Brief Introduction of Observational Seismology

Presented by **Yang Dake**

Today's presentator

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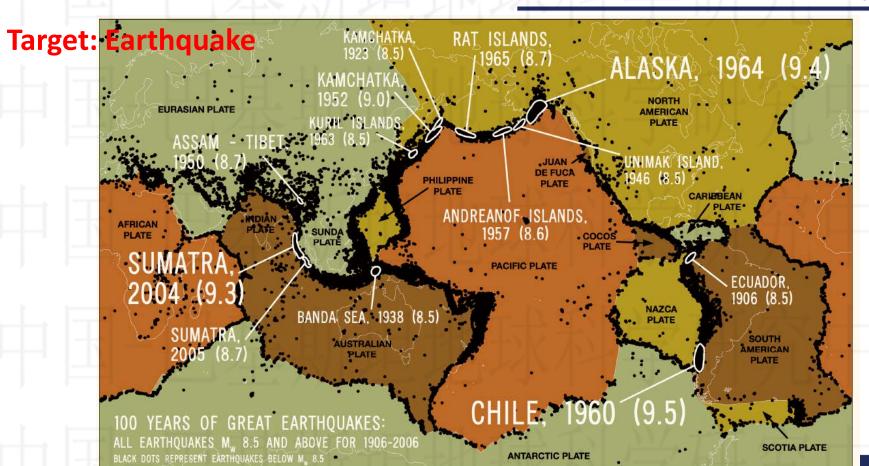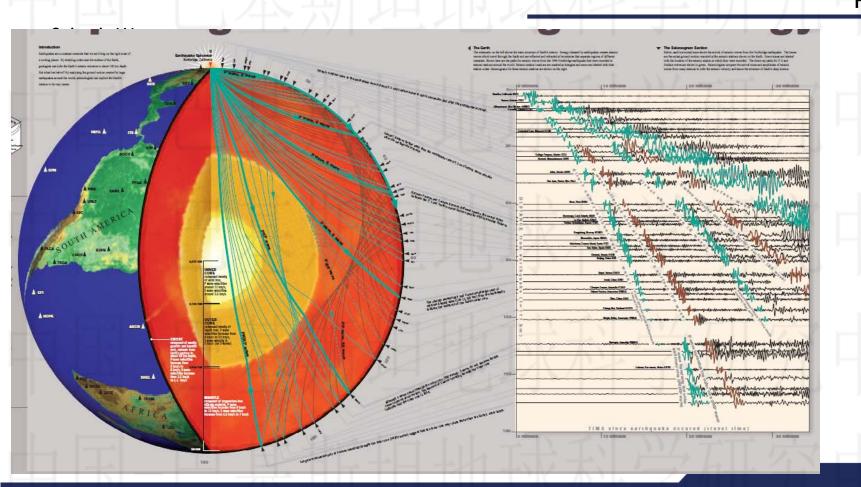yang.dake@qq.com
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★ 1. Background

2. History of Observational seismology

3. Global Seismic Networks

4. Challenges and prospects

Target: Earthquake

KAMCHATKA, 1923 (8.5)

RAT ISLANDS, 1965 (8.7)

ALASKA, 1964 (9.4)

KAMCHATKA, 1952 (9.0)

KURIL ISLANDS, 1963 (8.5)

ASSAM - TIBET, 1950 (8.7)

EURASIAN PLATE

NORTH AMERICAN PLATE

UNIMAK ISLAND, 1946 (8.5)

JUAN DE FUCA PLATE

PHILIPPINE PLATE

CARIBBEAN PLATE

ANDREANOF ISLANDS, 1957 (8.6)

COCOS PLATE

AFRICAN PLATE

INDIAN PLATE

SUNDA PLATE

PACIFIC PLATE

SUMATRA, 2004 (9.3)

ECUADOR, 1906 (8.5)

NAZCA PLATE

BANDA SEA, 1938 (8.5)

SUMATRA, 2005 (8.7)

AUSTRALIAN PLATE

SOUTH AMERICAN PLATE

CHILE, 1960 (9.5)

SCOTIA PLATE

100 YEARS OF GREAT EARTHQUAKES:
ALL EARTHQUAKES M_w 8.5 AND ABOVE FOR 1906-2006
BLACK DOTS REPRESENT EARTHQUAKES BELOW M_w 8.5

ANTARCTIC PLATE

What is observational seismology?

◆ **Science to study, mainly includes but not limited to**
  ➢ Earthquakes
  ➢ Propagation of elastic waves through the Earth
◆ **Branch of Geoscience**
  ➢ Geophysics
  ➢ Geology
◆ **Situation**
  ➢ Old and Young
  ➢ Underdeveloped and under developing
  ➢ Remains as great challenge

Why earthquake observation?

◆**We record earth motion data for:**
- ➢ Locating events and calculating its sizes
- ➢ Studying focal mechanism and cracking process
- ➢ Studying earth interior structure
- ➢ ……
- ➢ Earthquake early warning system
- ➢ ……
- ➢ Finally, Earthquake prediction/ Forecast

Timeline of seismological observation history

Big-Bang

Solar System forming

Earth forming

Human being

writing

ancient observing

old instrument

modern instrument

Seismoscope Ages

✧ **From early 2nd Century to late 1800's**
✧ **Sense shocks and a few data**

Early Seismograph Ages

✧ **~19th century to early 20th century**
✧ **Mechanical pendulum-based initial system**
✧ **Seismology became a part of advanced science**

Analog Seismograph Ages

✧ **~early 20th century to 1980s**
✧ **Electrical-magnetic seismograph**
✧ **High sensitivity, telemetry network**

Digital Seismograph Ages

✧ **1980s until now**
✧ **Force balanced feedback seismometer**
✧ **GPS, Internet, dense deployed arrays, Early Warning System**

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China Ages

张衡，78-139 A.D.
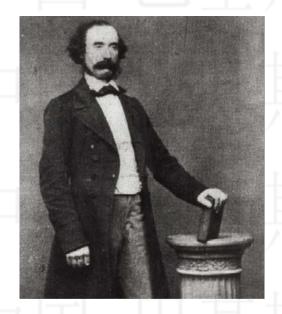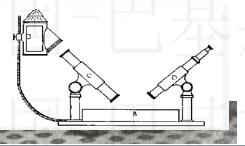
◆ **The first seismoscope in the world belongs to China**
  ✧ Zhang Heng, 132 A.D.

◆ **A long period of silence from 2nd century to 18th century**

◆ **Seismoscopes in Europe:**
  ✧ Mercury type
    ➢ 1703, J. de la Haute Feuille, France
    ➢ 1851, Robert Mallet, Ireland
  ✧ Mechanical pendulum type
    ➢ 1751, Andrea Bina,
    ➢ 1844, James Forbes, England

◆ **Detection of earthquake**
  ✧ direction, size and time of an earthquake
  ✧ Very low reliabilities

The early part of the nineteenth century was an extraordinary time for mathematics. French mathematicians Navier and Cauchy developed equations for elasticity. Then, in 1830 Poisson published a paper showing that there were two fundamental elastic waves: P and S waves. Poisson's Ratio, which is a measure of the S to P velocity, is widely used in seismology today.

Robert Mallet

➤ The inventor of the word **seismology**
➤ **The "first" seismologist**.
➤ His contributions to seismology mark the birth of the science.
➤ The first comprehensive **earthquake catalog** and **world seismicity map**.
➤ In the late 1840's Mallet used explosions to produce seismic waves and investigate the idea that seismic waves travel at different speeds in different rock types.
➤ After the 1857 Neapolitan earthquake, he used the orientation of cracks and fallen masonry produced an **isoseismal map** for the event. The map identified areas of similar intensities of shaking.

◆ **Milestones in seismology in Seismoscope ages**

✧ **132 A.D**. Zhang Heng, seismoscope.

✧ **1556**. earthquake in Shanxi, China. 830,000 deaths reported.

✧ **1676, Robert Hooke, Hooke's Law.**

✧ **1751** Nov. 1. Lisbon earthquake, the first event to be studied scientifically.

✧ **1830. Simeon-Denis Possion. Discovery of P and S waves**

✧ **1846.** Robert Mallet; his first general paper on earthquakes.

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◆ **The first "true seismograph"**
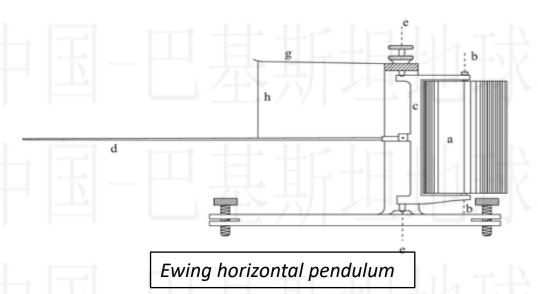
✧ Pilippo Cecci, 1875, Italy
✧ Record the relative motion of a pendulum and the earth as a function of time
✧ 3-component: N-S, E-W, vertical
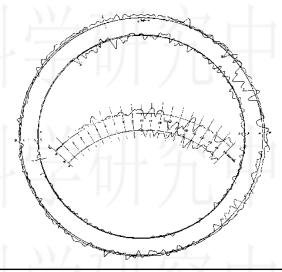
◆ **Contribution of a group of Englishmen in Japan**
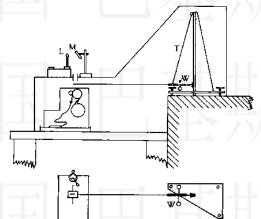
  ✧ John Milne
  ✧ James Ewing, Thomas Gray
  ✧ Worldwide use

Ewing horizontal pendulum
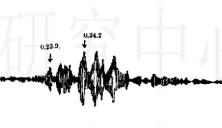
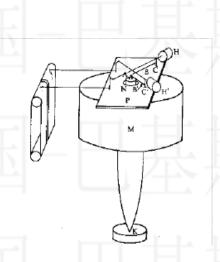A record, obtained with Ewing's horizontal-pendulum seismograph, of a strong local earthquake on March 8, 1881

In 1875 a 25 year old mining engineer named John Milne was invited to become a professor of geology at the Imperial University of Tokyo. Milne organized a seismic survey of Japan and soon recognized the importance of improving the seismogram. **Milne was a great promoter of instituting a world wide seismic network, designed several types of seismometers, and made the first accurate global travel time curve.**

◆ **Viscous damping inverted pendulum seismometer**
  ✧ Wiechert, 1901
  ✧ Heavy(1000kg) and sensitive
  ✧ Still operating in some modern observatories
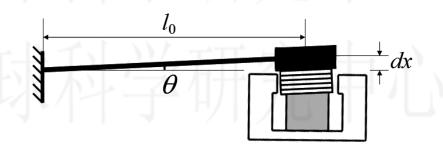
大维歇尔水平向地震仪

大维歇尔垂直向地震仪
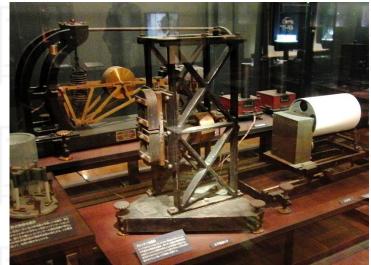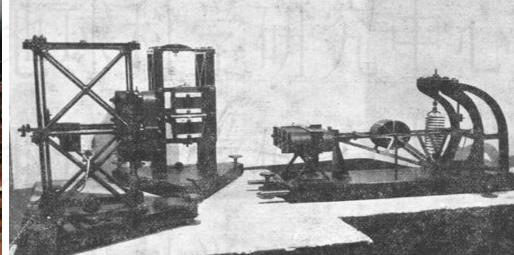
◆ **electromagnetic seismograph**

✧ Boris Borisovich Golitsyn, 1906
✧ Sensitive, broadband, large magnifying factor
✧ Opening of the analog seismometer age

◆**Milestones in seismology in early seismometer ages**

✧ **1865.** Seismological observations begun at Manila

✧ **1879.** Seismographs developed in Japan by the British group

✧ 1885. Lord Rayleigh, paper on theory of "Rayleigh waves."

✧ **1889. April 18.** First seismogram of a teleseim identified (Germany)

✧ 1899. Knott's equations for reflection and refraction coefficients of elastic waves

✧ **1901.** Inverted pendulum seismograph developed by Wiechert.

✧ **1906.** Galitzin electromagnetic seismograph developed (Russia).

✧ **1906 April 18.** California earthquake; great extent of strike-slip faulting; survey re-triangulation leading to elastic-rebound theory of earthquakes.

1889 APRIL 17. GR.M.T.
POTSDAM.

◆ **With damped seismographs, seismologists would be possible to calculate fairly accurate ground displacements for all recorded waves, not just short- period waves.**

◆ **Mathematical theory for calculating displacements from recorded waveforms would be forthcoming**

◆ **Seismology became as a part of advanced sciences, characterized by fairly accurate measurements and moderate theoretical developments, with some significant discoveries like Rayleigh and Love Waves, as well as the Pn waves that leads to the discovery of subcrustal discontinuity. The elastic- rebound theory was launched.**

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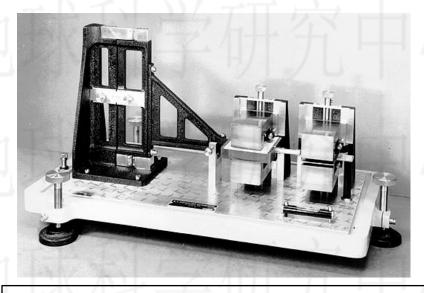
◆ **KEY: Electrical-magnetic seismograph**
  ✧ **Electronic circuits** were widely introduced in seismometers, various types of seismographs with high sensitivity were invented and widely used.
  ✧ **Feedback seismometer** were studied but **with limited effectiveness** and application.
  ✧ The **first telemetered seismic network** was built in South Africa
  ✧ **Larger coverage local telemetry seismic networks** were built in California, USA and independently in Japan.
  ✧ The Helicorder and similar drum types of multi-track ink-pen or photographic **recording machines** were invented.
  ✧ **Computers** was used to deal with signals by attached Analog-to- Digital apparatus, **digital signal processing theories** and technics were developed.

Examples of famous electrical-magnetic seismograph

Benioff variable reluctance seismometer

Short period

Sprengnether horizontal seismometer

Long period

◆ **Milestones in analog seismometer ages**
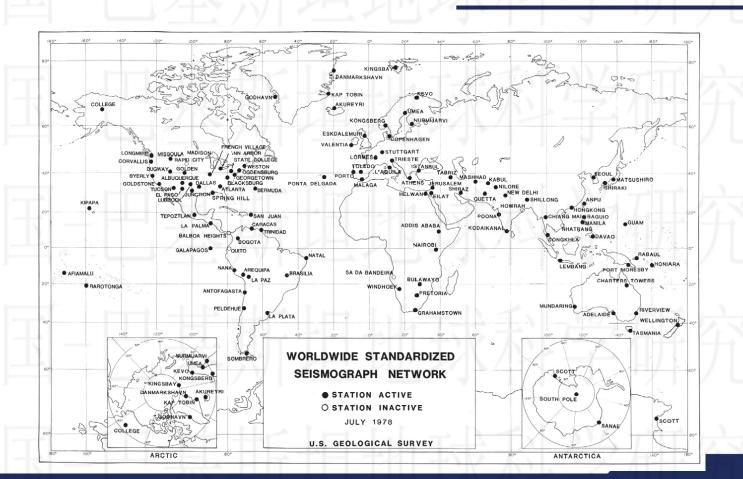
✧ 1909. discovery of the subcrustal discontinuity by A. Mohorovicic

✧ 1911. Theory of Love waves.

✧ 1913. Radius of the core determined by Gutenberg

✧ **1915.** Milne-Shaw seismograph developed by J.J. Shaw (England).

✧ **1923** September 1: Tokyo earthquake. The death toll in Tokyo exceeded 100,000, and nearly 2 million people were left homeless.

✧ **1923.** Wood-Anderson torsion seismometers began regular recording

✧ **1928**. K. Wadati, discovery of deep earthquakes.

✧ **1931.** Variable-reluctance seismometer developed by Benioff

✧ **1933**. March 3. Great Sanriku earthquake and tsunami.

✧ 1934. P'P' and relate waves discovered at Pasadena.

✧ 1935. Richter Magnitude scale published.

✧ 1936. Existence of the inner core suggested by Miss Lehmann in Copenhagen.
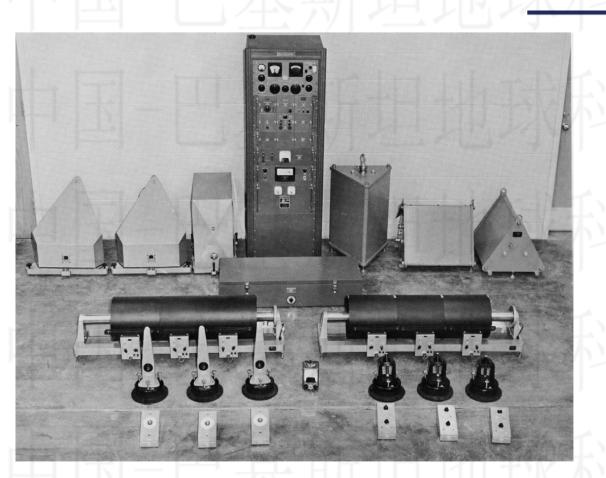
◆ **Milestones in analog seismometer ages**

- **1939**. December 27. Destructive earthquake in Turkey, first of a series extended and connected faulting.
- 1939. J-B travel time table and earth model were published.
- 1940. T wave described and named by Linehan in Weston, Massachusetts.
- **1946**. April 1. Aleutian tsunami, destructive on Hawaii; Seismic tsunami warning service organized in consequence.
- **1950**. August 15. Great earthquake, Tibet and Assam.
- 1952. Lg waves discovered by Ewig and Press in at Columbia University, New York.
- 1953. Pa and Sa waves discovered by Caloi at Rome and independently by Ewig and Press.
- **1960** May 22. The Great Chile earthquake of magnitude 9.5, ruptured a 1000 km section of the subduction zone. The first event to observe free oscillations of the Earth.
- 1965. J. Tuzo Wilson discovered the existence of Transform Faults.
- **1976** July 28. Tangshan earthquake, China. The deadliest earthquake of the 20th century.

◆ **WWSSN--a prototype of global network**

✧ Since 1960, finished installation in 1967.

✧ A total of 127 stations.

✧ Mainly for understanding global seismicity and tectonic processes

✧ A result of nuclear test ban discussions held in 1958: research needs for improving the national capability in the detection and discrimination of underground nuclear explosions.

✧ The WWSSN was a **technological milestone** in seismology, producing abundant high quality data for research.

✧ created a global network infrastructure, including the **data-exchange procedures** and **station technical capabilities** needed to support the establishment of the more advanced networks in operation today.

WORLDWIDE STANDARDIZED SEISMOGRAPH NETWORK
● STATION ACTIVE
○ STATION INACTIVE
JULY 1978
U.S. GEOLOGICAL SURVEY

Components of the World-Wide Standardized Seismograph Network system. **Long-period seismometers** are shown in the upper left, galvanometers and recorders in the lower left. **Short-period seismometers** are shown in upper right, galvanometers and recorder in lower right. **The electronics console** contains timing system, controls, and power supply.

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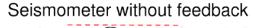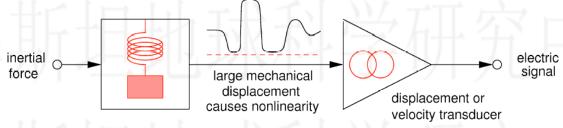
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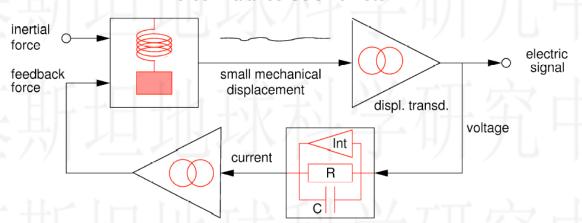
◆ **KEY1: force balanced feedback seismometer**
  ✧ Wielandt, 1981
  ✧ Very broad band seismic signals by one seismometer alone
  ✧ Very high sensitivity and very low noise level

◆ **KEY2: Analog-to-Digital technics improved rapidly**

◆ **KEY3: PCs and embedded systems was used in data acquisition system**

◆ **KEY4: Internet became popular**

◆ **KEY5: GPS timing service is introduced**

Force Balanced Feedback Seismometer

Seismometer without feedback

inertial force → large mechanical displacement causes nonlinearity → displacement or velocity transducer → electric signal

Force-Balance Seismometer

inertial force, feedback force → small mechanical displacement → displ. transd. → electric signal

voltage → Int, R, C → current → feedback force

Popular seismometers

STS-1

STS-2

Streckeisen
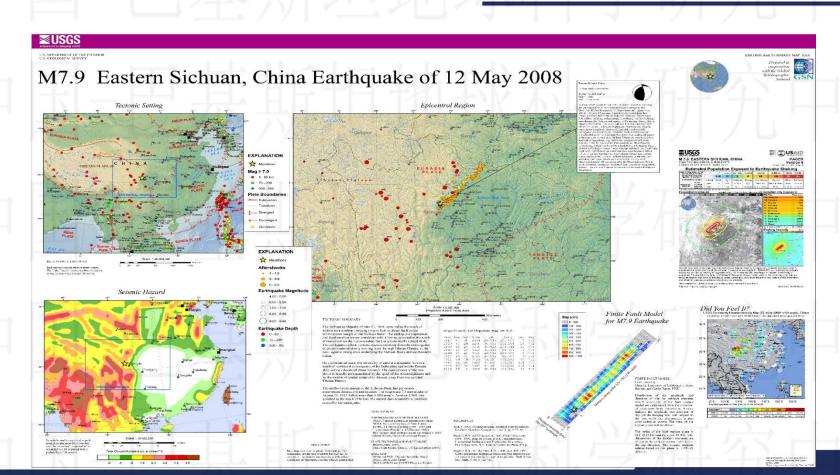
Guralp

Nanometrics
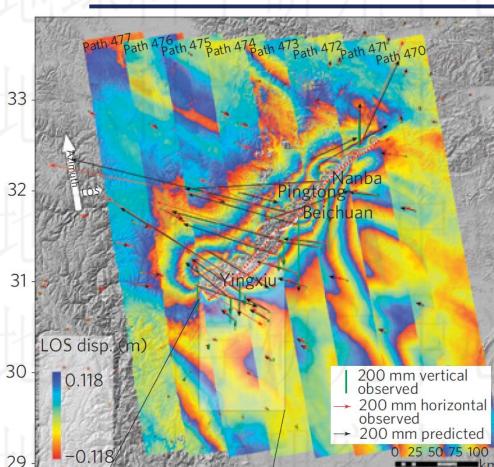
Achievements

✧ Nationwide, continental-wide and even worldwide telemetry earthquake monitoring system

✧ Real-time locations and magnitude calculations of earthquakes became fairly accurate and be released to public via Web/SMS/Facebook/Television

✧ Large coverage densely deployed seismograph arrays

✧ High-accuracy profiles of earth interior in multiple scales

✧ Earthquake Early Warning System was realized

➢ first in Japan for railway transportation safety

➢ After 1995 Kobe Earthquake, a nationwide alarming system was developed by JMA

➢ Now there is a global trend to develop EEWS

M7.8 South Island New Zealand Earthquake of 13 November 2016

◆**Seismology from Space**

---- InSAR

Shen et al., (2009)

◆Shakemap

➢ Real-time collection of seismic data allows for the construction of maps depicting shaking intensity within seconds of an Earthquake occurrence. Shake Maps can highlight areas of expected damage and help provide rapid emergency response

http://earthquake.usgs.gov/data/shakemap/

USGS ShakeMap : Kaikoura Earthquake, So. Island of New Zealand
Nov 13, 2016 11:02:56 UTC   M 7.8   S42.76 E173.08   Depth: 23.0km   ID:us1000778i
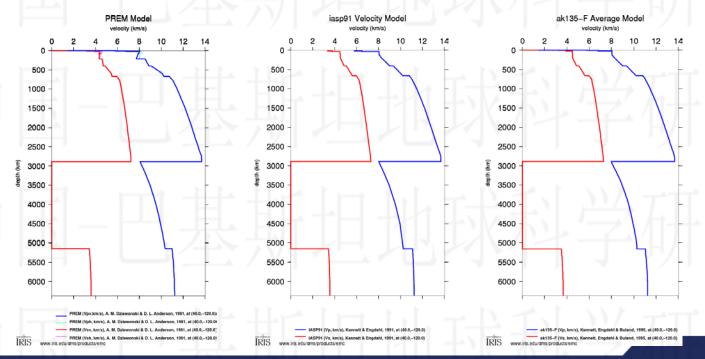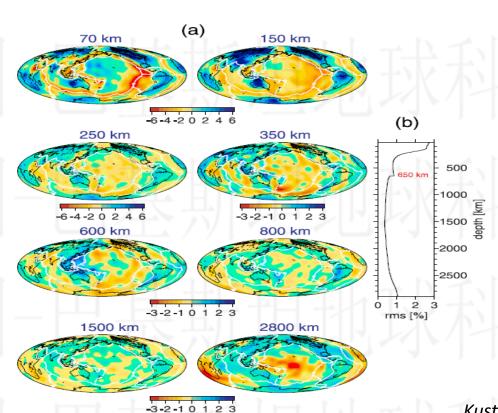
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

◆ Referece earth models

- ✧ **1981**, Preliminary reference Earth model (PREM). Dziewonski and Anderson.
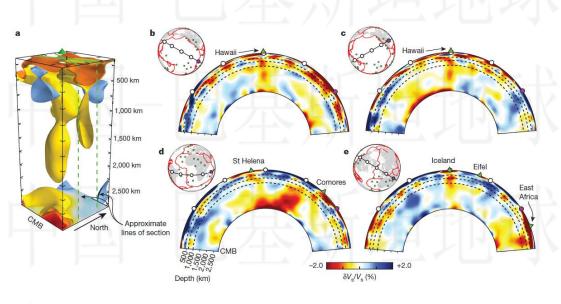- ✧ 1991, IASP91 model. Kennett and Engdahl (1991)
- ✧ 1995, AK135 model.

(a)
70 km   150 km
-6 -4 -2 0 2 4 6

250 km   350 km
-6 -4 -2 0 2 4 6   -3 -2 -1 0 1 2 3

600 km   800 km
-3 -2 -1 0 1 2 3

1500 km   2800 km
-3 -2 -1 0 1 2 3
$\delta v_S/v_S$[%]

(b)
650 km
depth [km]
500
1000
1500
2000
2500
0 1 2 3
rms [%]

◆**Imaging of the earth Interior**
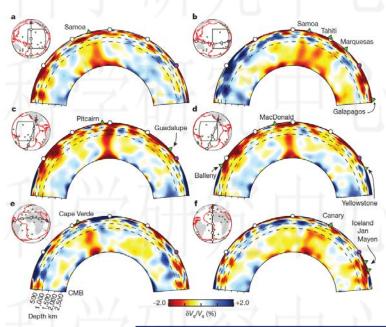
Kustowski, Ekstrom and Dziewonski (2008)

◆ 1971-2015:Hypothesis and imaging evidence of mantle plumes.

> Theory: Morgan, 1971

> Evidence: French and Romanowicz, 2015

1. Background
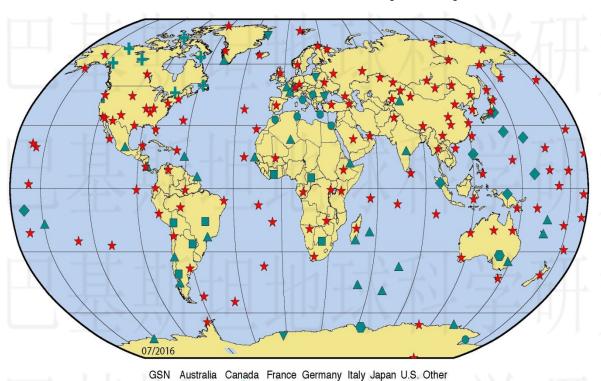
2. History of Observational seismology

3. Global Seismic Networks
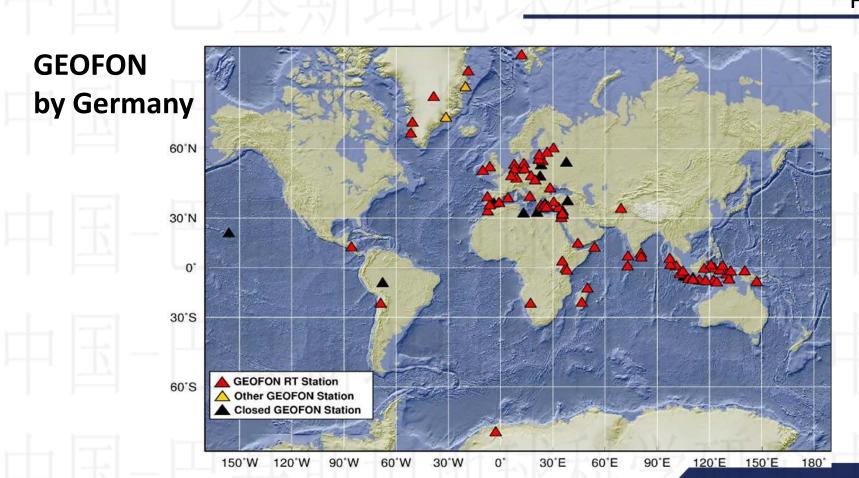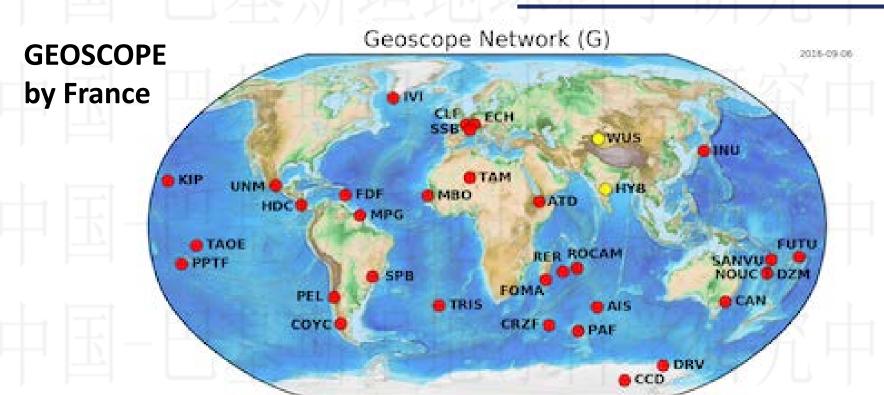
4. Challenges and prospects
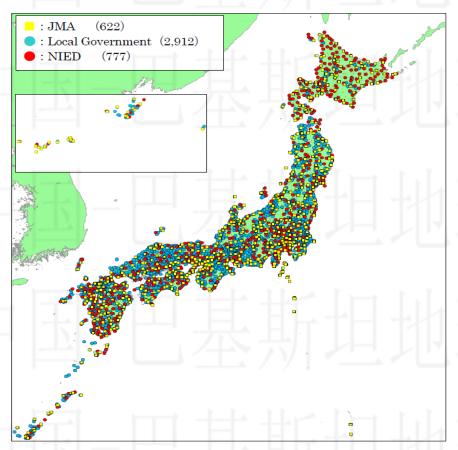
IRIS-Affiliated Global Seismic Networks (GSN)

07/2016

GSN   Australia   Canada   France   Germany   Italy   Japan   U.S.   Other

**GEOFON
by Germany**

GEOSCOPE
by France

Geoscope Network (G)

2018-09-06

IVI
CLF ECH
SSB
WUS
INU
KIP
UNM
HDC
FDF
TAM
MBO
HYB
MPG
ATD
TAOE
PPTF
RER ROCAM
FUTU
SANVU
NOUC DZM
SPB
FOMA
PEL
TRIS
AIS
CAN
COYC
CRZF
PAF
DRV
CCD

● real time/near-time stations   ○ temporarily interrupted stations
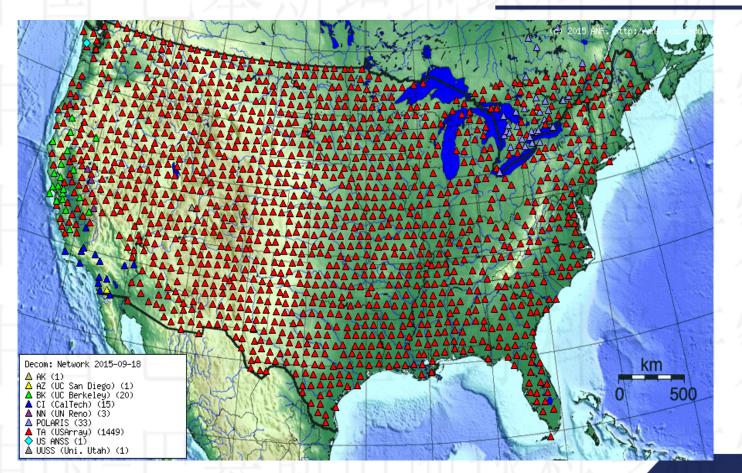
Japanese Networks

JMA: Japanese Meteorological Agency

Local Government

NIED: National Research Institute for Earth Science and Disaster Prevention
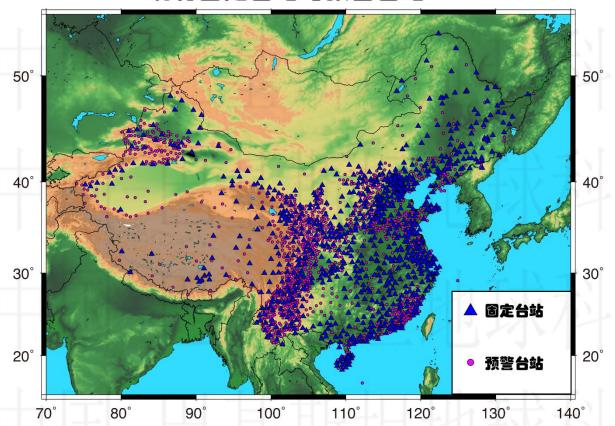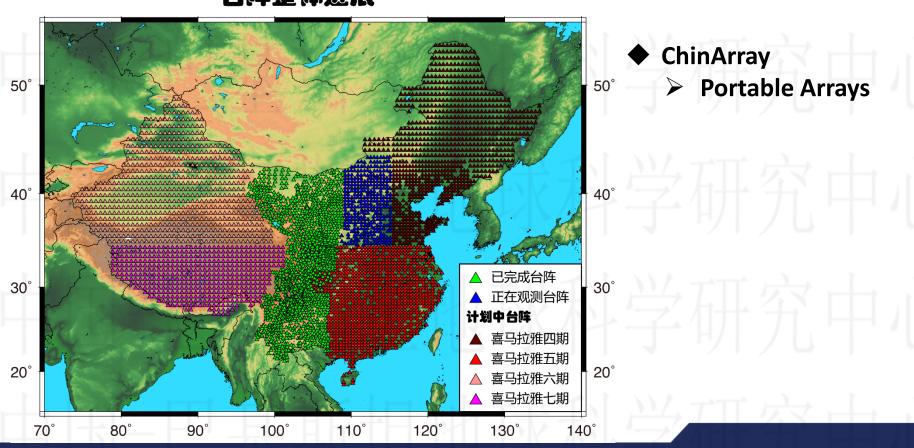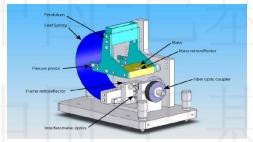
USArray

www.usarray.org

现有固定台站与预警台站

◆ **CEA Seismic Network**
  ➢ Permanent stations
  ➢ Earthquake Early Warning Stations

固定台站

预警台站

台阵整体进展

图例：
- 已完成台阵
- 正在观测台阵

计划中台阵
- 喜马拉雅四期
- 喜马拉雅五期
- 喜马拉雅六期
- 喜马拉雅七期

◆ **ChinArray**
  ➢ **Portable Arrays**

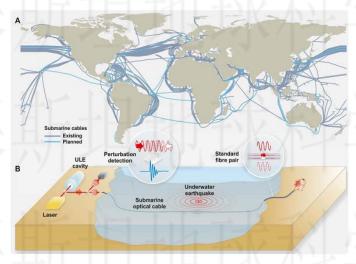1. Background

2. History of Observational seismology

3. Global Seismic Networks
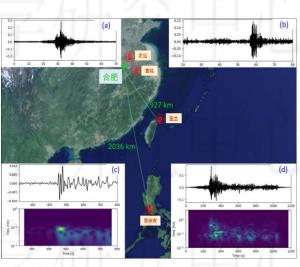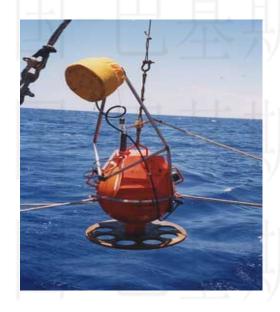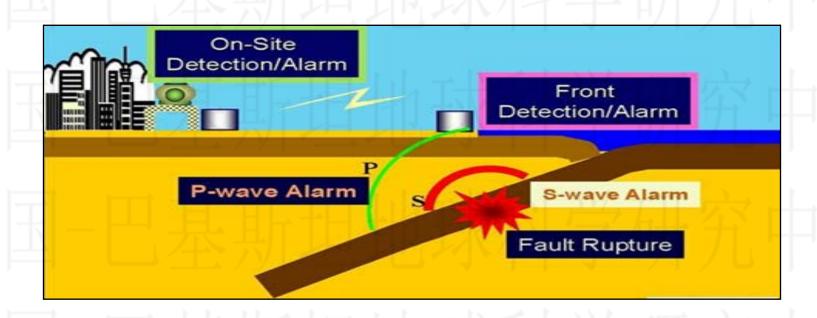
4. Challenges and prospects

✧ **New seismometers**
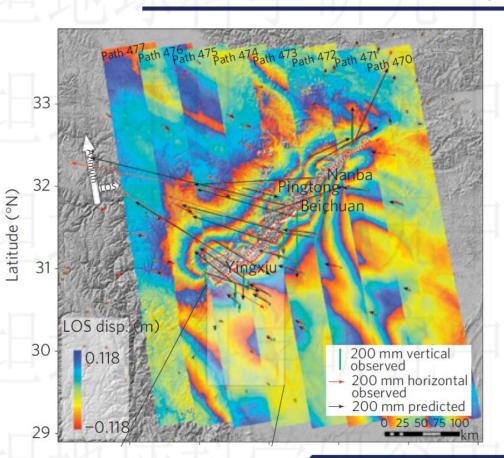
✧ **March into the Deep-Ocean**

✧ **Earthquake monitoring for Earthquake Early warning**

✧ **Earthquake monitoring us not only seismometers**
  ➢ Seismology from Space

✧ **Cooperate among countries**
- ➤ Build stations together
- ➤ Share data with each other
- ➤ Communicate

谢 谢 ！

баярлалаа ขอบใจ ಸನ್ಯವಿದ شكريه

धन्यवाद ধন্যবাদ ধন্যবাদ

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Thank You ！