Why seismograms are so important?

Yoshio Okamoto

@Thailand Science Highschools

地震学 の目的

- 震源メカニズム　から　予知？（非線形物理）

  Why? What? → Where? When? How?

  Japan, China, Italy and USA

- 波を用いて，地球内部構造を調べる（波の物理学）
- →Global Seismology

  Europe

Andrija Mohorovičić

38 languages

Article Talk | Read Edit View history Tools

From Wikipedia, the free encyclopedia

Andrija Mohorovičić (23 January 1857 – 18 December 1936) was a Croatian[1] geophysicist. He is best known for the eponymous Mohorovičić discontinuity and is considered one of the founders of modern seismology.[2][3]

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Early years
Career in education
Meteorology
Seismology
Legacy
Works
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Early years [edit]

The house in Volosko where Mohorovičić was born

Mohorovičić was born in Volosko, Opatija, where his father (also named Andrija), was a blacksmith, making anchors. The younger Andrija also loved the sea and married a captain's daughter, Silvija Vernić. They had four sons. Mohorovičić obtained his elementary education in his home town, then continued at the gymnasium of neighbouring Rijeka. He received his higher education in mathematics and physics at the Faculty of Philosophy in Prague in 1875, where one of his professors was Ernst Mach. At 15, Mohorovičić knew Italian, English and French. Later he learned German, Latin, and Ancient Greek.[4]

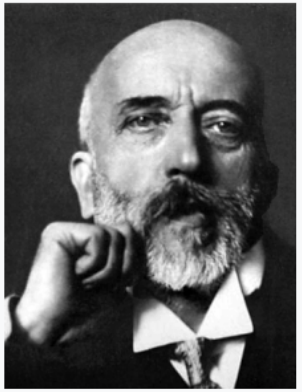
Career in education [edit]

He taught first at high school in Zagreb (1879–1880), then at secondary school in Osijek. From 1880 he taught for nine years at the Royal Nautical School in Bakar, near Rijeka. Work started or completed there was important to his later scientific career. From 1893, when he became a corresponding member of the Faculty of Philosophy, University of Zagreb, to 1917–18 he taught in the fields of geophysics and astronomy. In 1898 he became a full member of what was then the Yugoslav Academy of Sciences and Arts in Zagreb, where he was a private docent. In 1910 he became a titular associate university professor.[4]

Meteorology [edit]

In Bakar he was first exposed to meteorology, which he taught at the Royal Nautical School. This

Andrija Mohorovičić

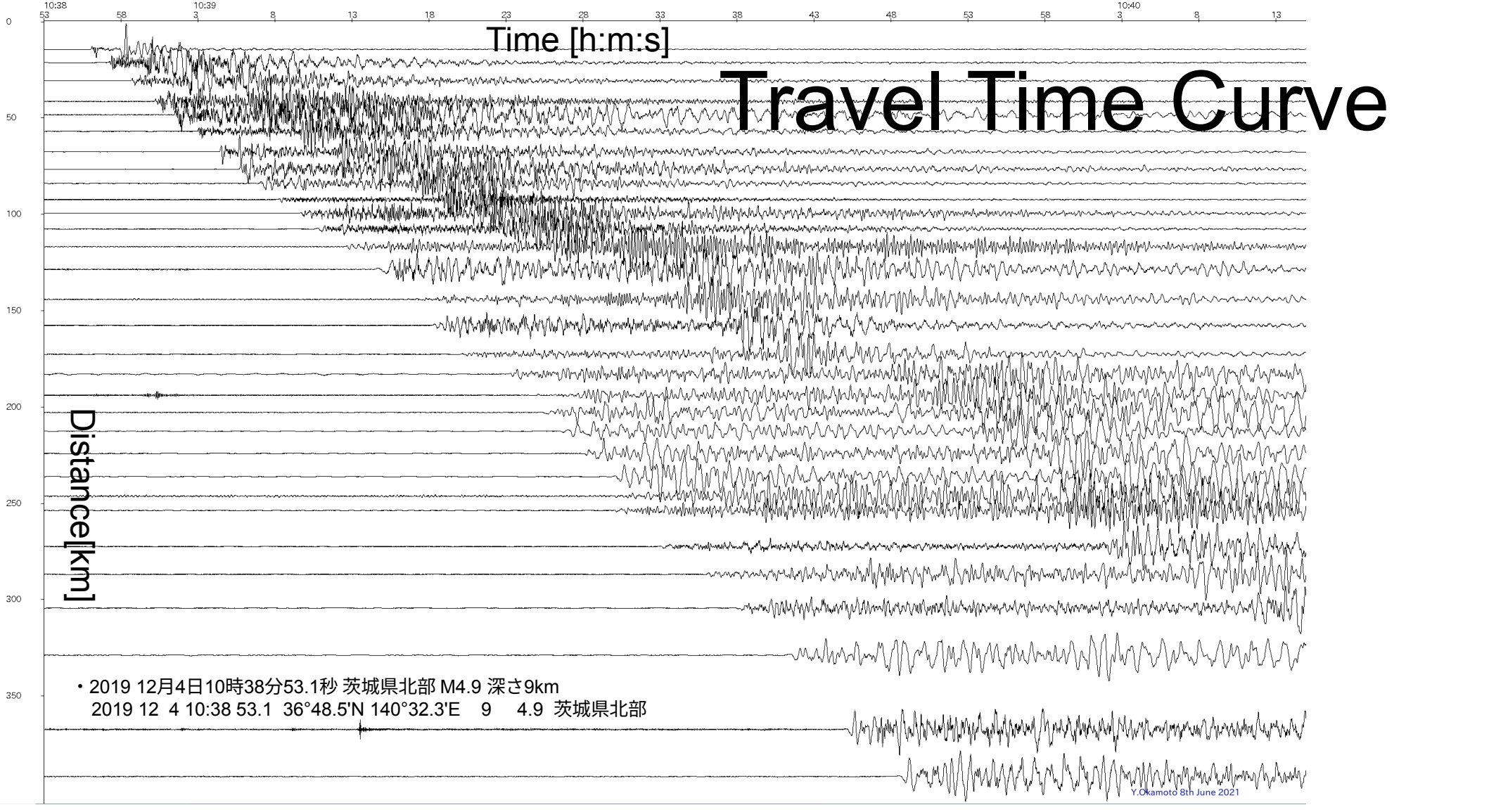


Portrait of Andrija Mohorovičić

Born	23 January 1857 Opatija, Austrian Littoral, Austrian Empire
Died	18 December 1936 (aged 79) Zagreb, Sava Banovina, Kingdom of Yugoslavia
Known for	Eponym for the Mohorovičić discontinuity

Discovery of Moho Discontinuity

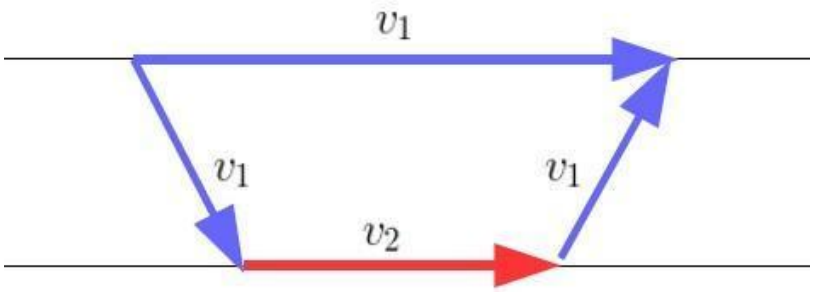
Get citation


Time [h:m:s]
Travel Time Curve
Distance[km]
・2019 12月4日10時38分53.1秒 茨城県北部 M4.9 深さ9km
2019 12 4 10:38 53.1 36°48.5'N 140°32.3'E 9 4.9 茨城県北部
Y.Okamoto 8th June 2021

地殻とマントルの２層構造

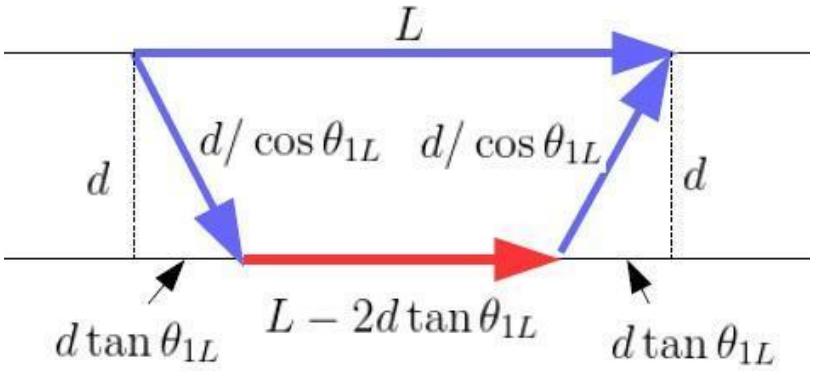
震源から遠くなるとMoho面を通る波が早くつく

速度

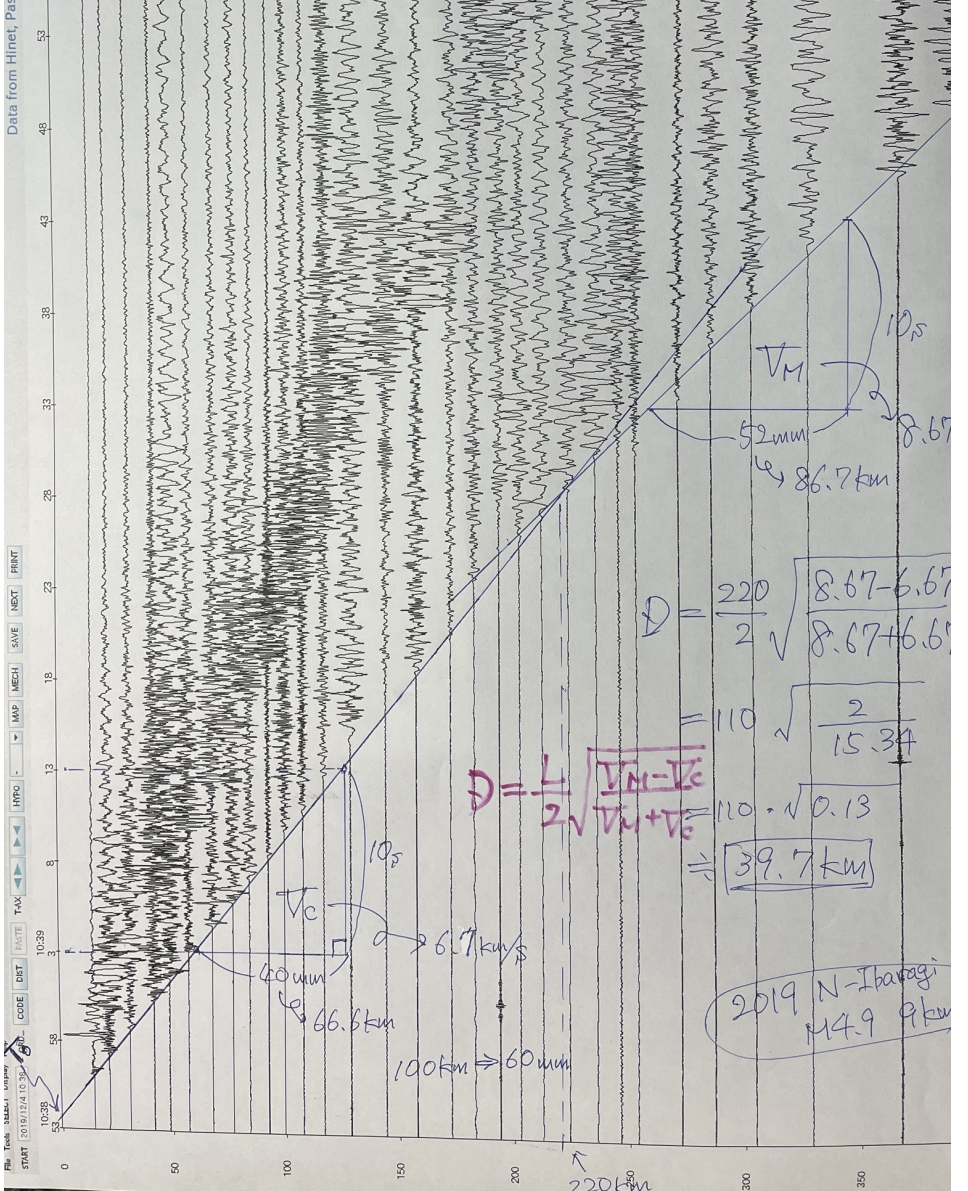


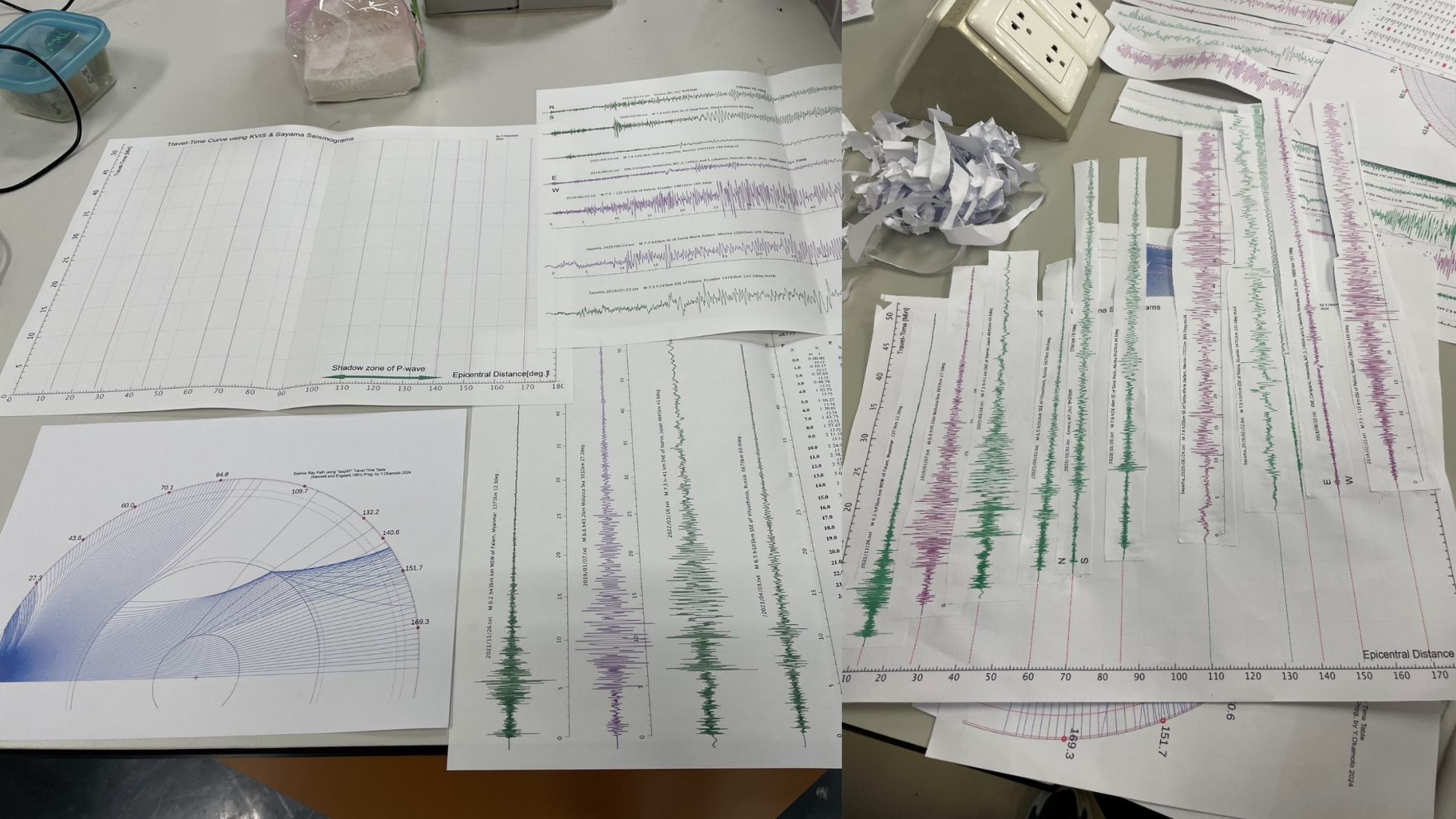
$$d = \frac{L}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

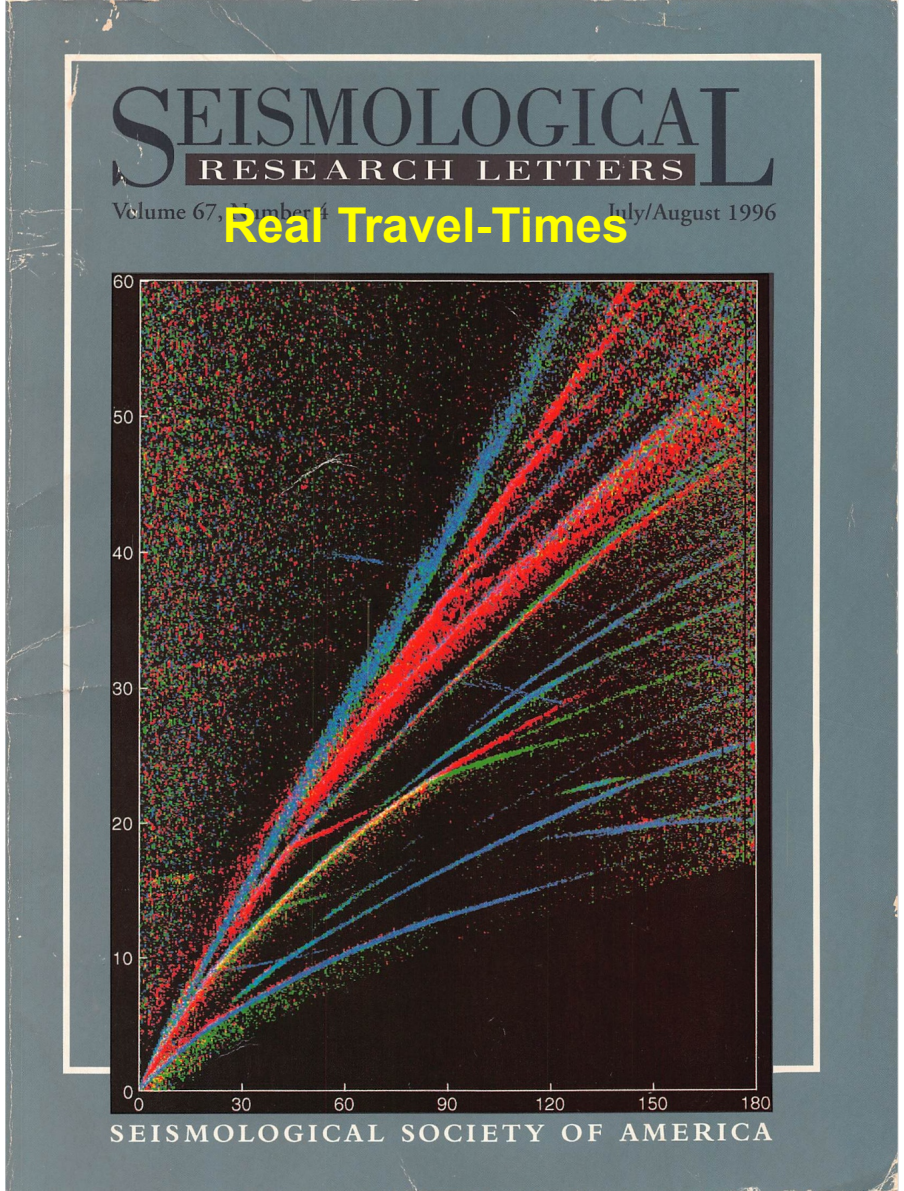
距離



https://tnakabou.seesaa.net/article/201408article_17.html




Travel-Time Curve using KVIS & Sayama Seismograms
Travel-Time [Min]
Shadow zone of P-wave
Epicentral Distance[deg.]
Seismic Ray Path using "iasp91" Travel Time Table
(Kennett and English(,1991) Prog: by Y.Okamoto 2024
84.8
70.1
60.0
43.6
27.3
109.7
132.2
140.6
151.7
169.3
Epicentral Distance

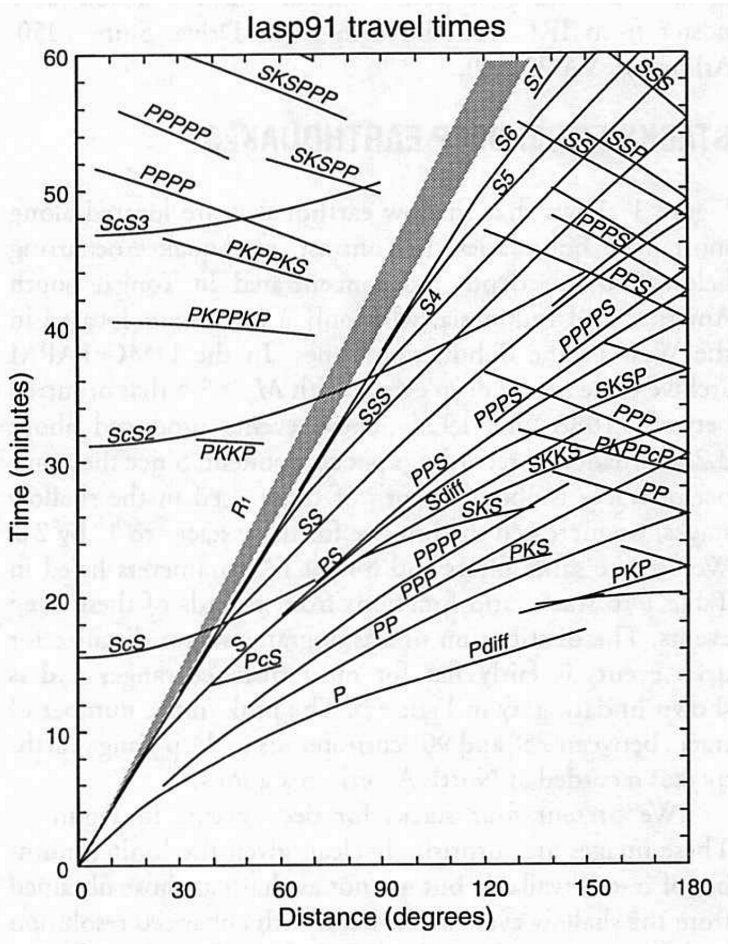


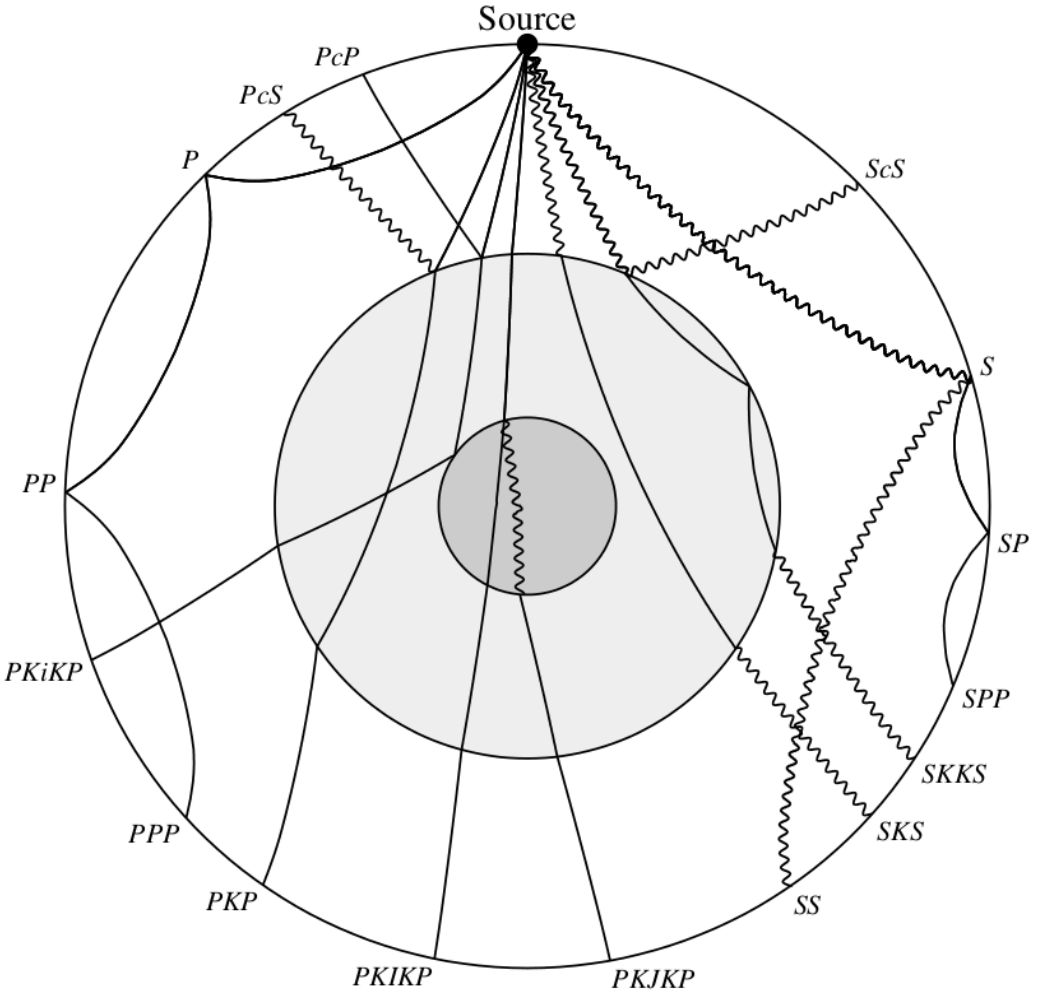
Global Stacking of Broadband Seismograms

Luciana Astiz, Paul Earle and Peter Shearer

Seismological Research Letters, Vol. 67, No. 4, p. 14,
x005F_x0002_1996.

Theoretical Travel-Times





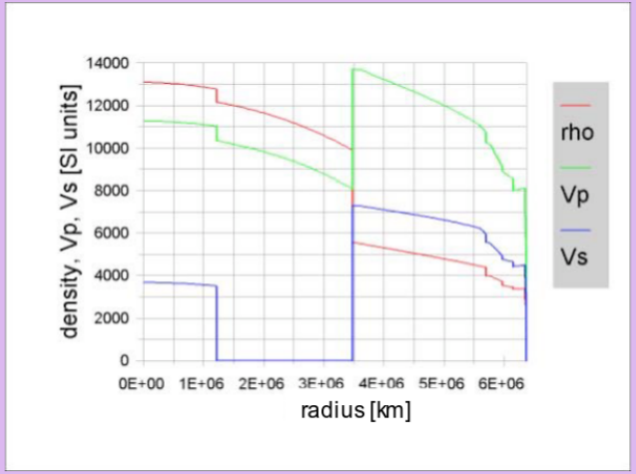
Introduction to Seismology
By P.Shearer, 1999

Figure 4.15 Global seismic ray paths and phase names, computed for the PREM velocity model. *P* waves are shown as solid lines, *S* waves as wiggly lines. The different shades indicate the inner core, the outer core, and the mantle.

ANU THE AUSTRALIAN NATIONAL UNIVERSITY | PHYS3070 | RSES Research School of Earth Sciences

LECTURE 7 - Wiechert-Herglotz inversion for 1D velocity structure of the Earth

Hrvoje Tkalčić



Emil Wiechert

Gustav Herglotz

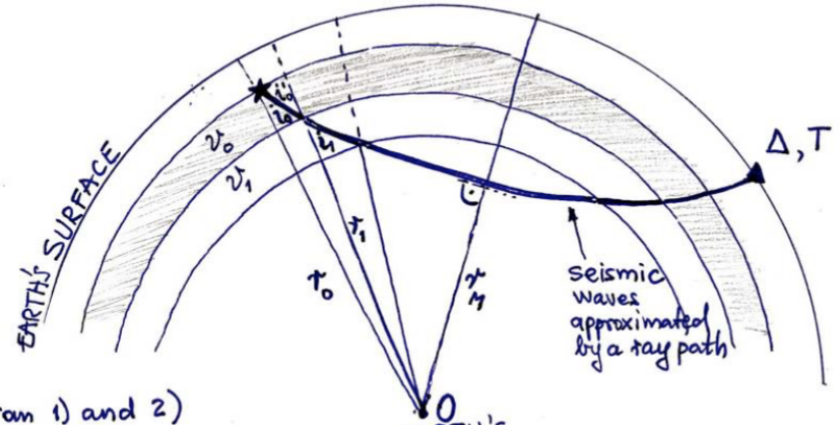
**** N.B. The material presented in these lectures is from the principal textbooks, other books on similar subject, the research and lectures of my colleagues from various universities around the world, my own research, and finally, numerous web sites. I am grateful for some figures I used in this lecture to L. Braile. I am thankful to many others who make their research and teaching material available online; sometimes even a single figure or an idea about how to present a subject is a valuable resource. Please note that this PowerPoint presentation is not a complete lecture; it is most likely accompanied by an in-class presentation of main mathematical concepts (on transparencies or blackboard). ****

https://geo.mff.cuni.cz/~cm/stavba/Wiechert_Herglotz.pdf

Ray geometry: ray parameter - from Lecture 6

LET'S CONSIDER THE FOLLOWING GEOMETRY OF A RAY PATH:

Laterally homogeneous Earth (radial symmetry or 1D)



Δ - epicentral distance

T - travel time

1) sinus rule

$$\frac{r_0}{r_1} = \frac{\sin(\pi - i_0')}{\sin i_0} = \frac{\sin i_0'}{\sin i_0}$$

2) Snell's law

$$\frac{v_0}{v_1} = \frac{\sin i_0'}{\sin i_1}$$

From 1) and 2)

$$\frac{v_0}{v_1}\sin i_1 = \frac{r_0}{r_1}\sin i_0$$

$$p = \frac{r_1}{v_1}\sin i_1 = \frac{r_0}{v_0}\sin i_0 = \frac{r_2}{v_2}\sin i_2 \ldots$$

$$\boxed{p = \frac{r}{v}\sin i}$$

Ray parameter is constant along the path

$$\frac{r}{v} = \eta \Rightarrow p = \eta \sin i \Rightarrow p = \frac{r_M}{v_M}$$

r - ray radius

r_0 - Earth's radius

i - angle of incidence

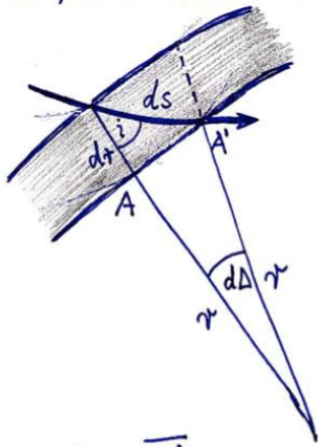
r_M - radius of the deepest sampling point (bottoming point)

v_M - velocity at the bottoming point

https://geo.mff.cuni.cz/~cm/stavba/Wiechert_Herglotz.pdf

Ray theory: travel time and epicentral distance

NOW, LET'S DERIVE T AND Δ USING THE RAY PARAMETER:



$$\cos i = -\frac{dr}{ds}$$

$$ds = -\frac{dr}{\cos i}$$

$$v = \frac{ds}{dt}$$

$$dt = \frac{ds}{v} = -\frac{dr}{v \cos i}$$

$$\frac{T}{2} = \int_{r_0}^{r_M} -\frac{dr}{v \cos i}$$

From $p = \eta \sin i$, where $\eta = \frac{r}{v}$

$$\sin i = \frac{p}{\eta}$$

$$\cos i = \sqrt{1 - \frac{p^2}{\eta^2}}$$

$$\frac{T}{2} = -\int_{r_0}^{r_M} \frac{dr}{v \cos i} = -\int_{r_0}^{r_M} \frac{\eta \, dr}{r \sqrt{1 - \frac{p^2}{\eta^2}}}$$

$$T = 2 \cdot \int_{r_M}^{r_0} \frac{\eta^2 \, dr}{r \sqrt{\eta^2 - p^2}}$$

TRAVEL TIME

$$\tan i = -\frac{\overline{AA'}}{dr}$$

$$\overline{AA'} = -dr \cdot \tan i$$

$$\overline{AA'} = r \, d\Delta$$

$$r \, d\Delta = -dr \cdot \tan i$$

$$d\Delta = -\frac{dr \cdot \tan i}{r}$$

$$\Delta = 2 \int_{r_M}^{r_0} \frac{\tan i}{r} dr$$

$$\tan i = \frac{\sin i}{\cos i} = \frac{\sin i}{\sqrt{1 - \sin^2 i}}$$

$$\tan i = \frac{p}{\eta \sqrt{1 - \frac{p^2}{\eta^2}}}$$

$$\tan i = \frac{p}{\eta \sqrt{1 - p^2/\eta^2}}$$

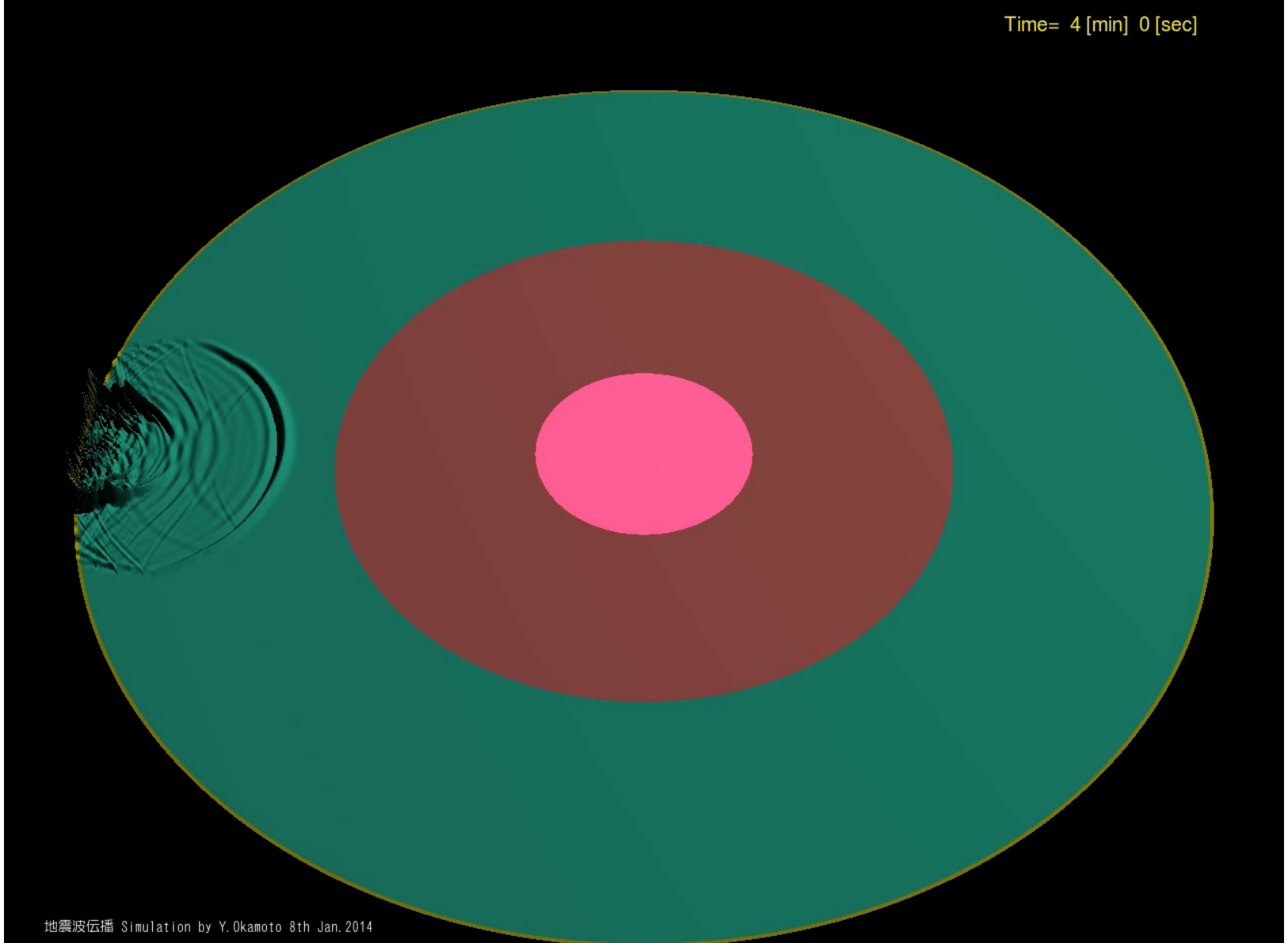
$$\Delta = 2 \int_{r_M}^{r_0} \frac{p}{r \sqrt{\eta^2 - p^2}} dr$$

EPICENTRAL DISTANCE

https://geo.mff.cuni.cz/~cm/stavba/Wiechert_Herglotz.pdf

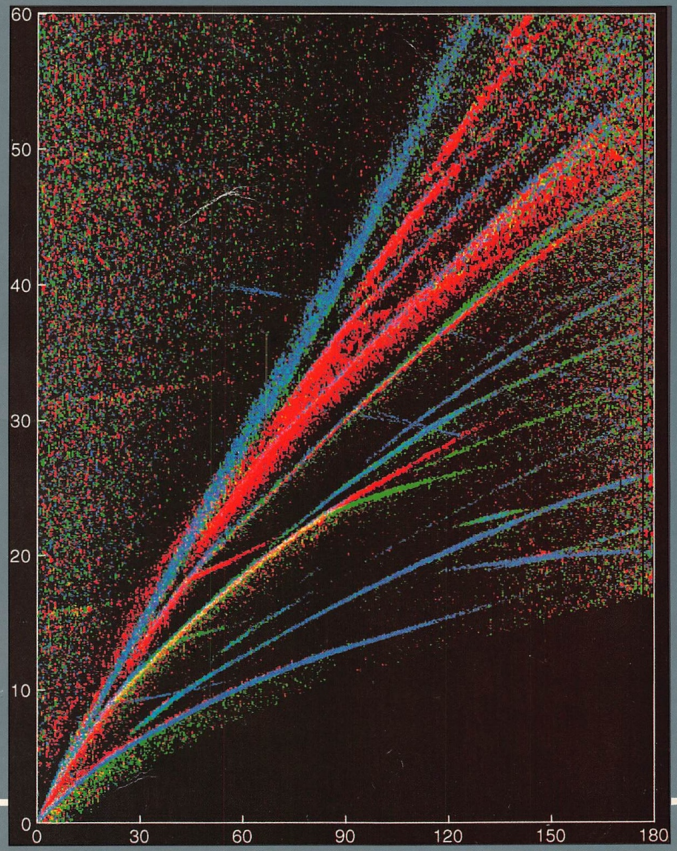
• Real-Theoretical Discordant

- Revise the previous velocity model
- JEFFREYS−BULLEN Standard Travel-Time curve (1967)
- PREM（Preliminary Reference Earth Model）by Dziewonski & Anderson (1981)
- IASP91（International Association of Seismology and Physics of the Earth's Interior）by Kennett (1991)
- AK135 (Kennett et al., 1995)
- But these are one dimensional model. (Only depends on depth)


Time= 4 [min] 0 [sec]
地震波伝播 Simulation by Y.Okamoto 8th Jan.2014

SEISMOLOGICAL RESEARCH LETTERS

Volume 67, Number 4 July/August 1996



SEISMOLOGICAL SOCIETY OF AMERICA

graphic

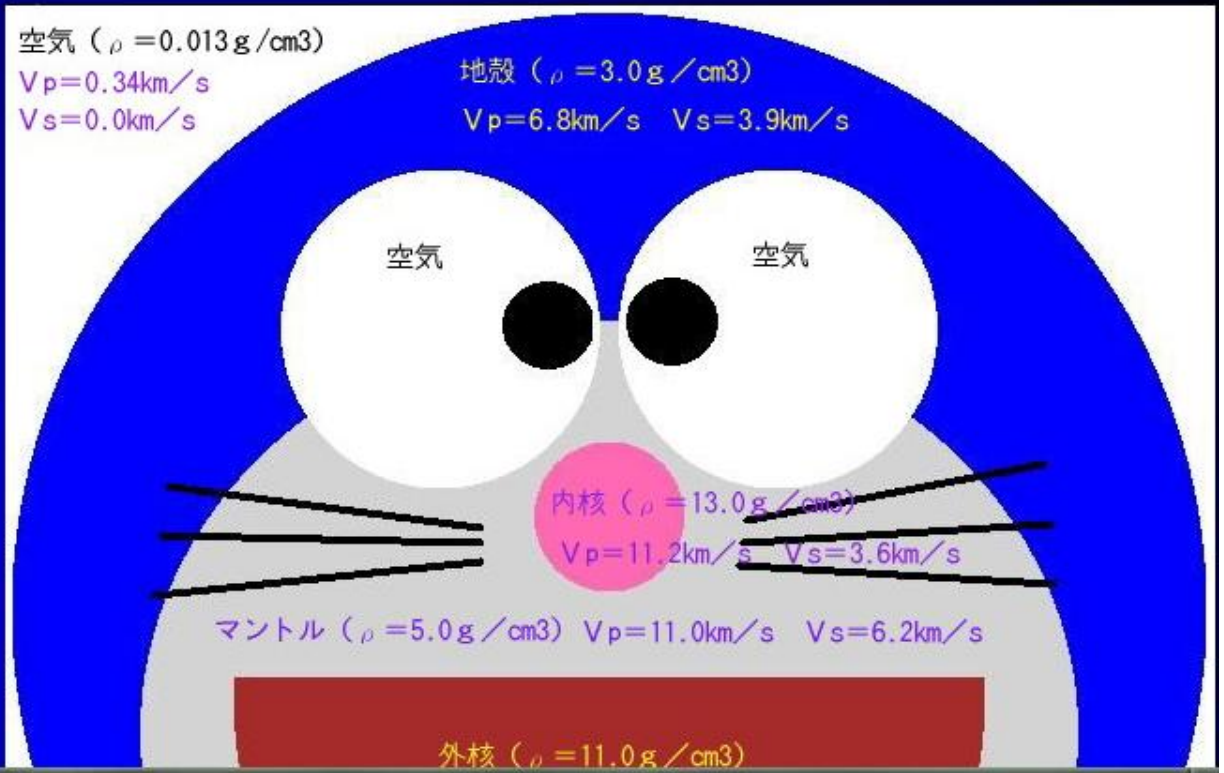
Vertical comp.

Radial comp.

90 120 150 180deg0 30 60 90 120 150 180d

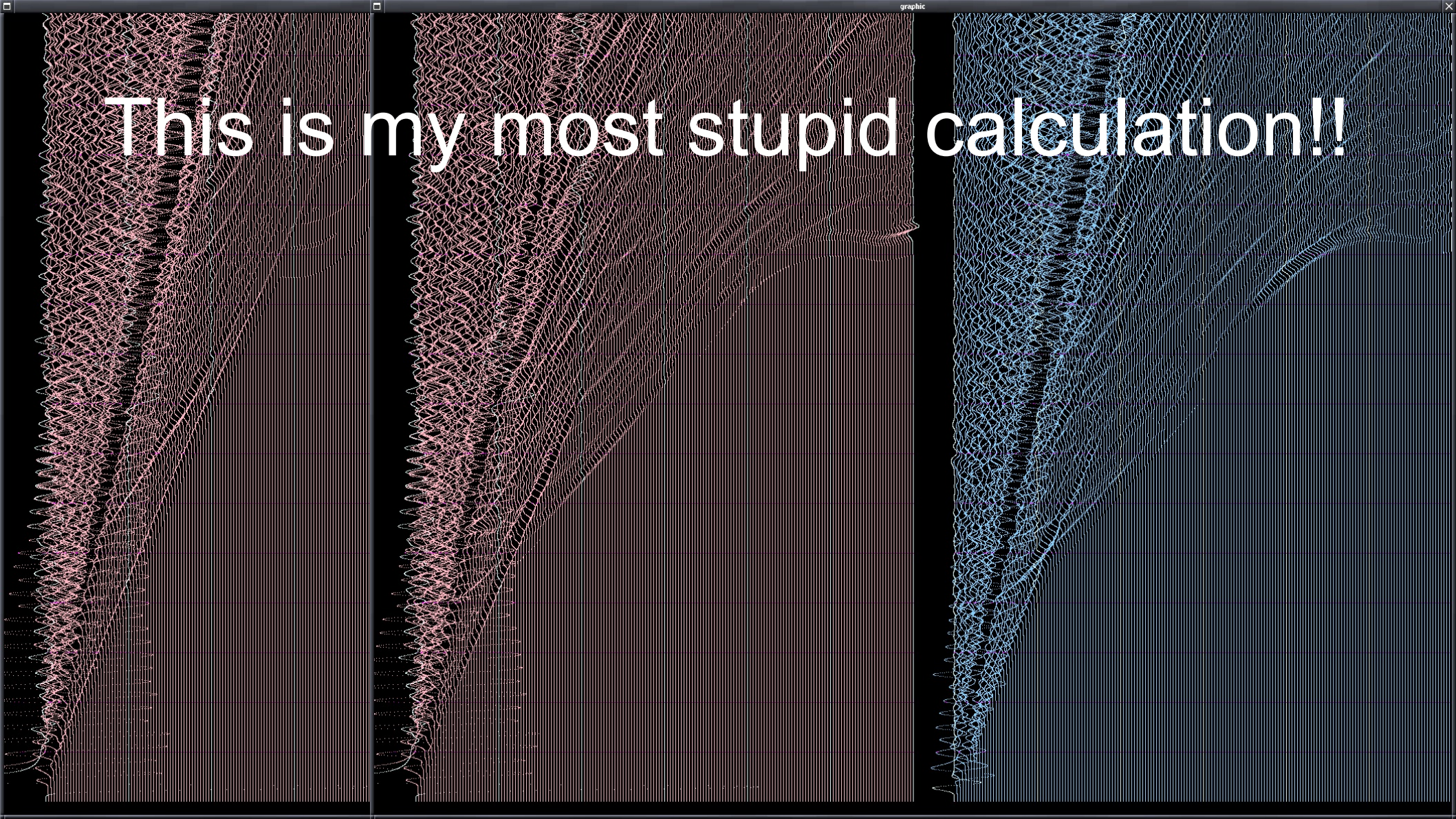
§6. 4 地震波伝播モデル(その3)

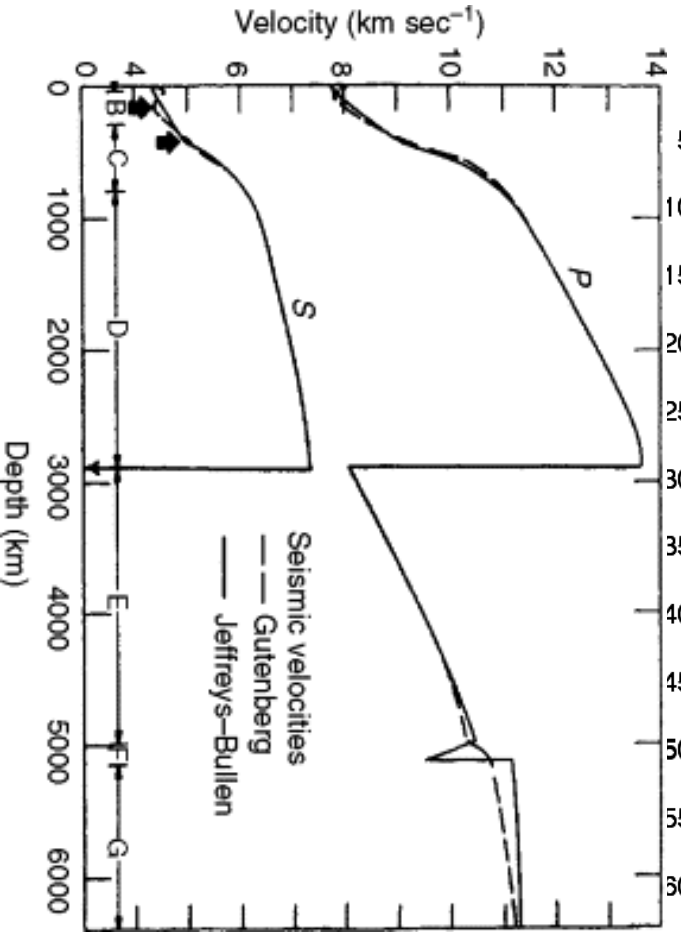
- "どらあーす"モデル
  - 円，楕円，半円
  - 地殻，マントル，外核，内核そして空洞
- 動画と走時曲線

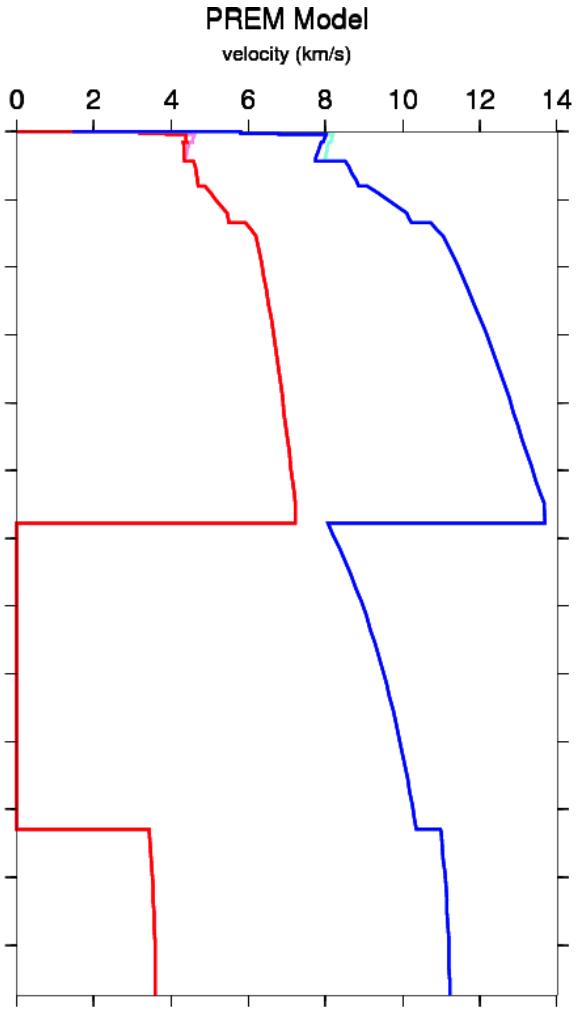


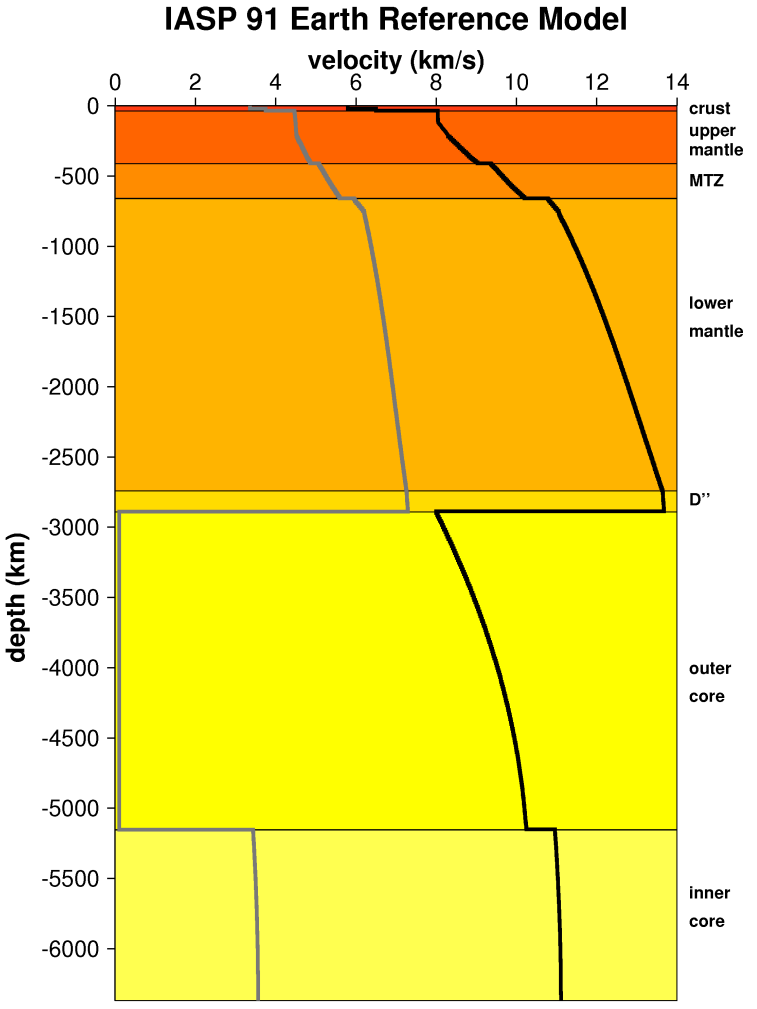
XAnim: Dora_3.fli

Draemon Earth!!


graphic
This is my most stupid calculation!!


Velocity (km sec^{-1})
Depth (km)
P
S
Seismic velocities
Gutenberg
Jeffreys–Bullen
B
C
D
E
F
G


PREM Model
velocity (km/s)
PREM (Vpv,km/s), A. M. Dziewonski & D. L. Anderson, 1981, at (40.0,−120.0)
PREM (Vph, km/s), A. M. Dziewonski & D. L. Anderson, 1981, at (40.0,−120.0)


IASP 91 Earth Reference Model
velocity (km/s)
depth (km)
crust
upper mantle
MTZ
lower mantle
D''
outer core
inner core

iasp91, Kennet & Engdahl,1991

Seismic Ray

Y.Okamoto 2022 Jan.