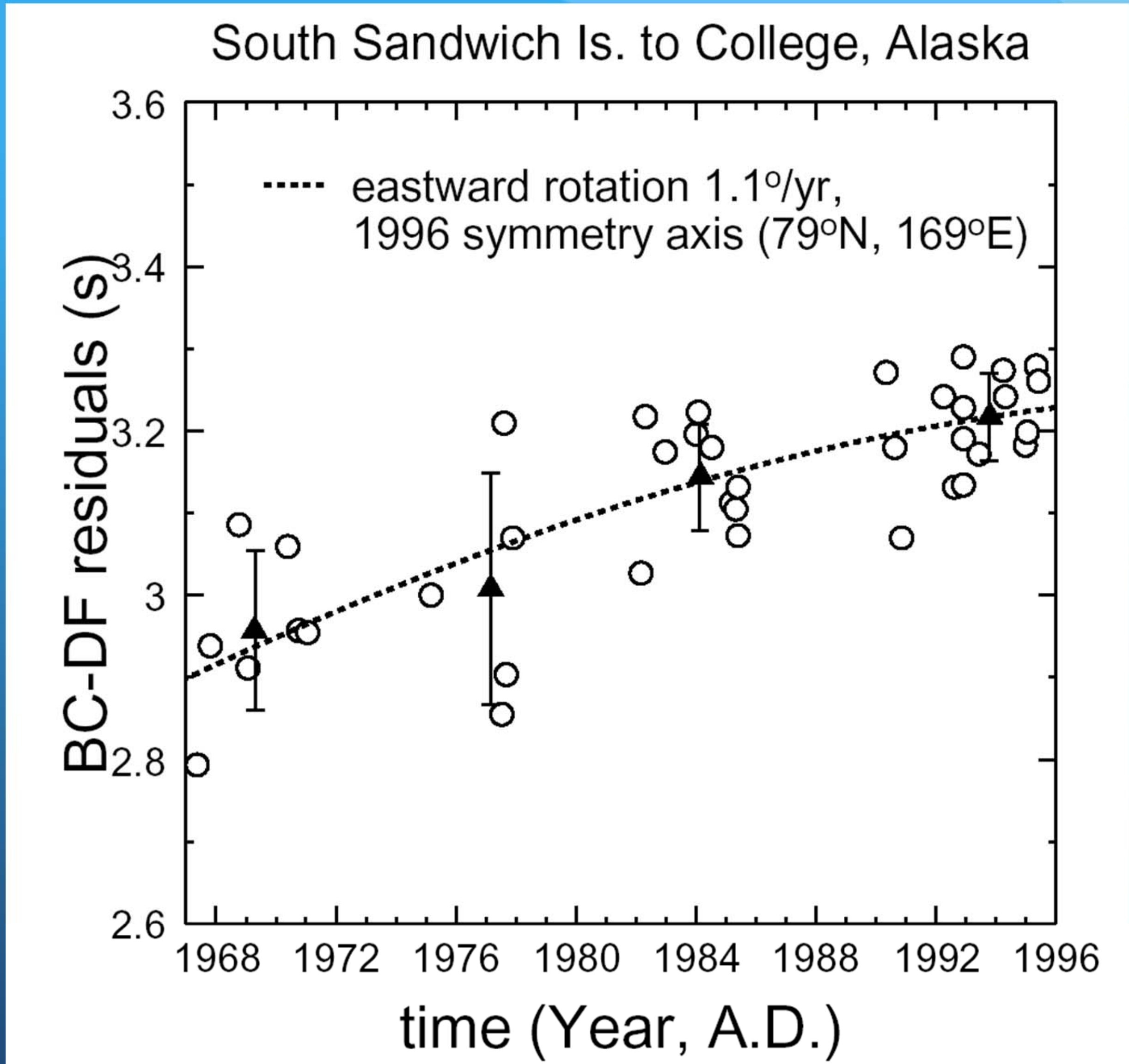


Glatzmaier and Roberts, Science, 1996


Station
RAY PATHS
Inner core's pole of symmetry is tilted 10° away from earth's axis
INNER CORE
OUTER CORE
Earthquake

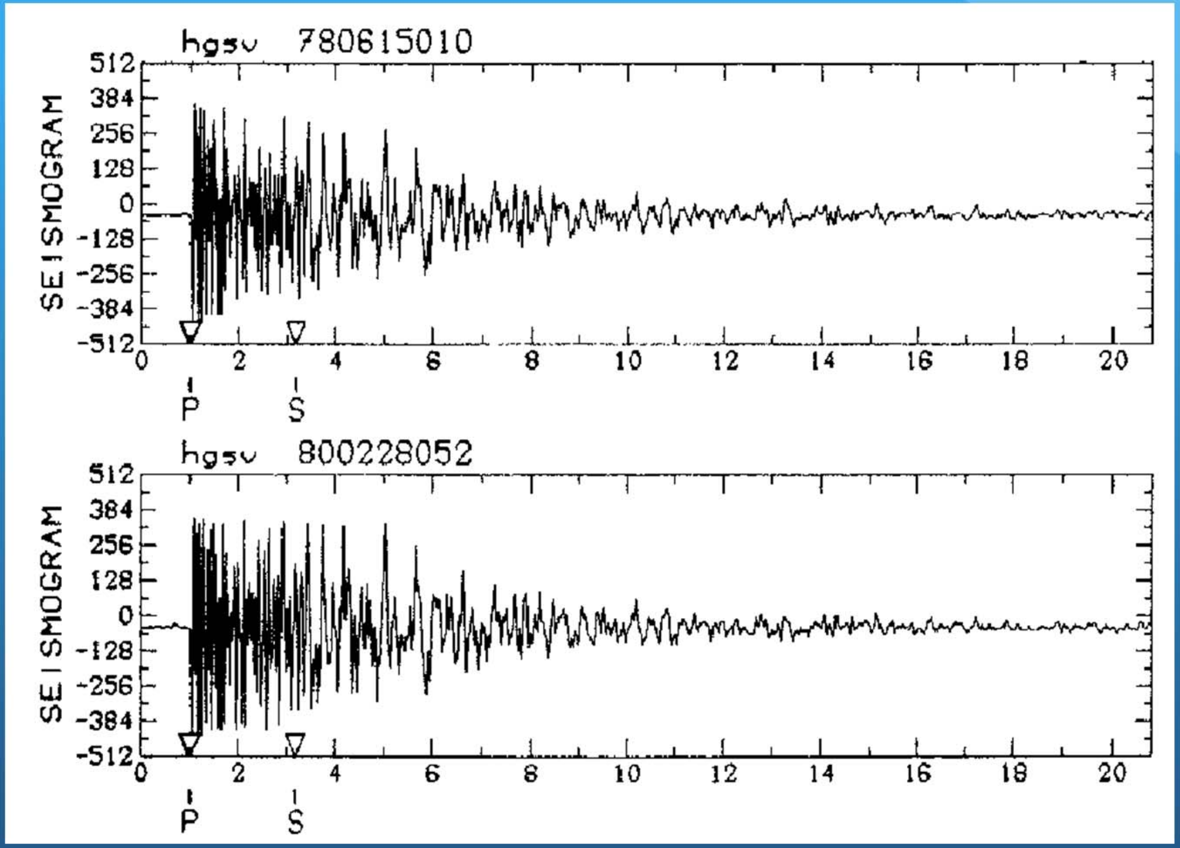


Song and Richards, Nature, 1996



Song and Richards, Nature, 1996

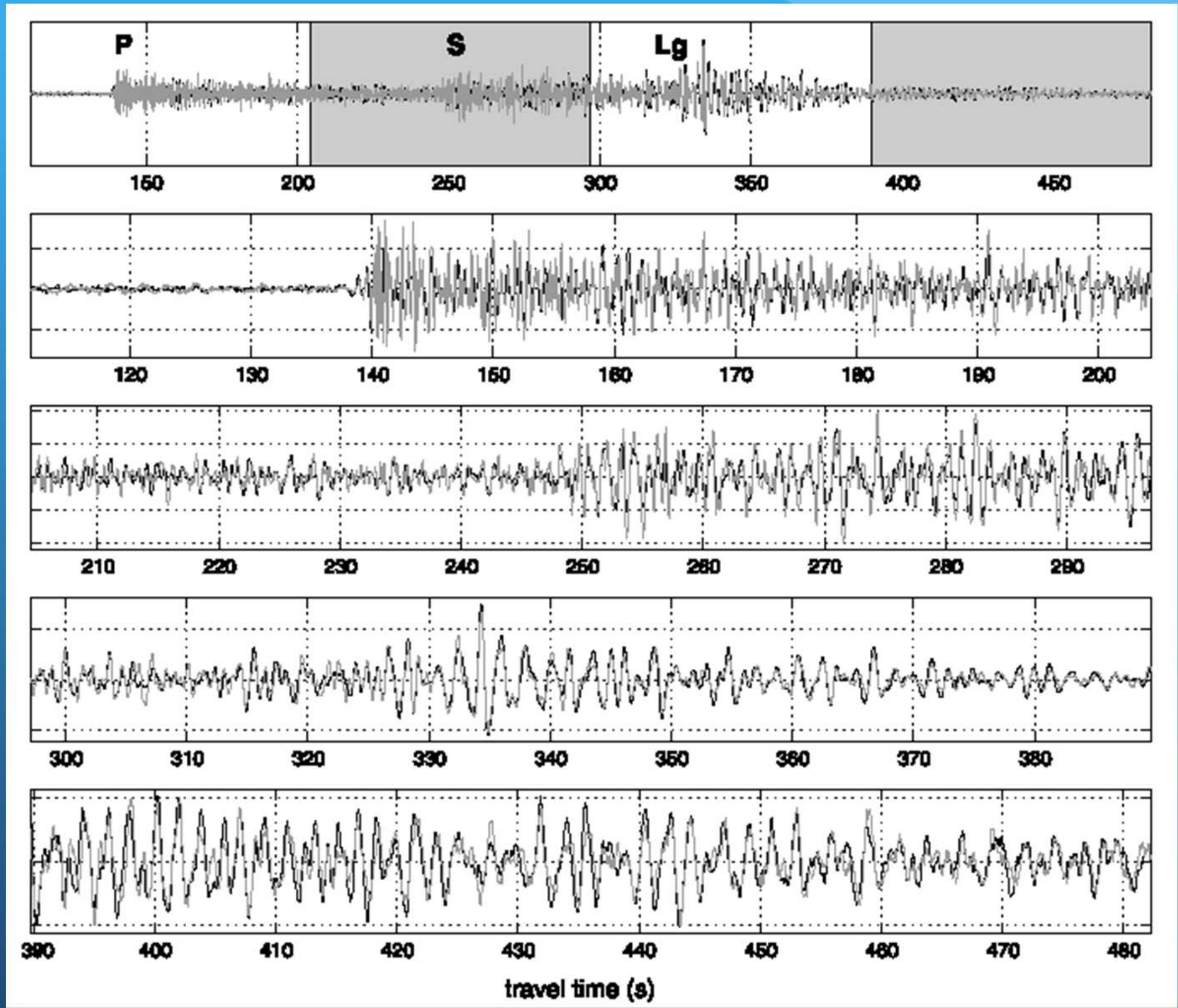
Earthquake doublets



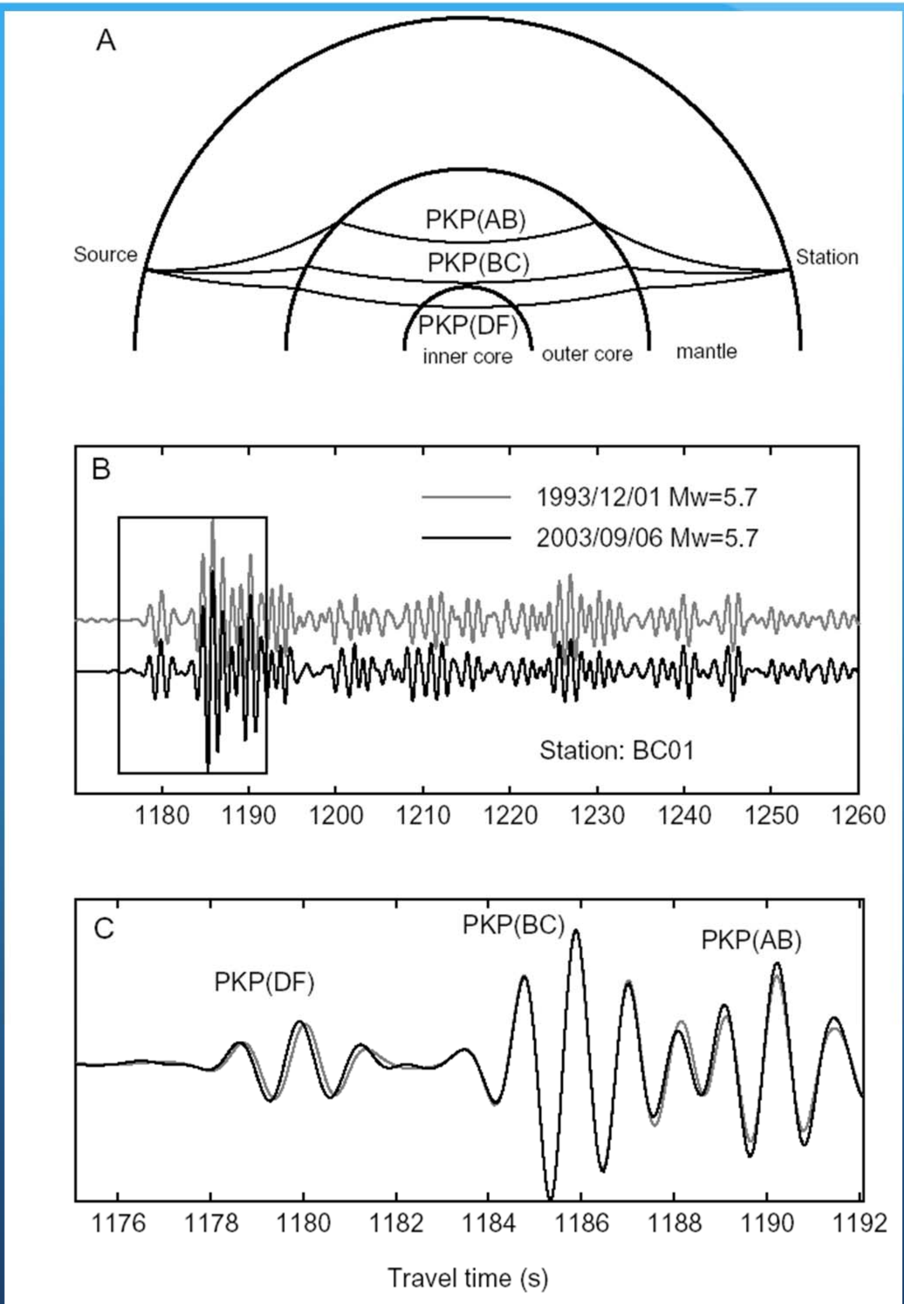
Poupinet, Frechet, and Ellsworth, JGR, 1984:

Monitoring velocity variations in the crust using earthquake doublets: an application to the Calaveras Fault, California.

An example of earthquake doublets

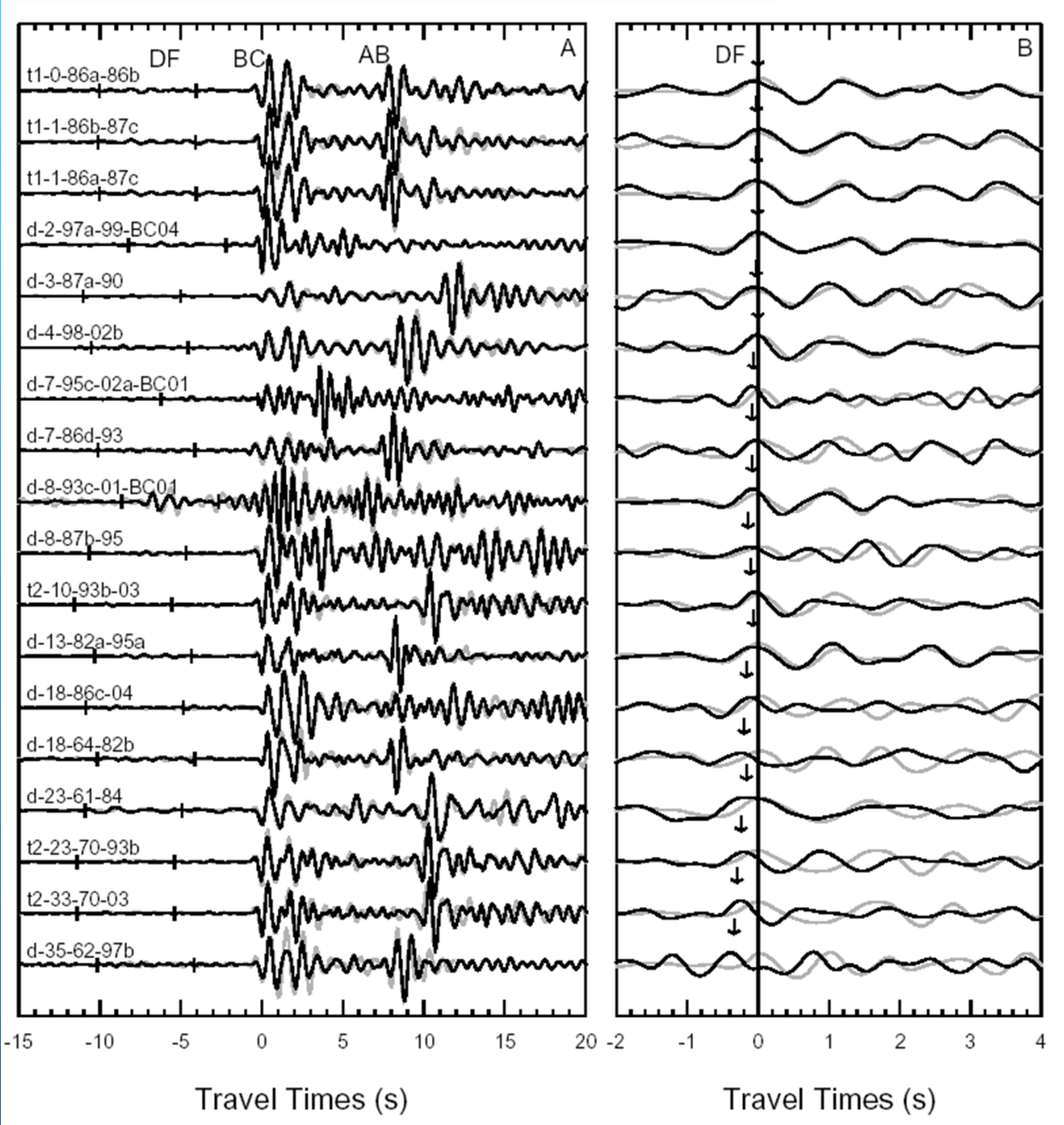


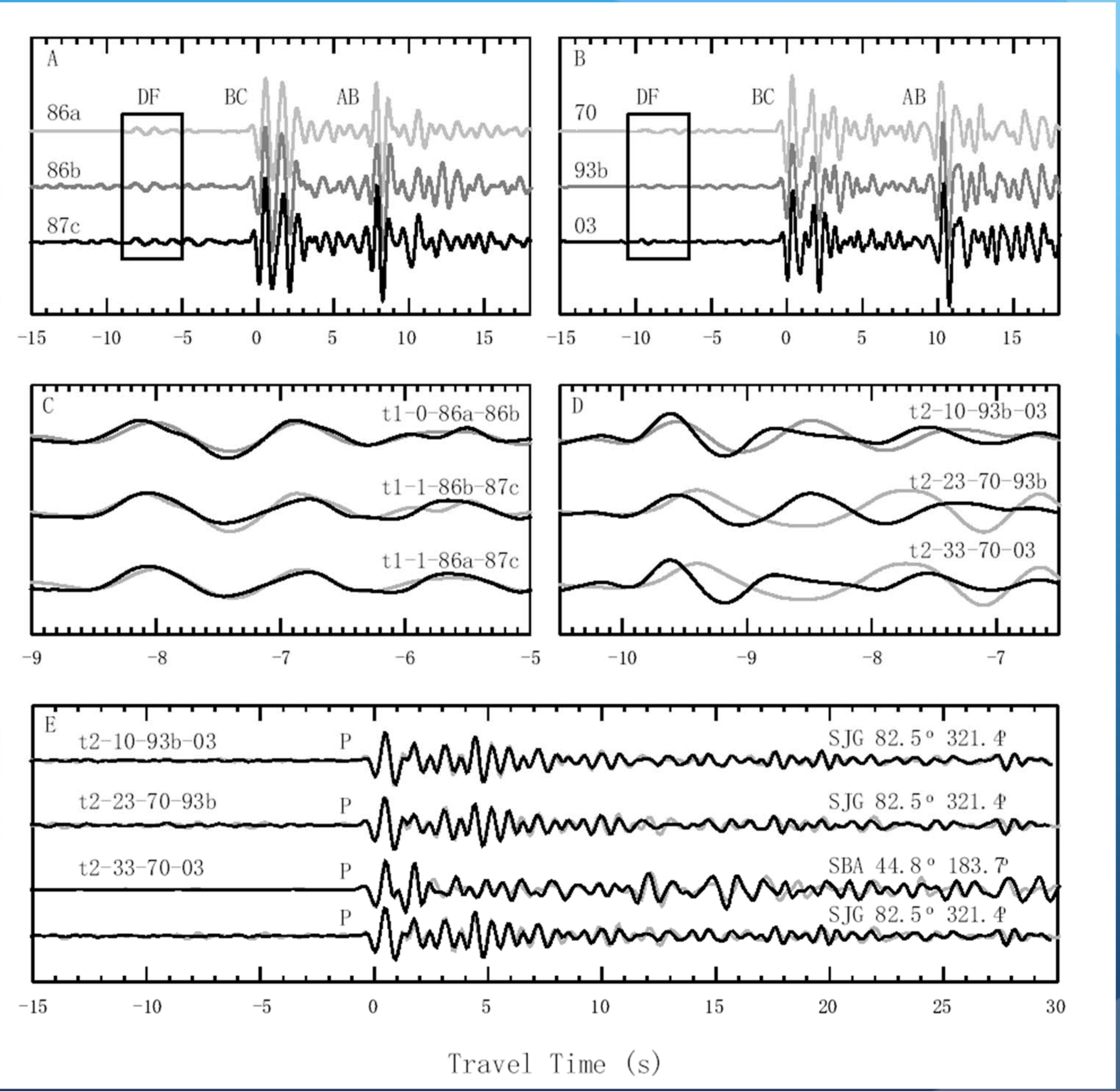
Schaff and Richards, Science, 2004



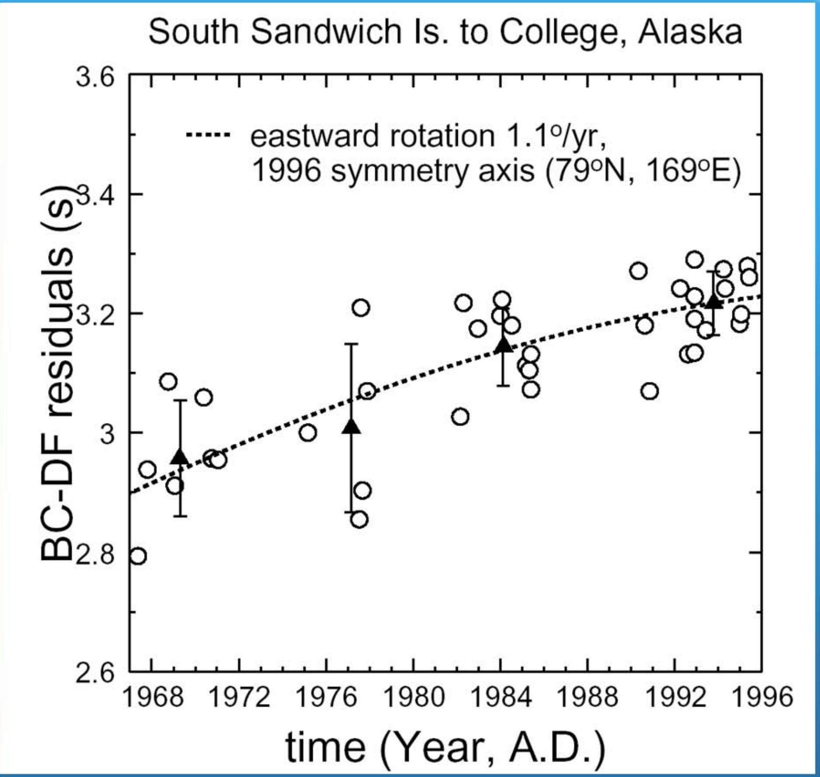
Zhang et al., submitted to Science, 2005

South Sandwish Is. Doublets Recorded at College, AK



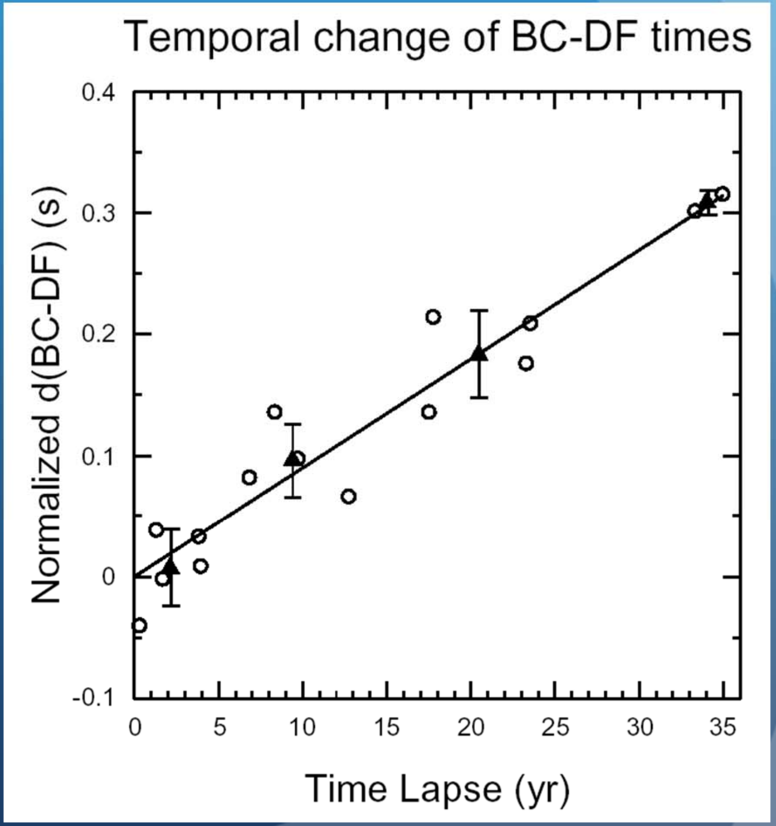


A
86a
86b
87c
DF
BC
AB
B
70
93b
03
C
t1-0-86a-86b
t1-1-86b-87c
t1-1-86a-87c
D
t2-10-93b-03
t2-23-70-93b
t2-33-70-03
E
t2-10-93b-03
t2-23-70-93b
t2-33-70-03
P
SJG 82.5° 321.4°
SBA 44.8° 183.7°
Travel Time (s)



Song and Richards, 1996:

Slope=0.0109 +/- 0.0014 s/year



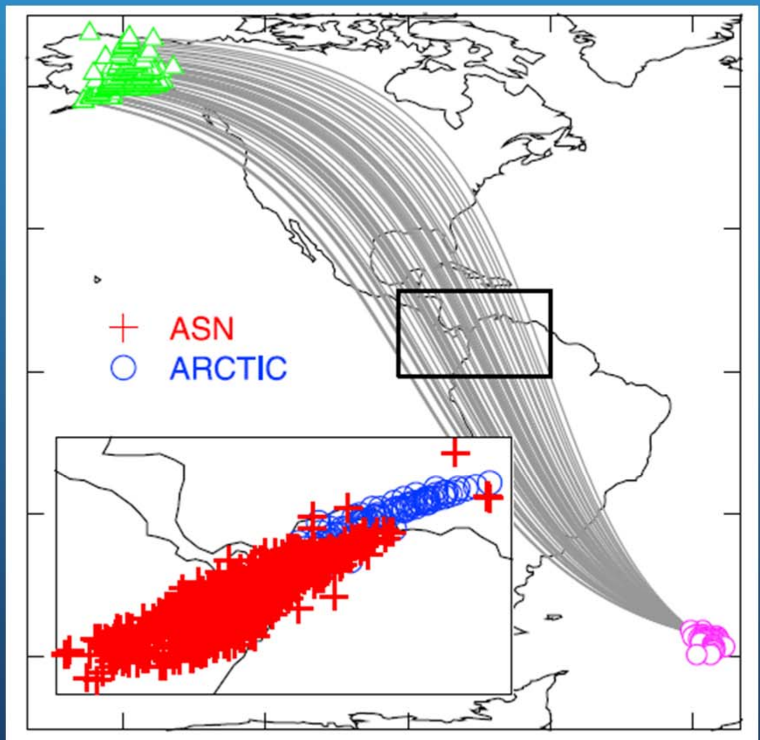
Measurements from doublets:

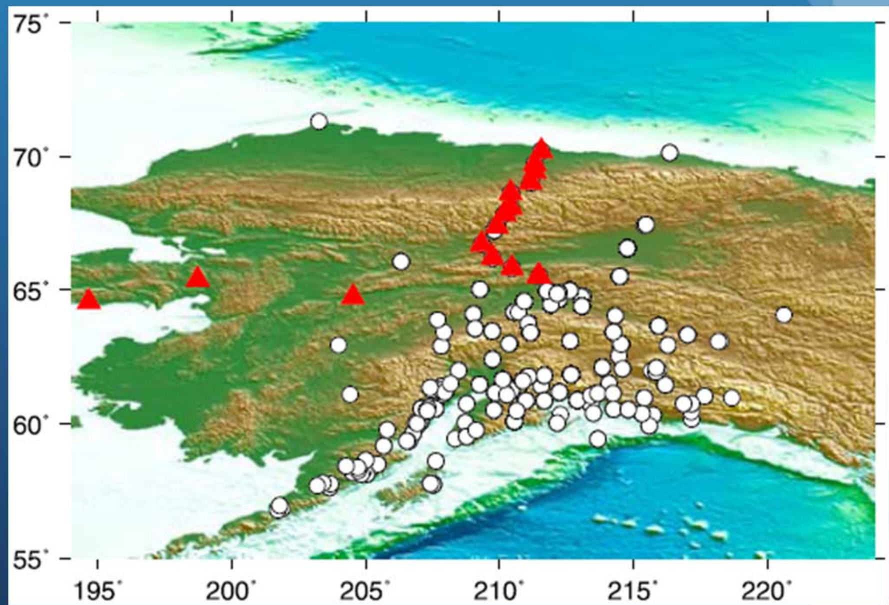
Slope=0.0090 +/- 0.0005 s/year

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, B04307, doi:10.1029/2009JB006294, 2010

Inner core rotation and its variability from nonparametric modeling

Daniela Lindner,[1] Xiaodong Song,[1] Ping Ma,[2] and Doug H. Christensen[3]






Arctic Circle
Dalton Highway ALASKA Latitude 66° 33'

Geophys. J. Int. (2008) **175**, 386–399 doi: 10.1111/j.1365-246X.2008.03909.x

Topography of Earth's inner core boundary from high-quality waveform doublets

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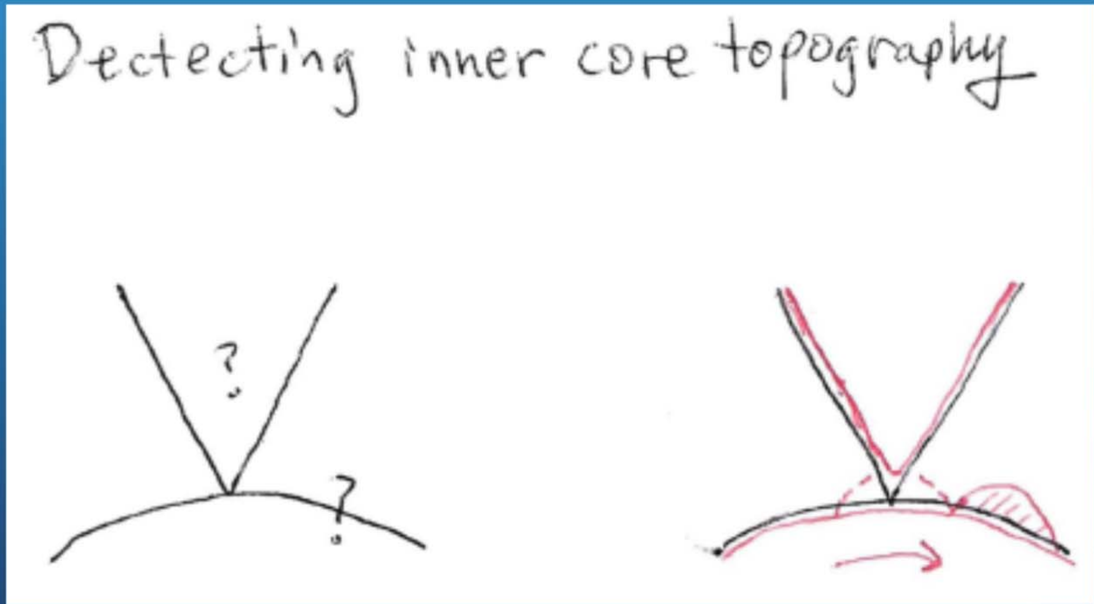
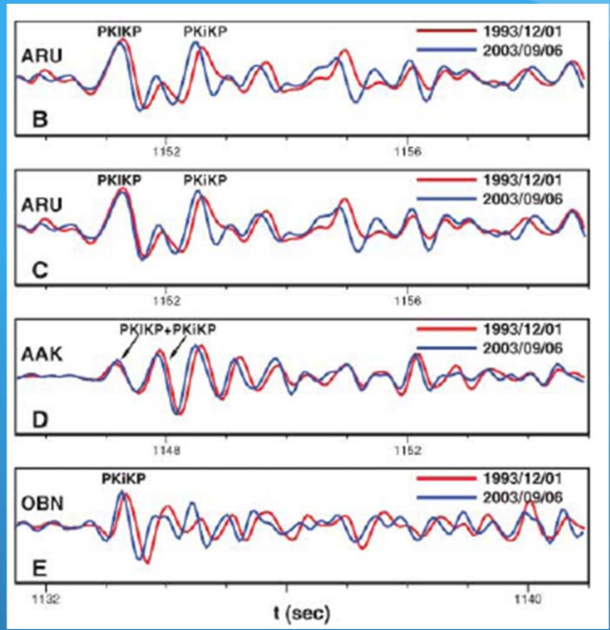
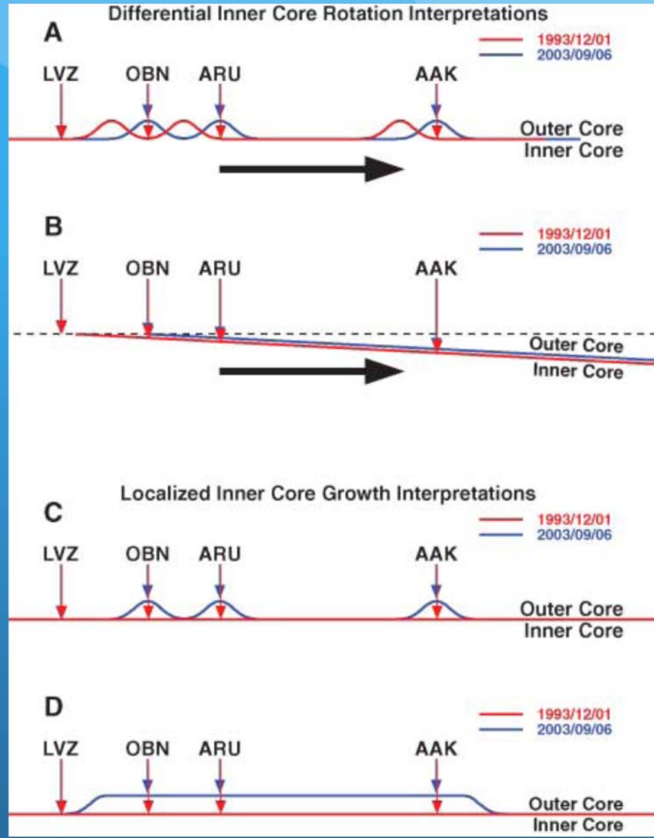
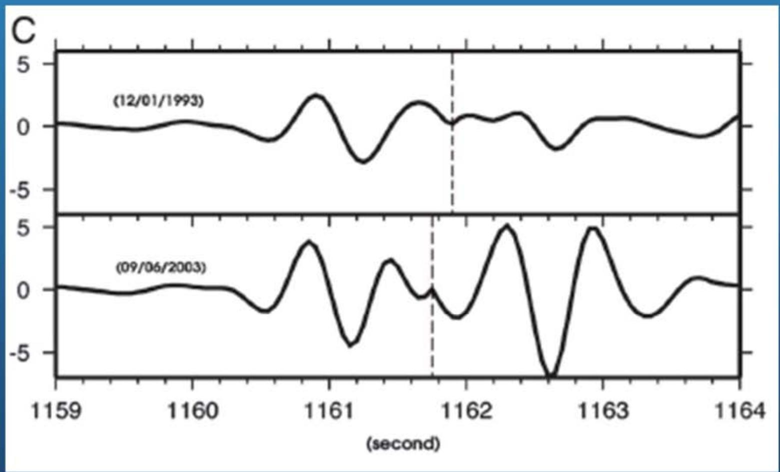
Department of Geology, University of Illinois, Urbana, IL 61801, *USA. E-mail: xsong@uiuc.edu*

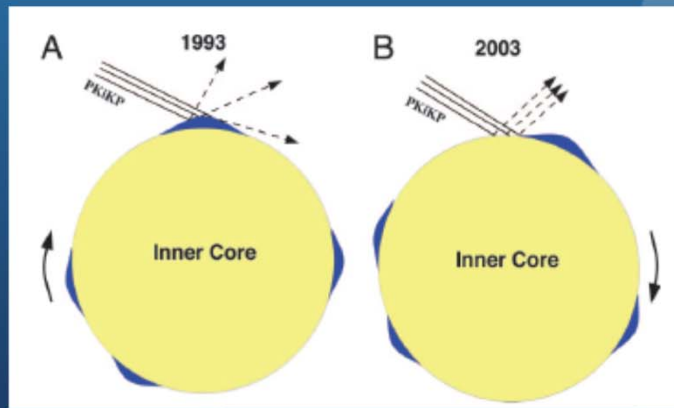


Wen, Science, 2006



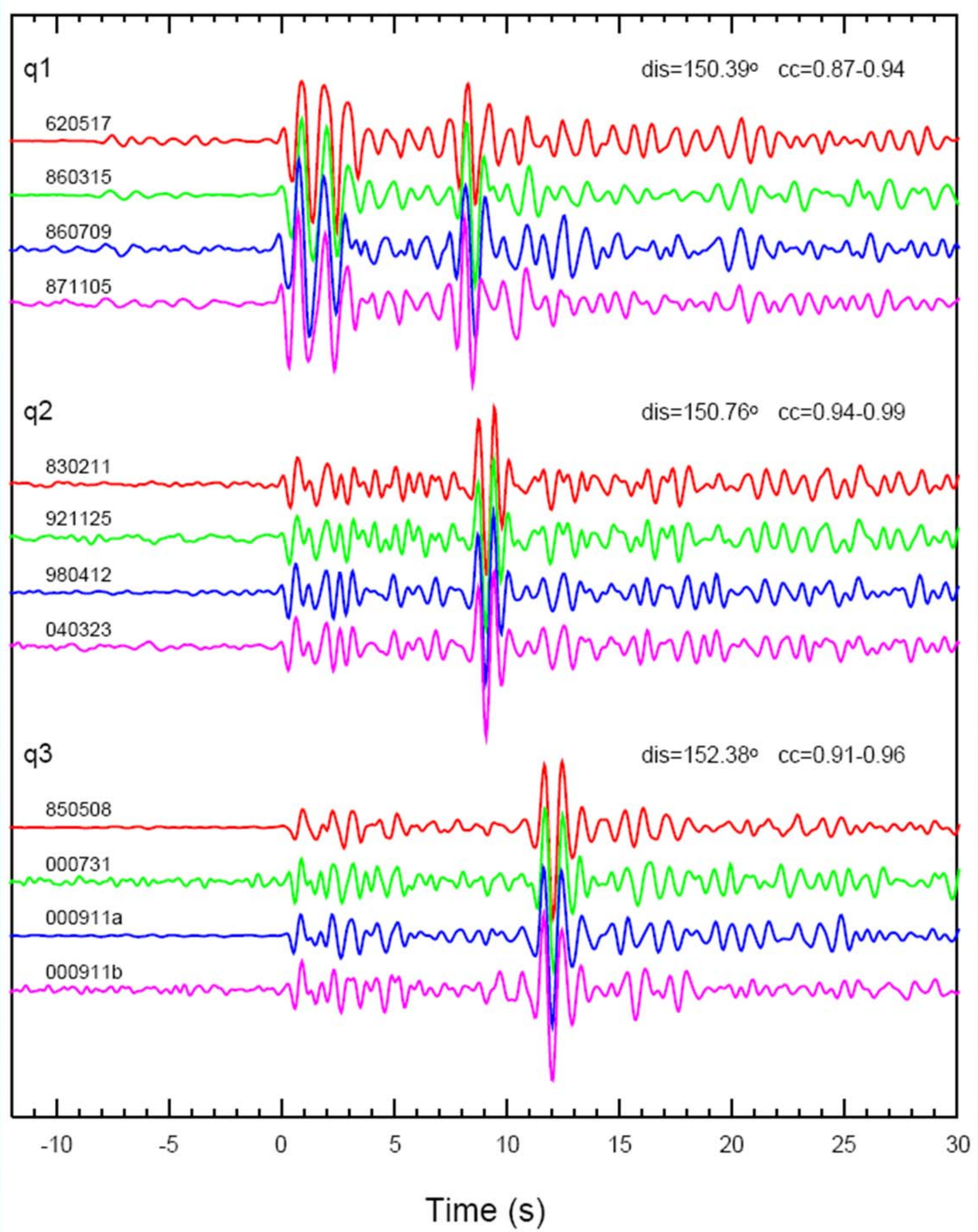


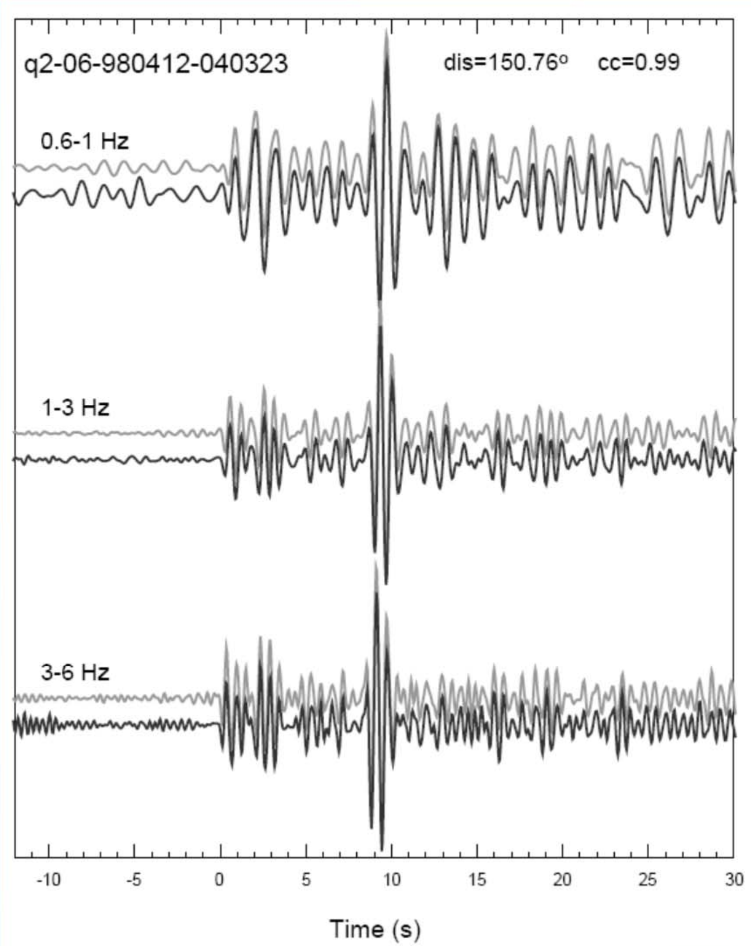




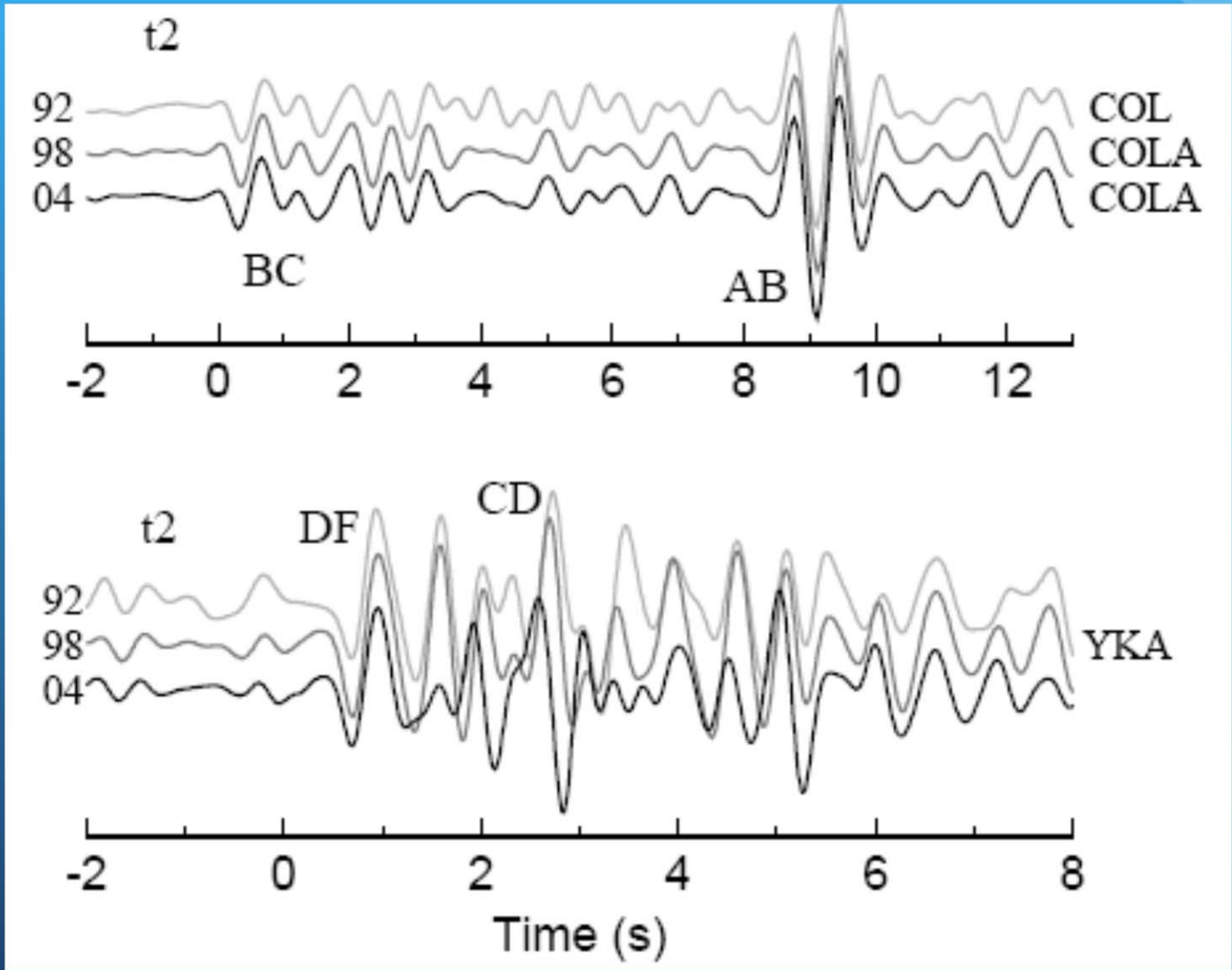
Cao, Masson, Romanowicz, PNAS, 2007

Examples of waveform doublets





A triplet from S. Sandwich Is. to Yellow Knife Array (YKA)

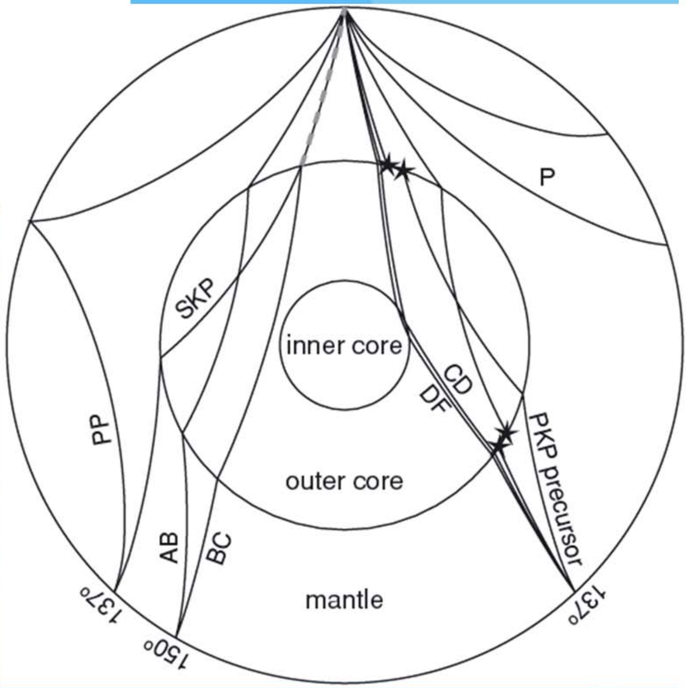


Song and Dai, GJI, 2008

Geophys. J. Int. (2008) 175, 386–399 doi: 10.1111/j.1365-246X.2008.03909.x

Topography of Earth's inner core boundary from high-quality waveform doublets

Xiaodong Song and Wei Dai
Department of Geology, University of Illinois, Urbana, IL 61801, USA. E-mail: xsong@uiuc.edu



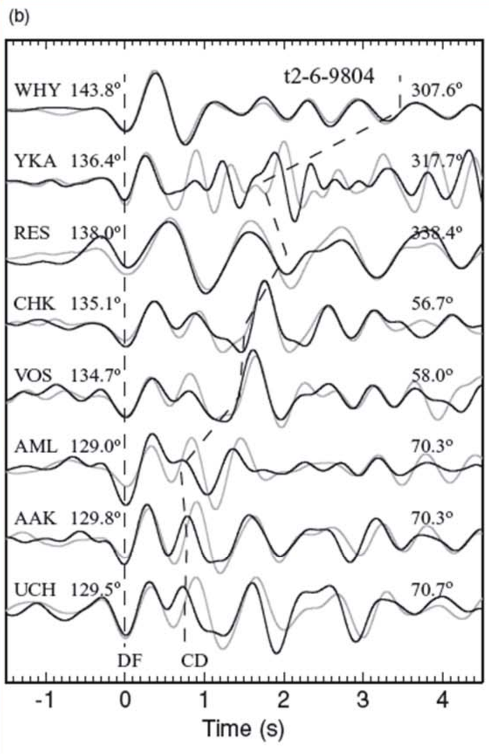


Figure 12. (Continued).

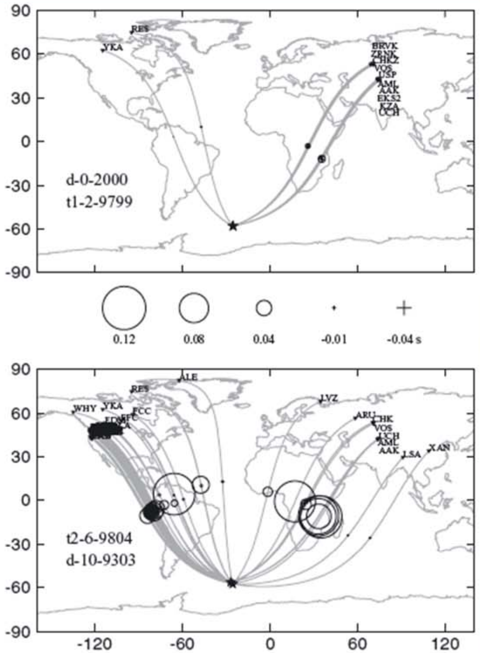
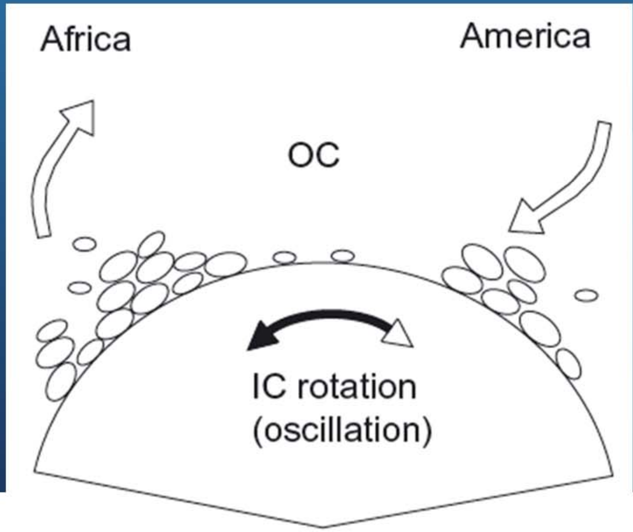
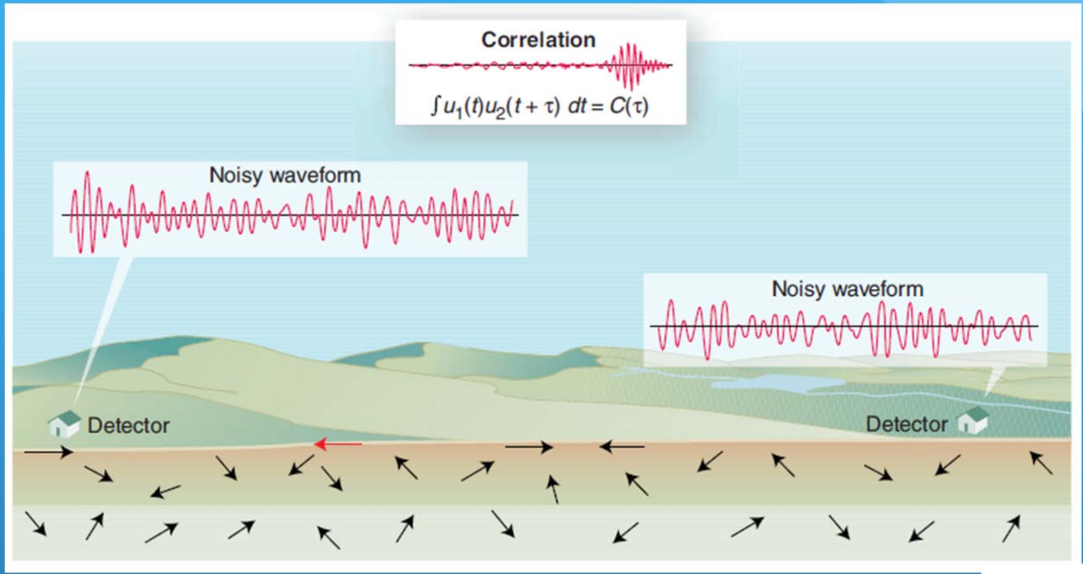
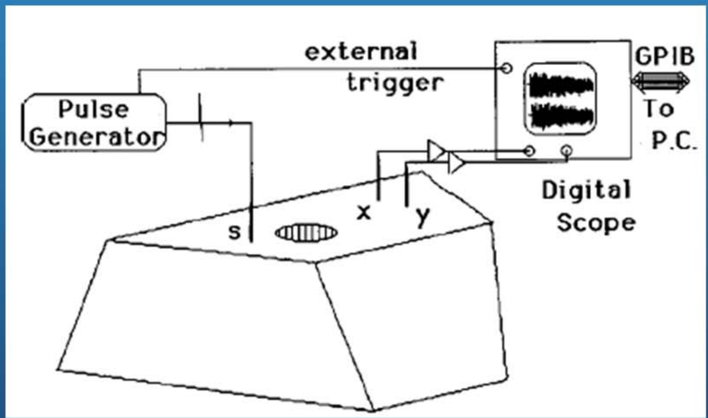


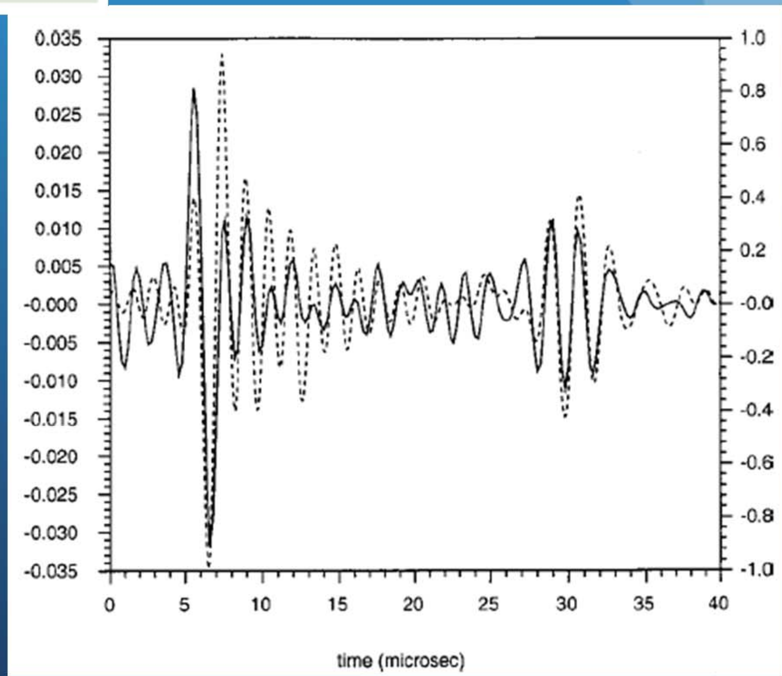
Figure 13. Relative time-shifts (ddt) between CD and DF for doublets with (a) short time separations (9799 and 2000–2000 pairs) and (b) long time separations (9303 and 9804 pairs). The relative time-shifts (circles and crosses) are plotted at the ICB bounce points of the ray paths. The symbol size is proportional to the size of the relative time-shift.





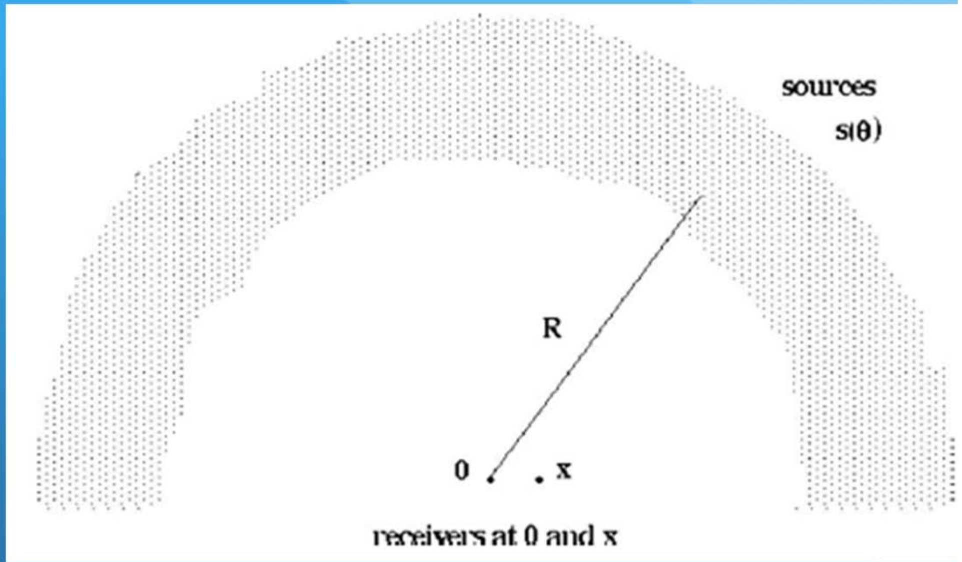
Weaver, Science, 2005

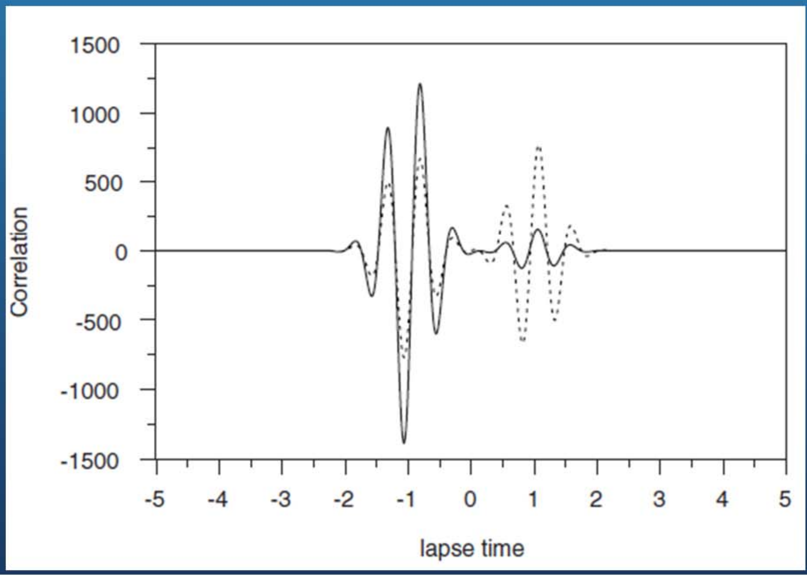




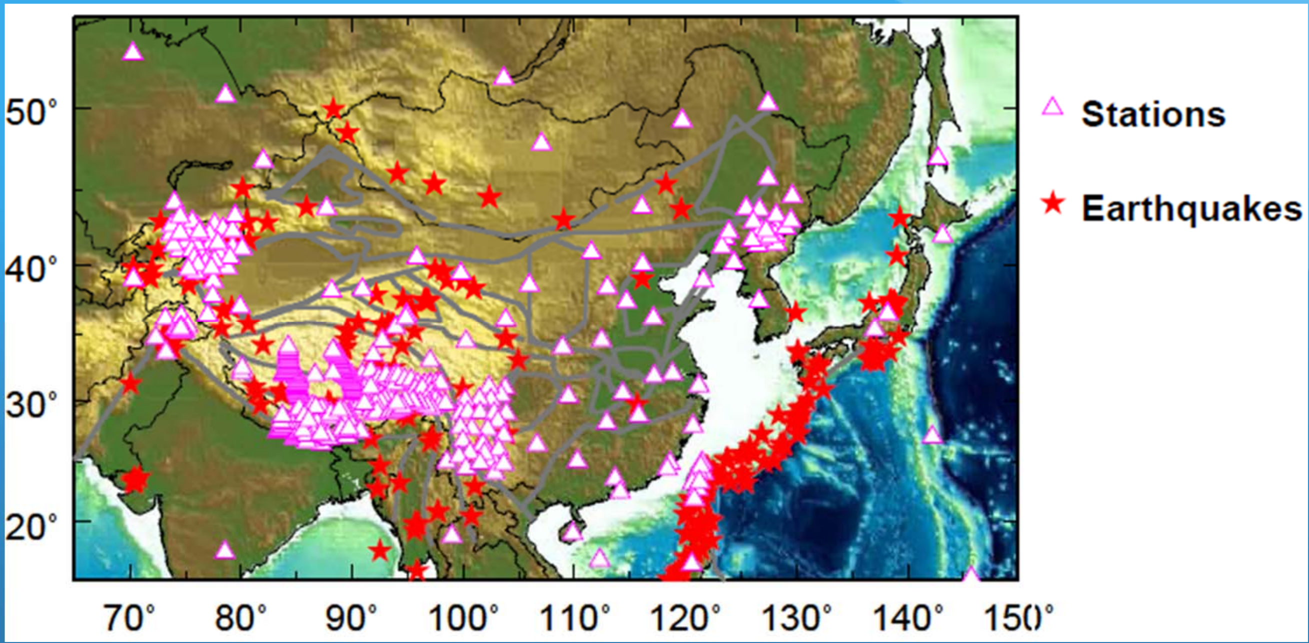
Lobkis and Weaver, JASA, 2001

Noise field does not need to be fully diffuse to obtain accurate travel times!

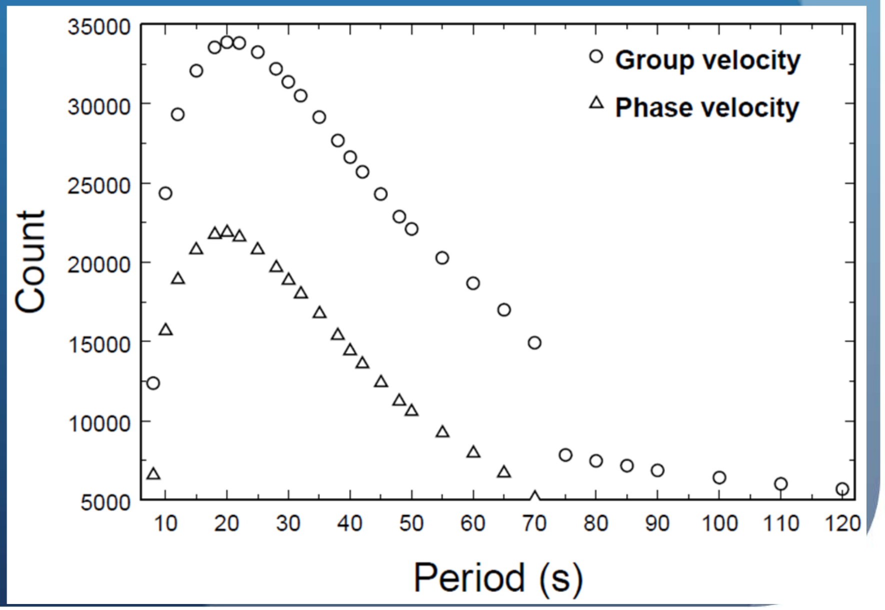


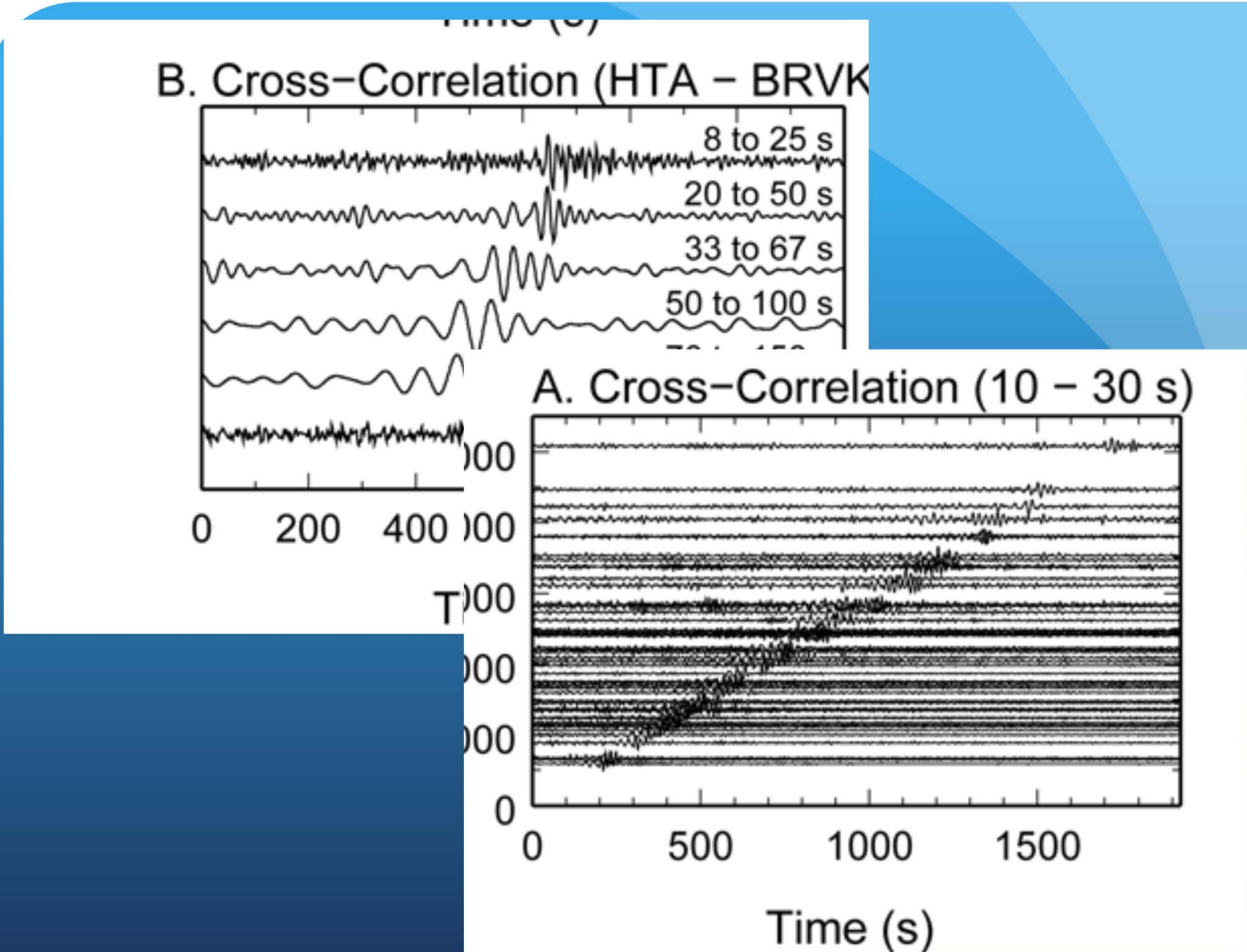


Weaver et al., JASA, 2009

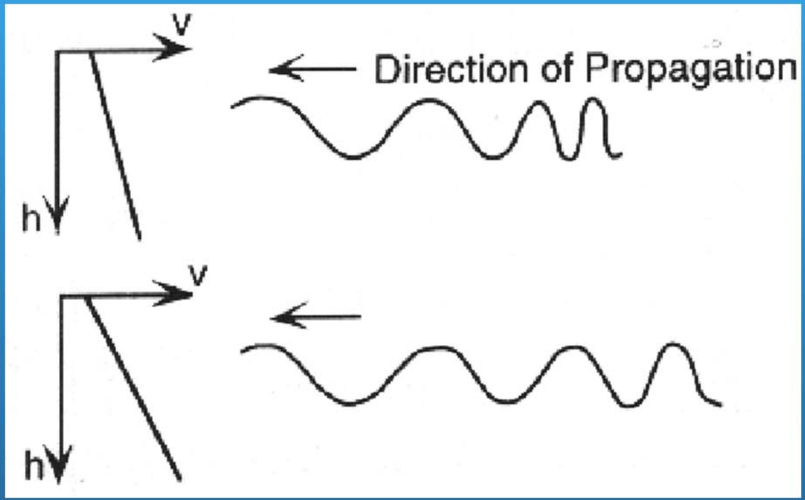


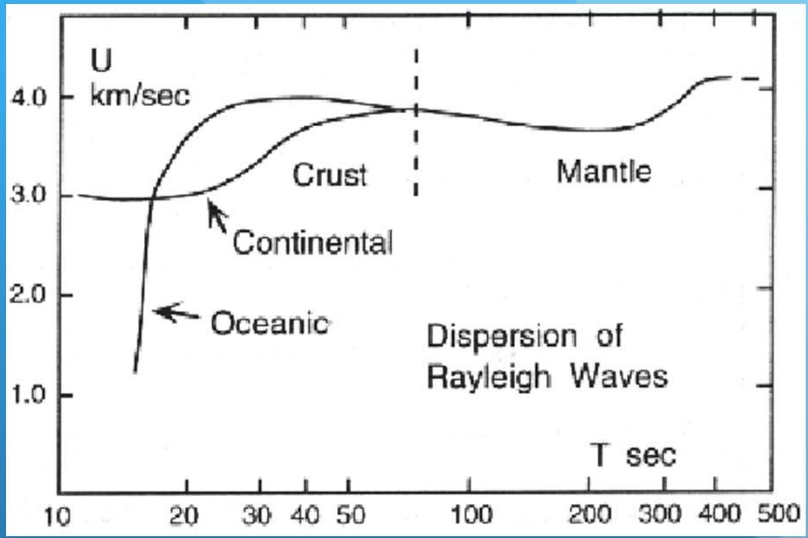
Surface wave tomography: ambient noise + earthquake data



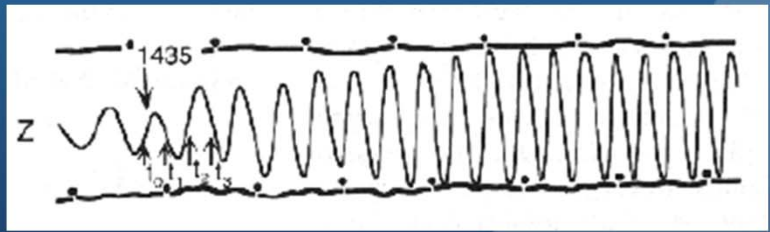


B. Cross−Correlation (HTA − BRVK
8 to 25 s
20 to 50 s
33 to 67 s
50 to 100 s
0
200
400
A. Cross−Correlation (10 − 30 s)
0
0
500
1000
1500
Time (s)

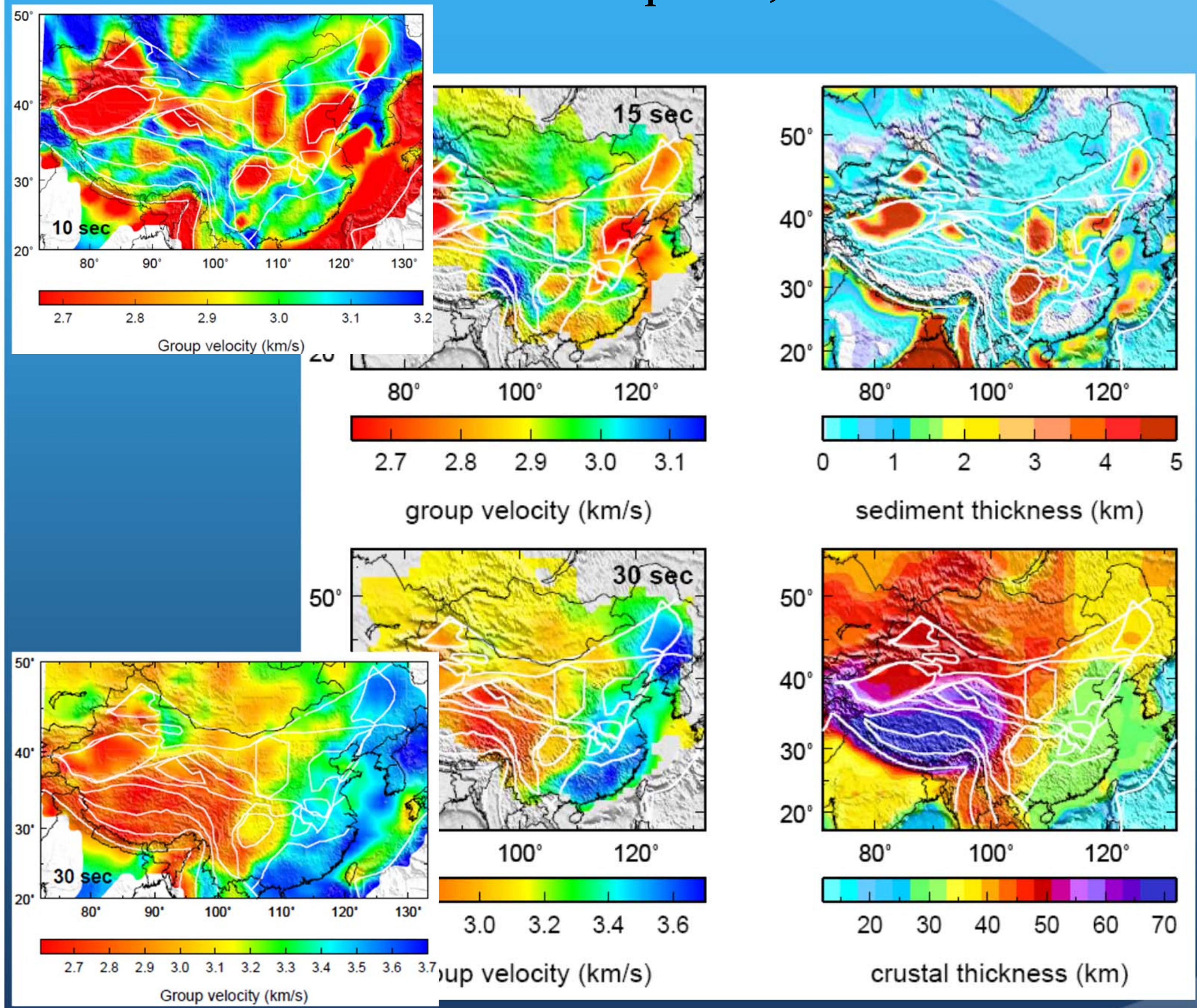




Strong gradient cause
greater dispersion

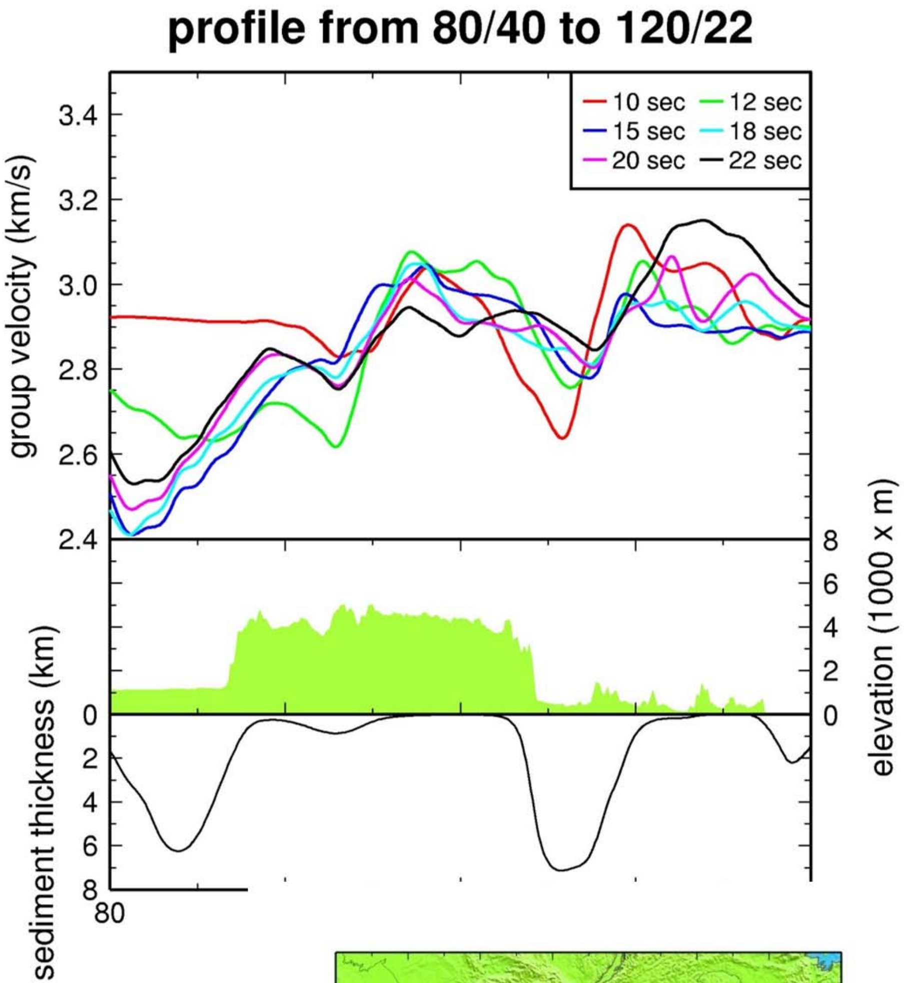


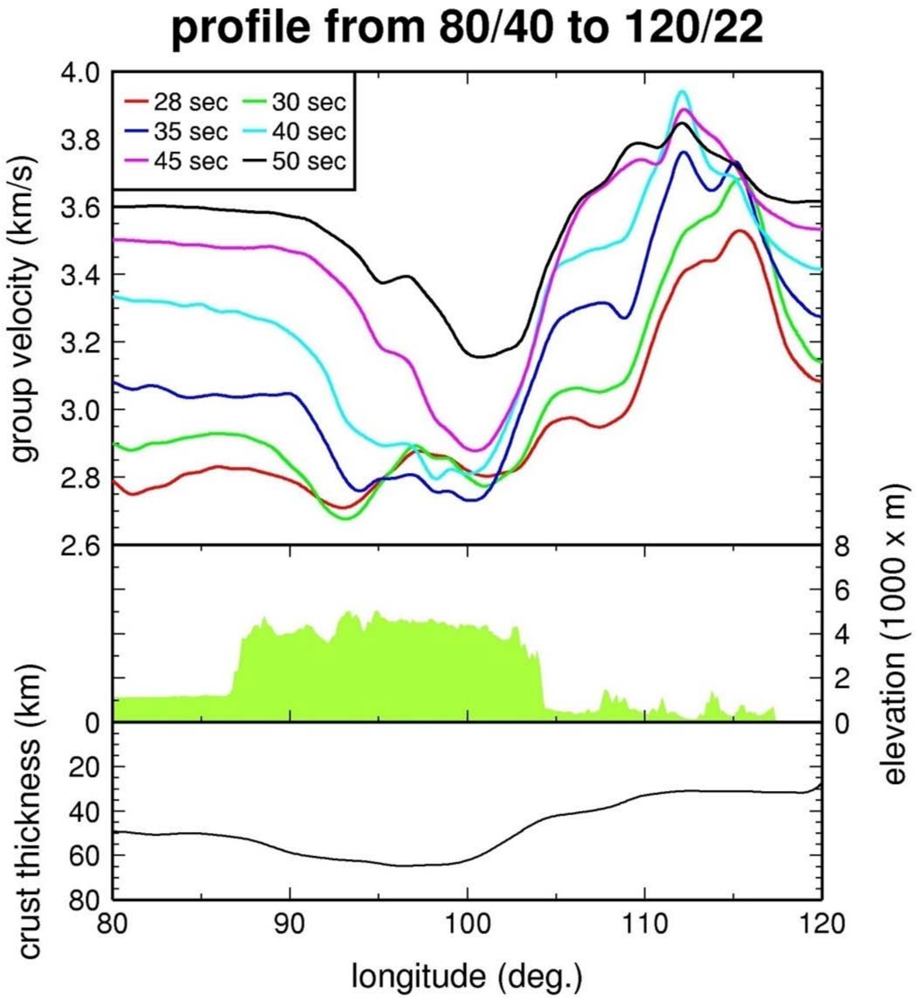
Zheng et al., G3, 2008; Sun et al., Earthq. Sci., 2010

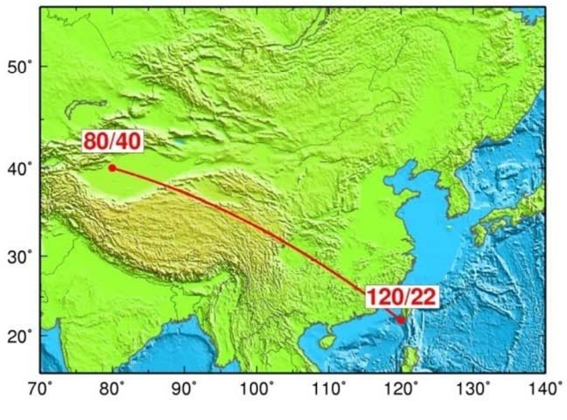


Rayleigh group velocities (10 s) and sediment thickness

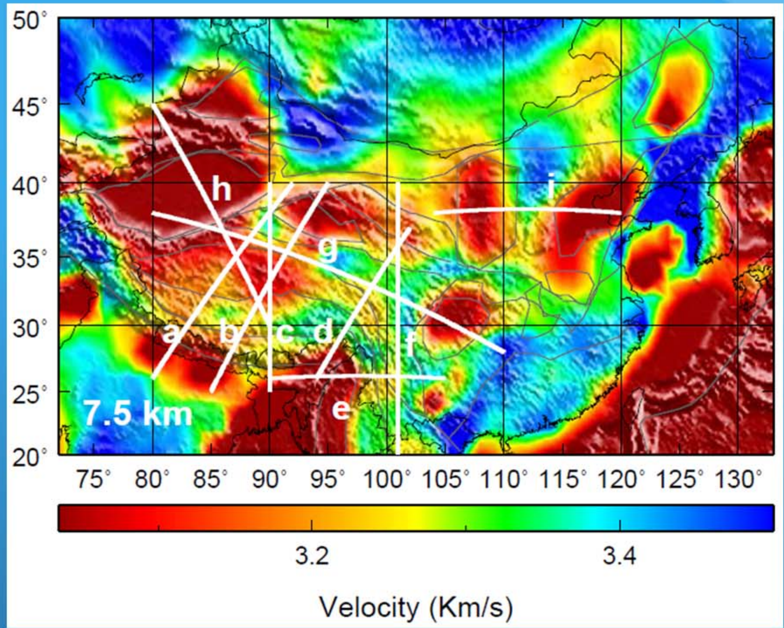
Rayleigh group velocities (30 s) and crustal thikcness



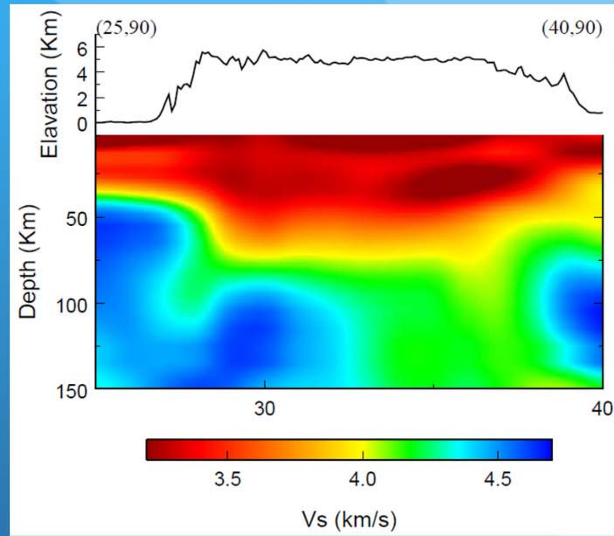


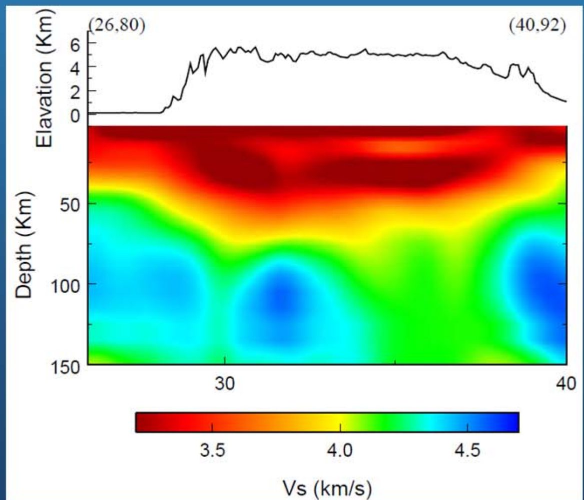


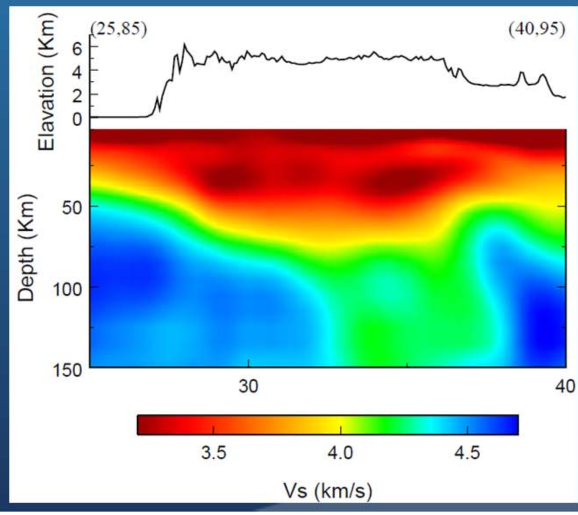
Zheng et al., G3, 2008


50°
45°
40°
35°
30°
25°
20°
75° 80° 85° 90° 95° 100° 105° 110° 115° 120° 125° 130°
h
g
i
a b c d
f
e
7.5 km
3.2
3.4
Velocity (Km/s)

c


(25,90)
(40,90)
Elevation (Km)
6
4
2
0
Depth (Km)
50
100
150
30
40
3.5
4.0
4.5
Vs (km/s)

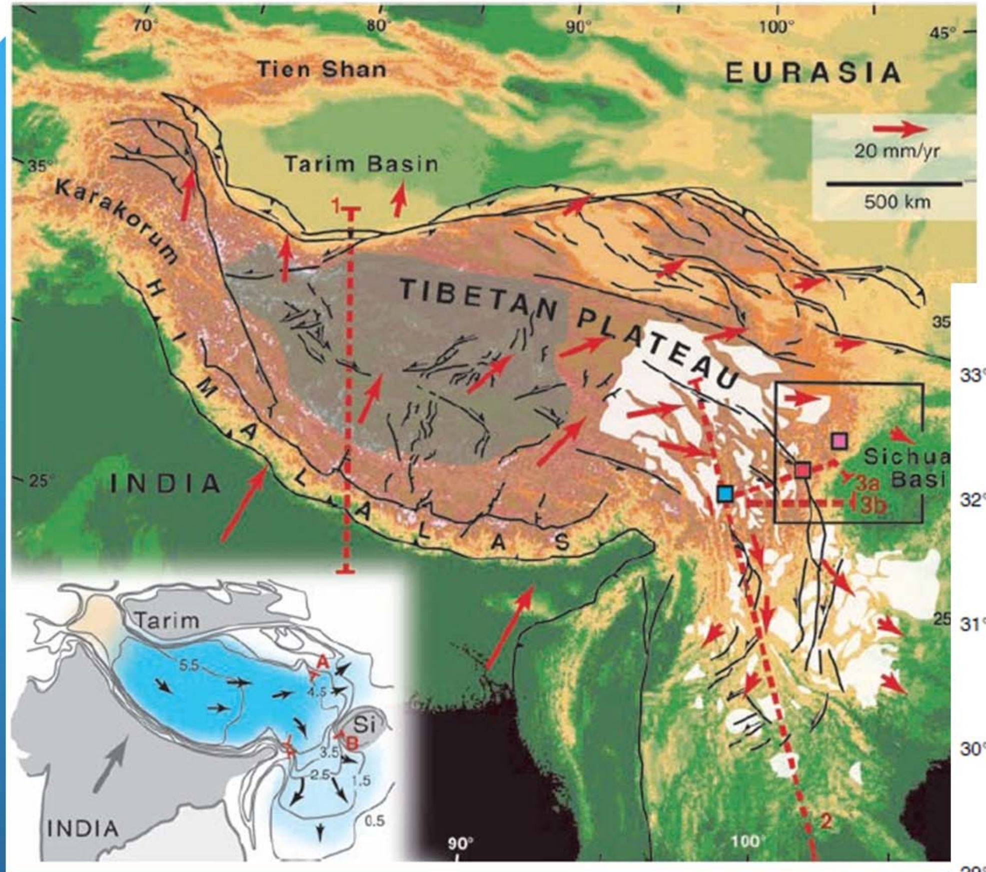

(26,80)
(40,92)
Elevation (Km)
6
4
2
0
Depth (Km)
50
100
150
30
40
3.5
4.0
4.5
Vs (km/s)

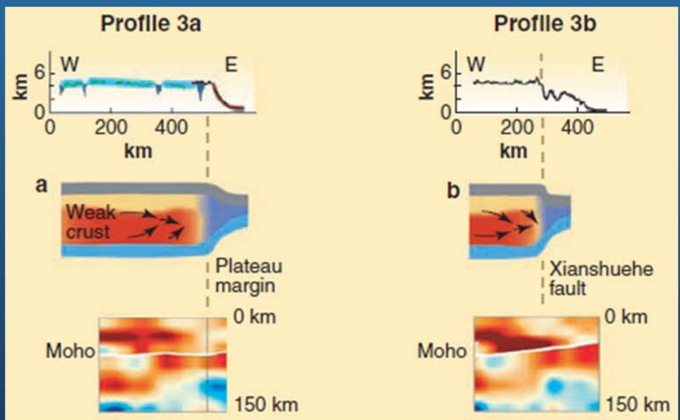

(25,85)
(40,95)
Elevation (Km)
6
4
2
0
Depth (Km)
50
100
150
30
40
3.5
4.0
4.5
Vs (km/s)

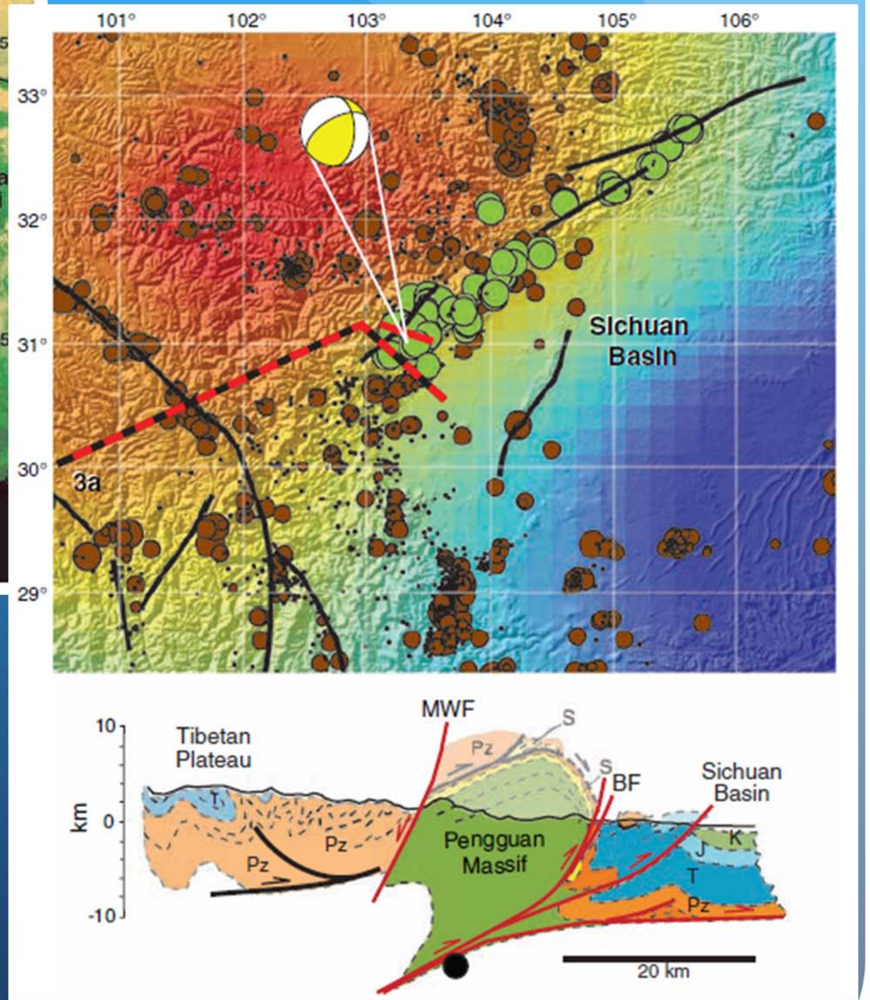
b

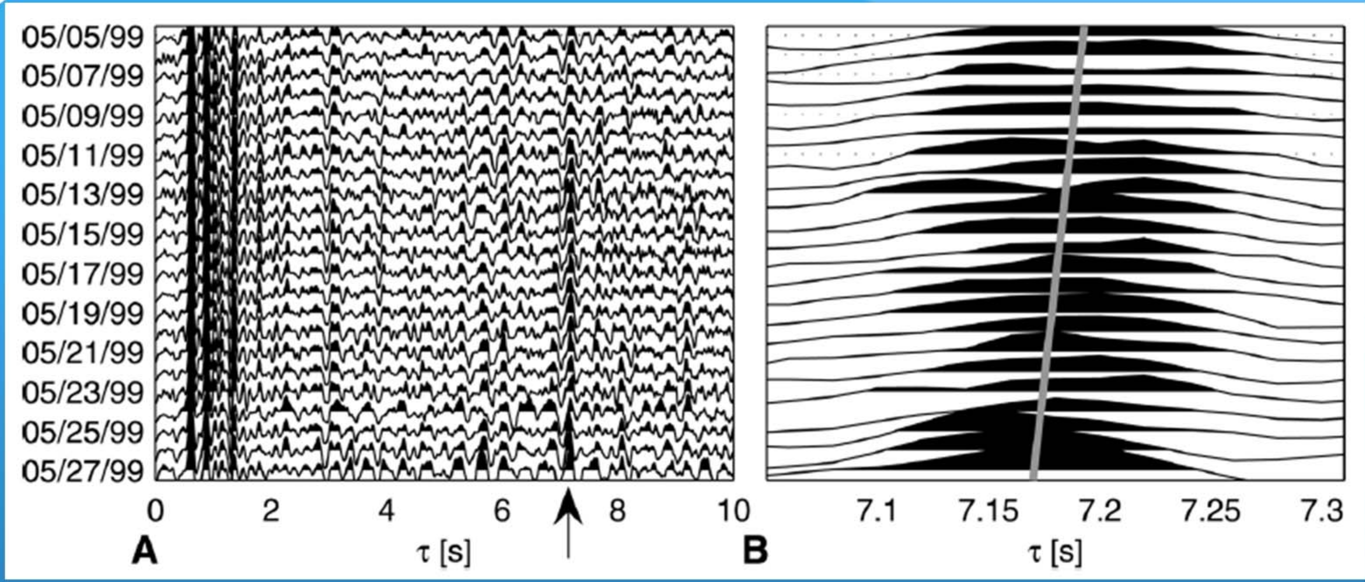
a

Royden et al., Science, 2008

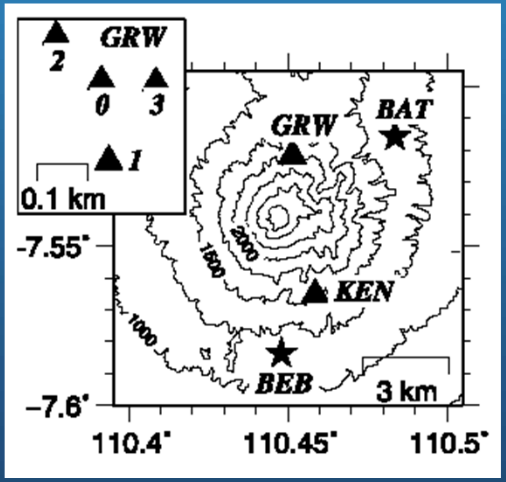








Green function between GRW0 and GRW1

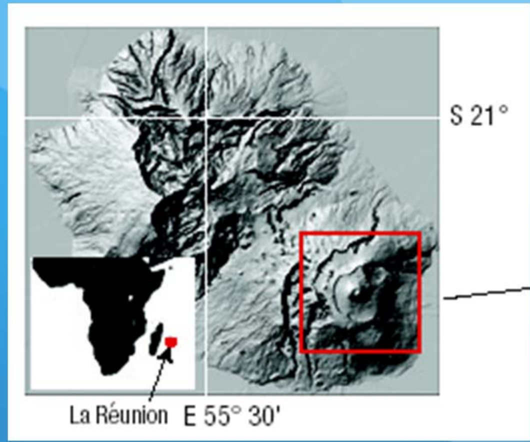


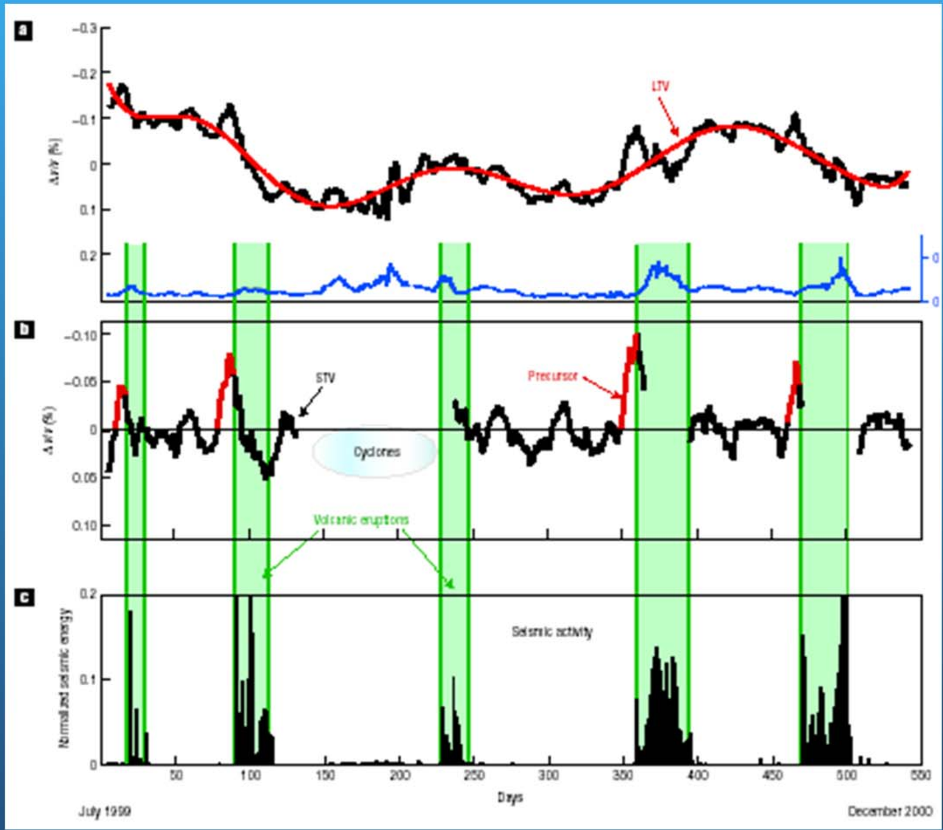
Clear time shifts in the coda (0.015% per day). The temporal shifts show show a strong seasonal influence, which are explained by precipitation and ground water level fluctuation.

Merapi Vocano, Indonesia

Sens-Schonfelder and Wegler, GRL, 2006

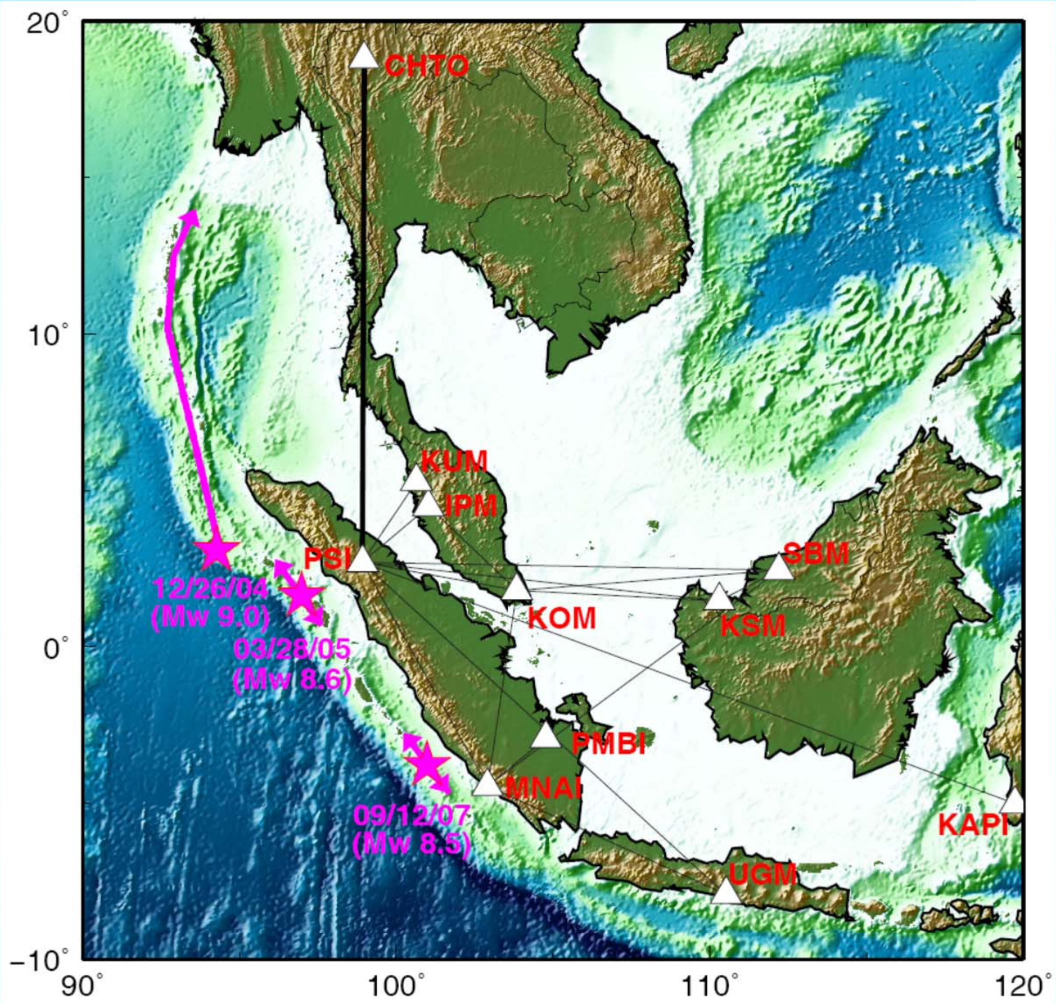
Volcano monitoring and forcasting





Brenguier et al., Nature Geoscience, 2008

The Piton de la Fournaise volcano, La Reunion island. Green functions from ambient noise correlation show decrease prior to eruptions (of the order of 0.05%), which is explained by inflation of volcano edifices.

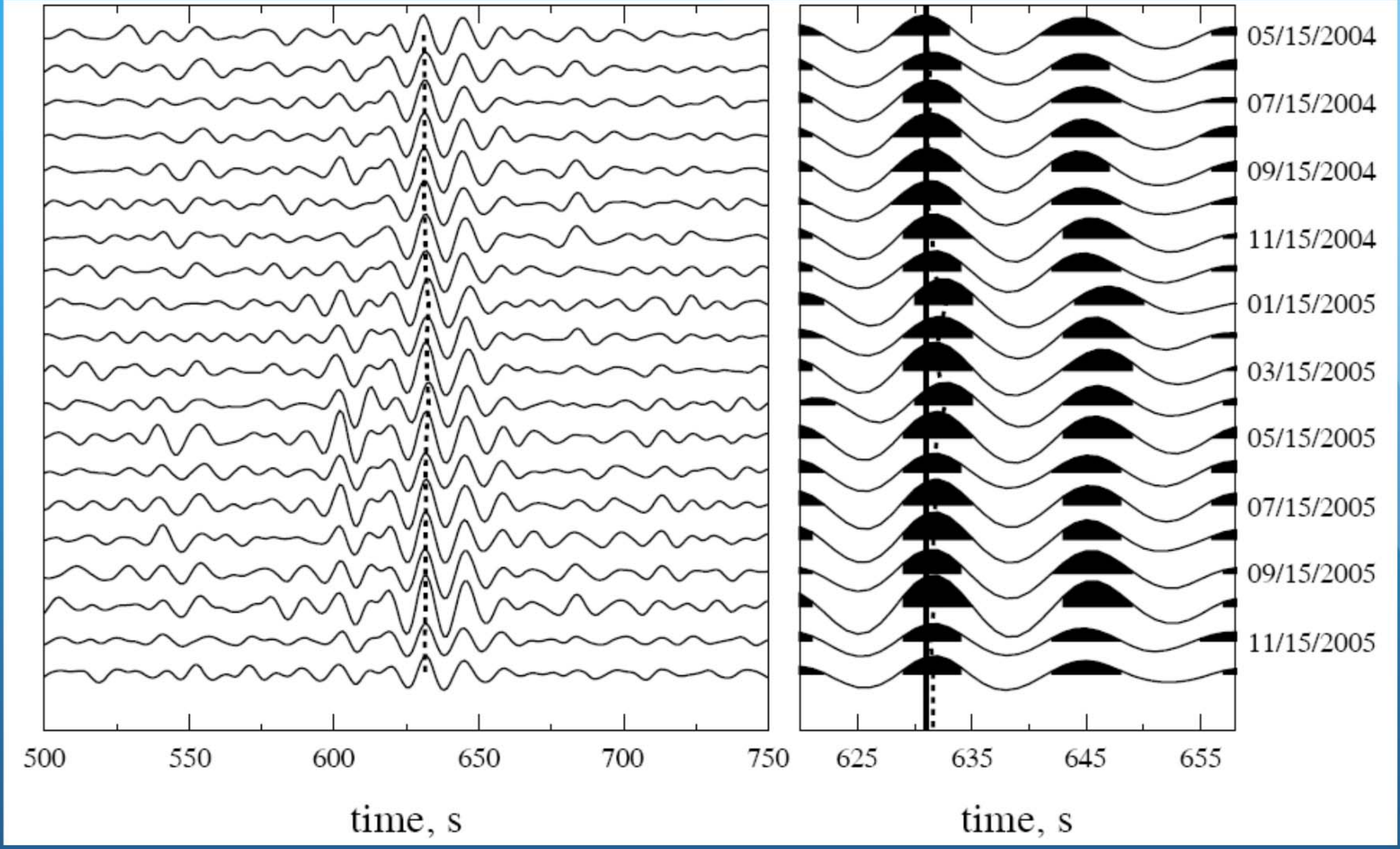


Sumatra earthquakes:

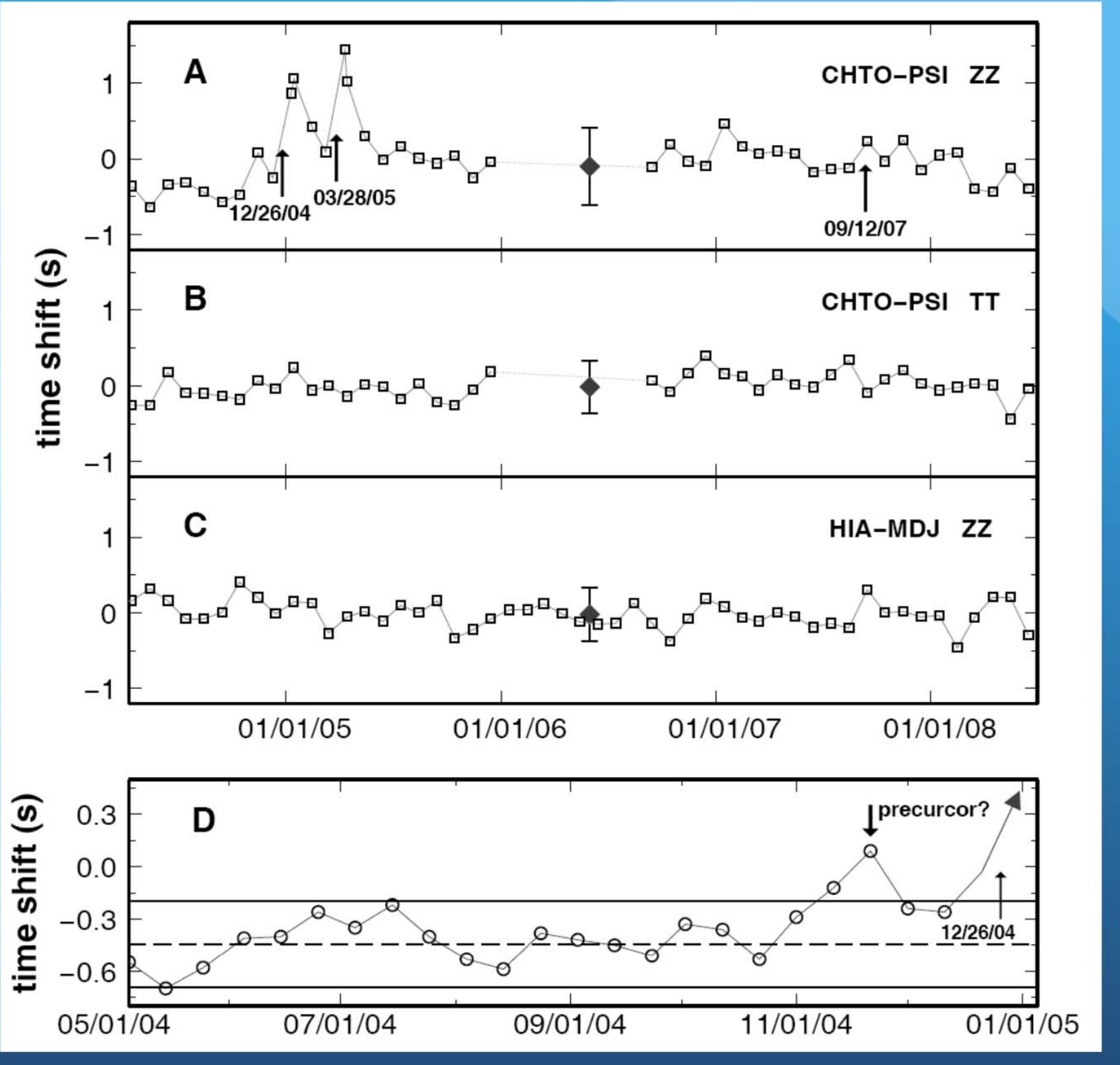
2004/12/26 1: 1: 9.0, 3.09
94.26 28.6, Mw = 9.0

2005/ 3/28 16:10:31.5, 1.67
97.07 25.8, Mw = 8.6

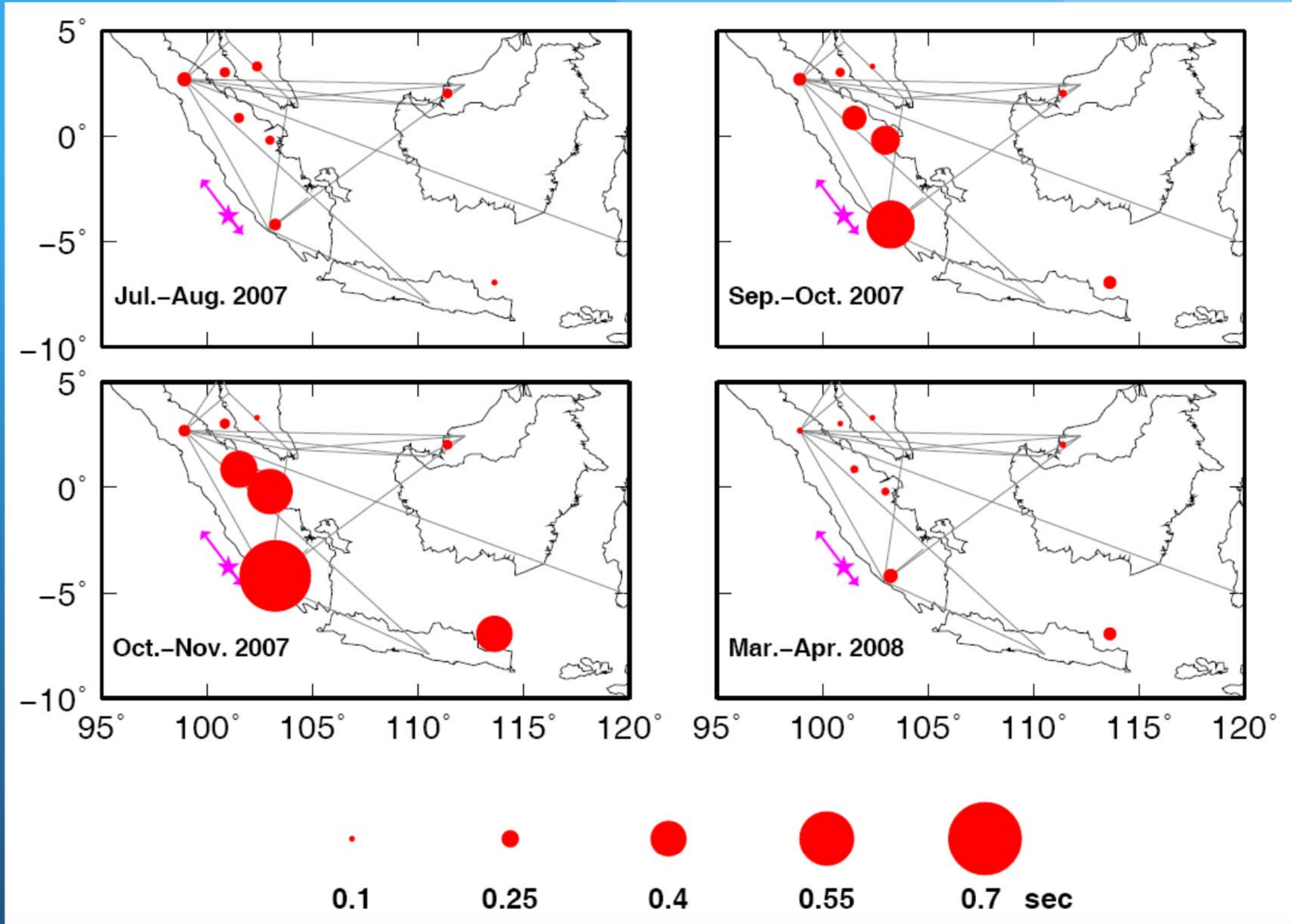
2007/ 9/12 11:11:15.6, -3.78
100.99 24.4, Mw = 8.5



Green functions from ambient noise correlation of PSI and CHTO stations (before and after 2004 and 2005 events)

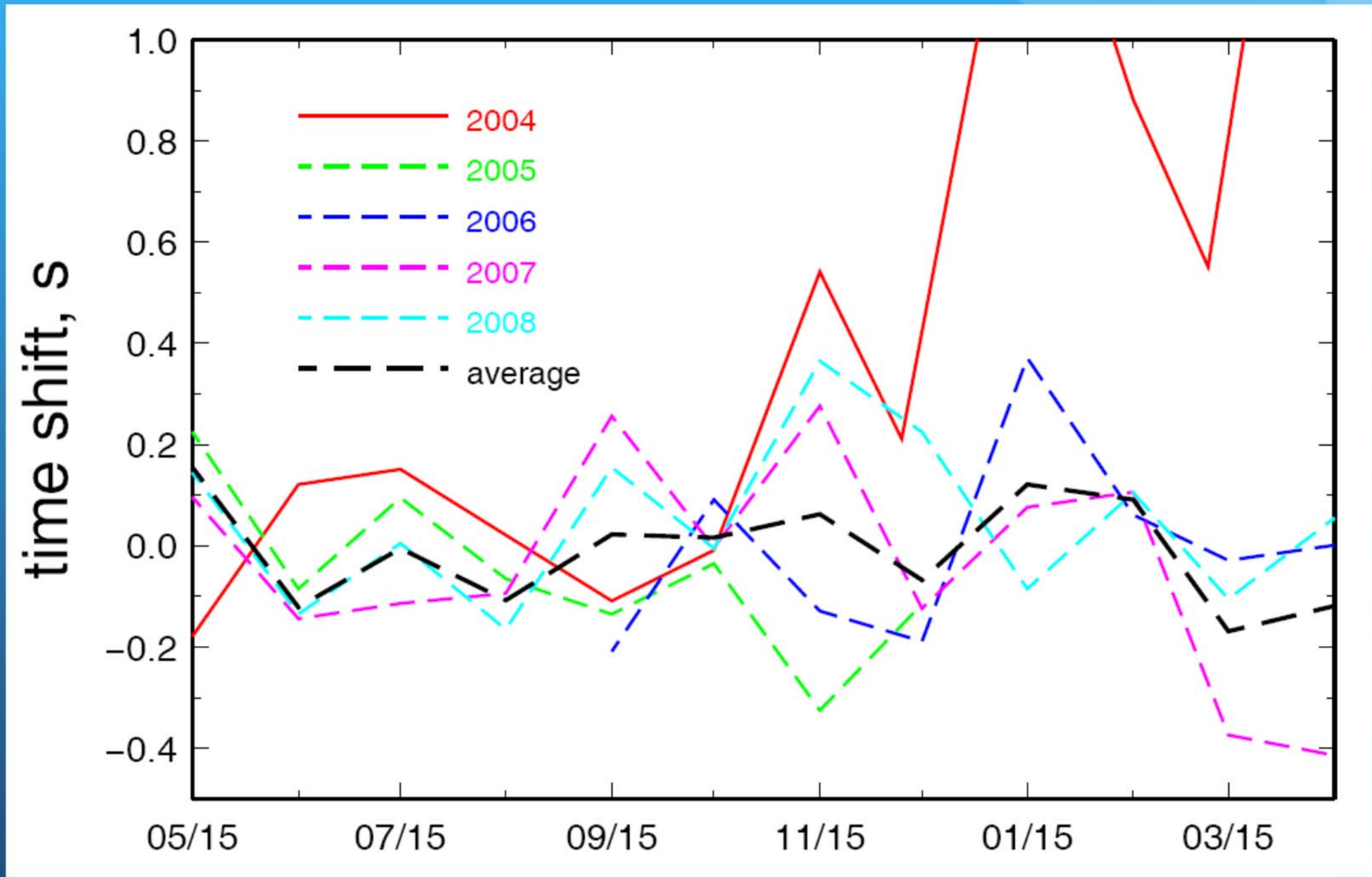


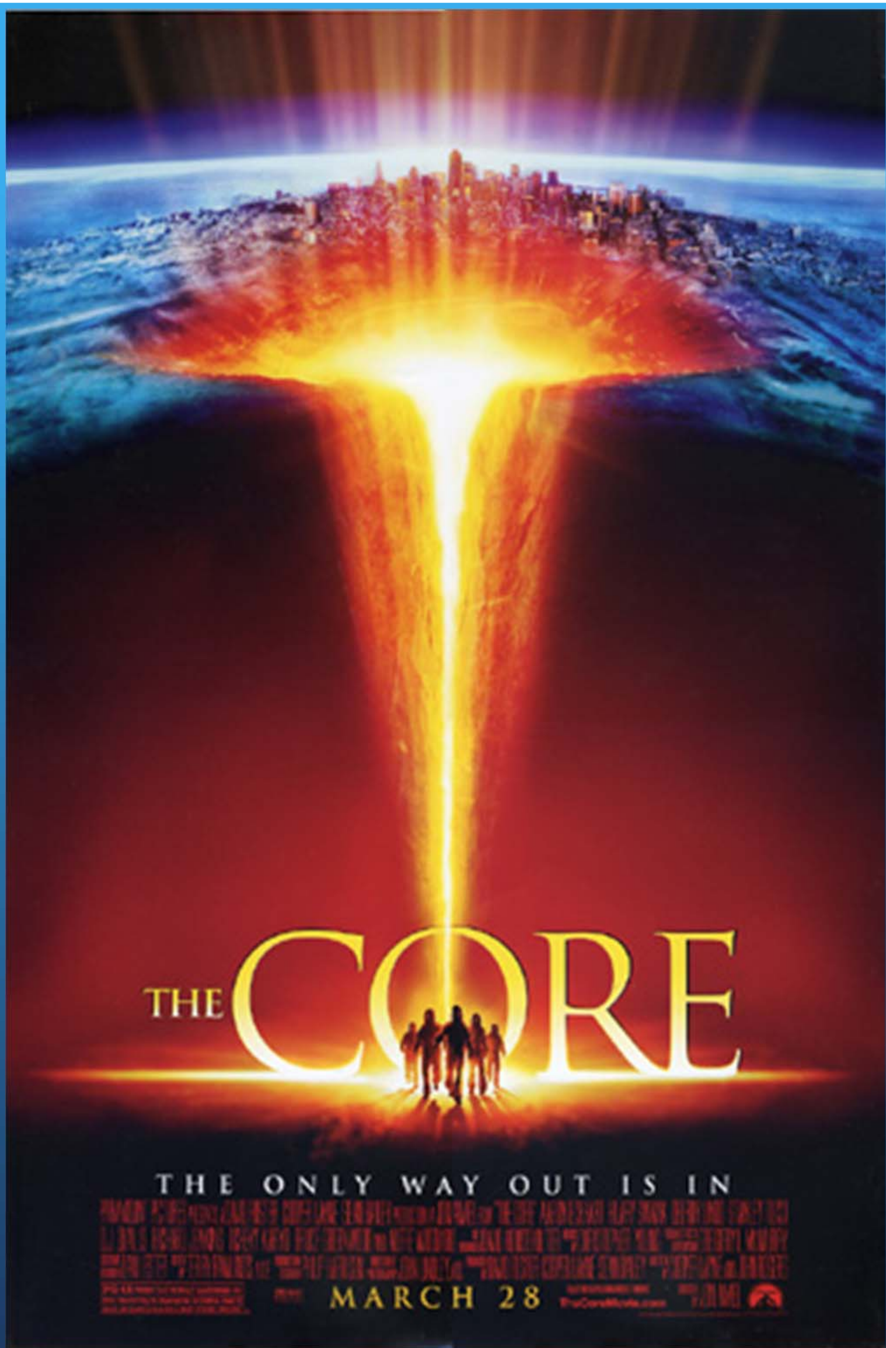
Travel time shifts as a function of time.



Temporal shifts for 2007 event

Precursors before 2004 events?




THE CORE
THE ONLY WAY OUT IS IN
MARCH 28