Advances in Earth Science Help Detect Nuclear Explosions

… and a new way to think about arms-control monitoring

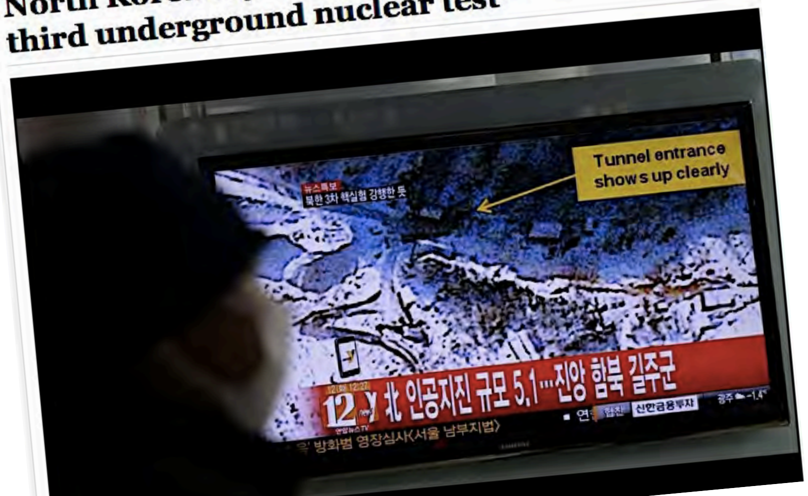
Raymond Jeanloz

University of California, Berkeley

2013 Annual AAAS Meeting

The Washington Post

North Korea says it has successfully conducted third underground nuclear test



The Christian Science Monitor

North Korea tests third nuclear device, prompting emergency UN meeting (+video)

Experts say North Korea's successful detonation of a third nuclear device is concerning because it indicates the country may be getting closer to the ability to put a nuclear device on a missile.

By Steven Borowiec, Contributor / February 12, 2013

United States Mission to the United Nations

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Remarks by Ambassador Susan E. Rice, U.S. Permanent Representative to the United Nations, at the Security Council Stakeout

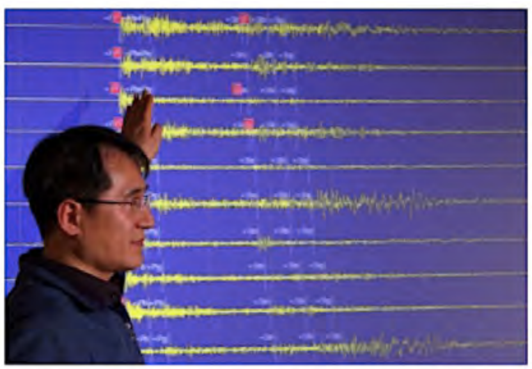
Susan E. Rice

U.S. Permanent Representative to the United Nations

U.S. Mission to the United Nations

New York, NY

February 12, 2013



A South Korean official explains what looks like the seismic signature of an underground nuclear test that North Korea conducted on 12 February.

LEE JI-EUN, YONHAP/AP

The New York Times — Asia Pacific

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

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China Looms Over Response to Blast Test by North Korea

Kyodo News, via Associated Press

A TV news report in Tokyo showing the North Korean leader Kim Jong-un after the country's third nuclear test.

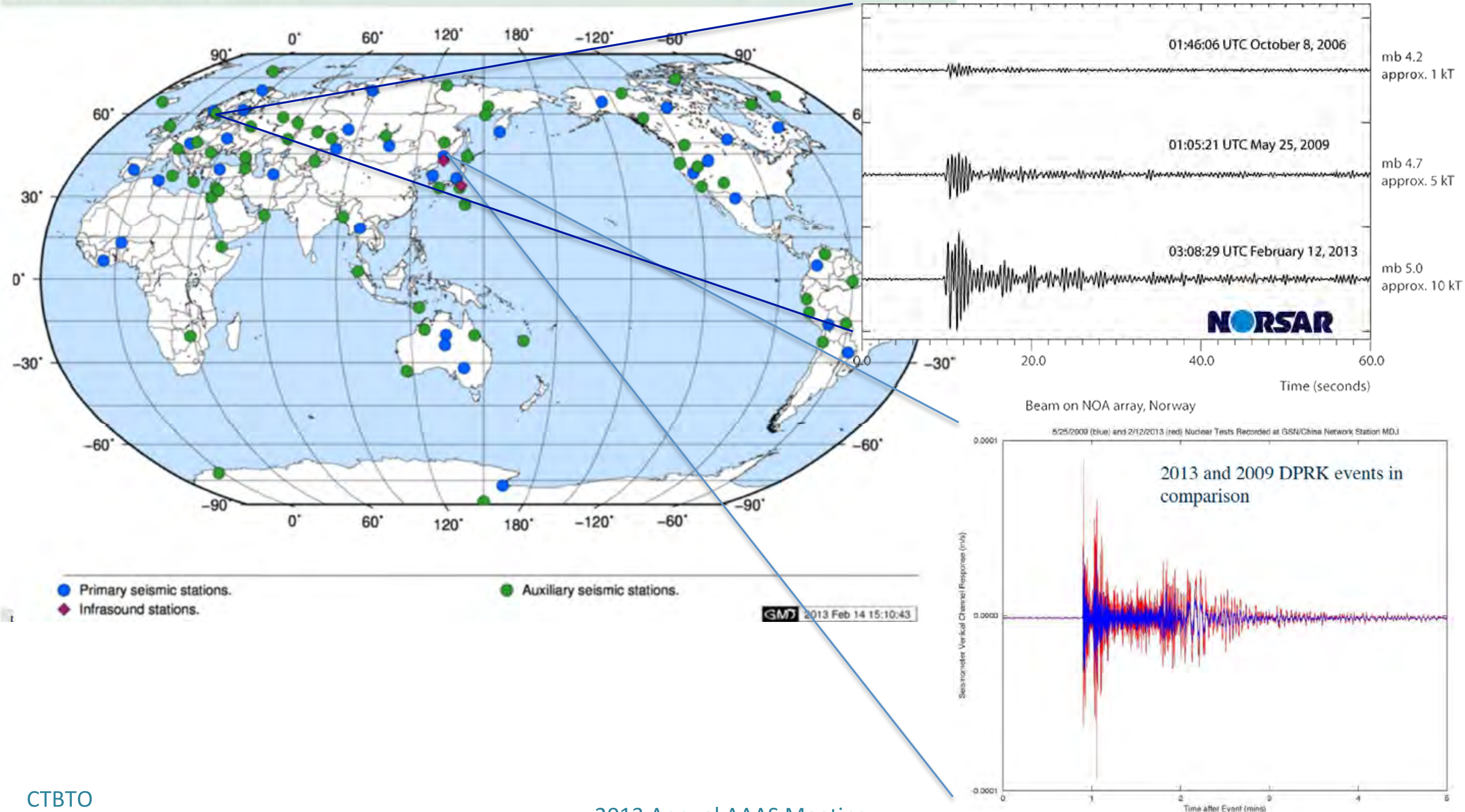
By NEIL MacFARQUHAR and JANE PERLEZ

Published: February 12, 2013 | 402 Comments

International Monitoring System Detection

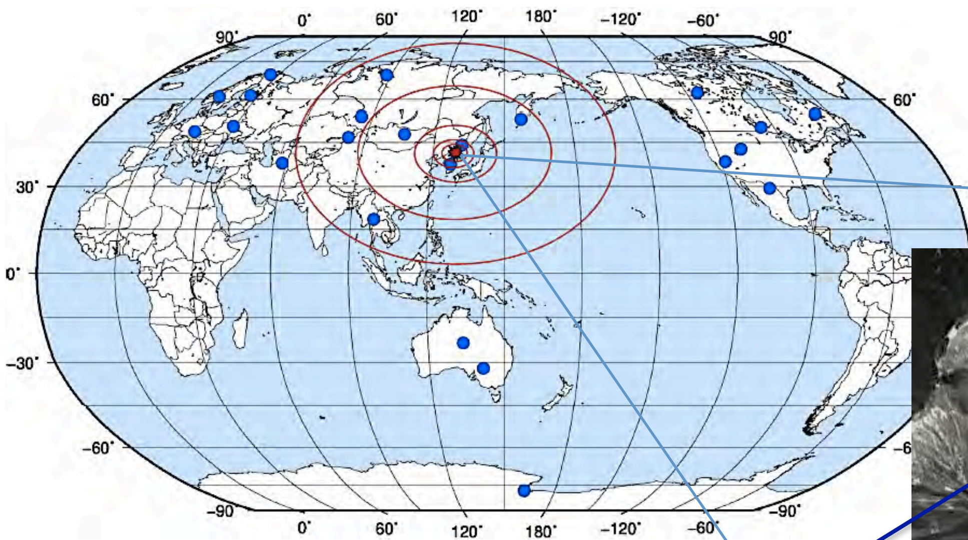
Status quo: 96 stations have detected the event, including 2 infrasound

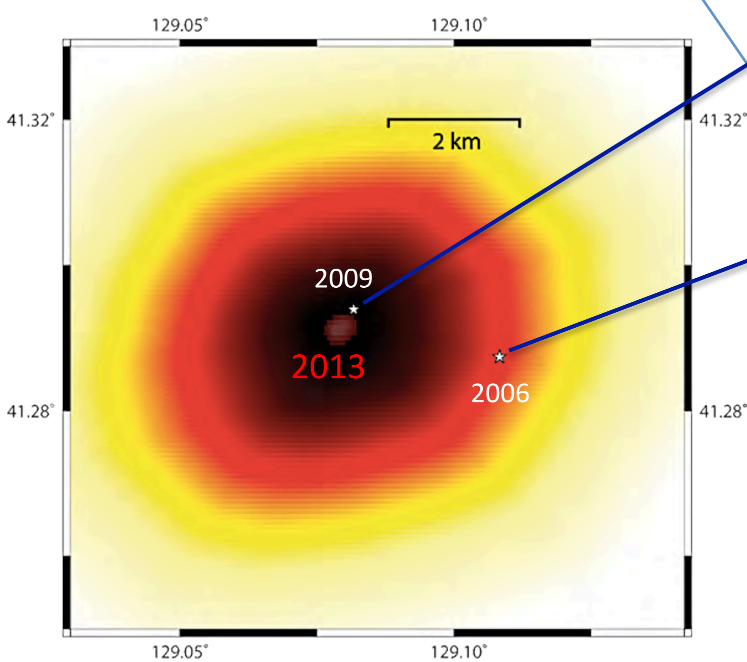
CTBTO PREPARATORY COMMISSION

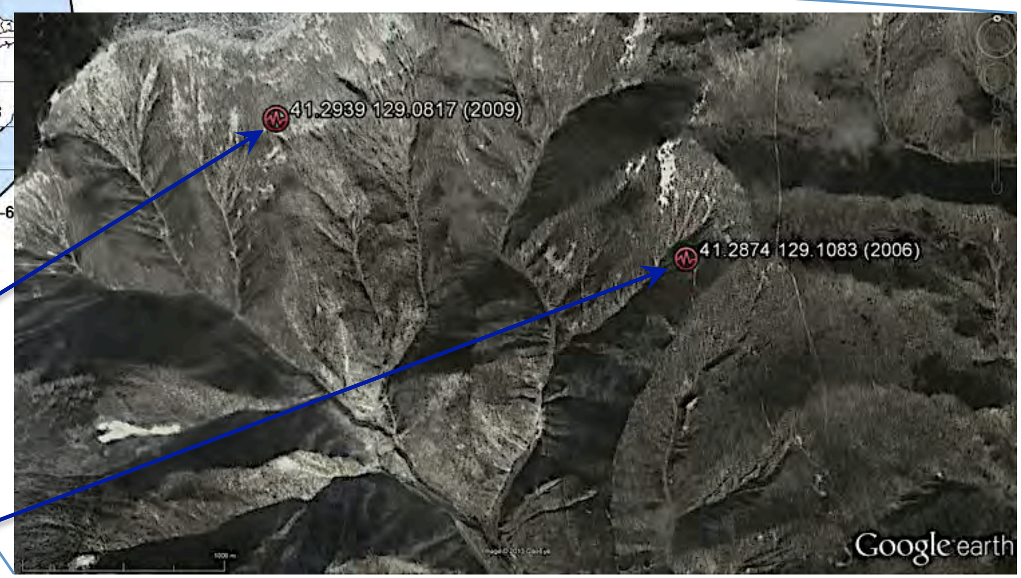


CTBTO
NORSAR

Location – from across the World



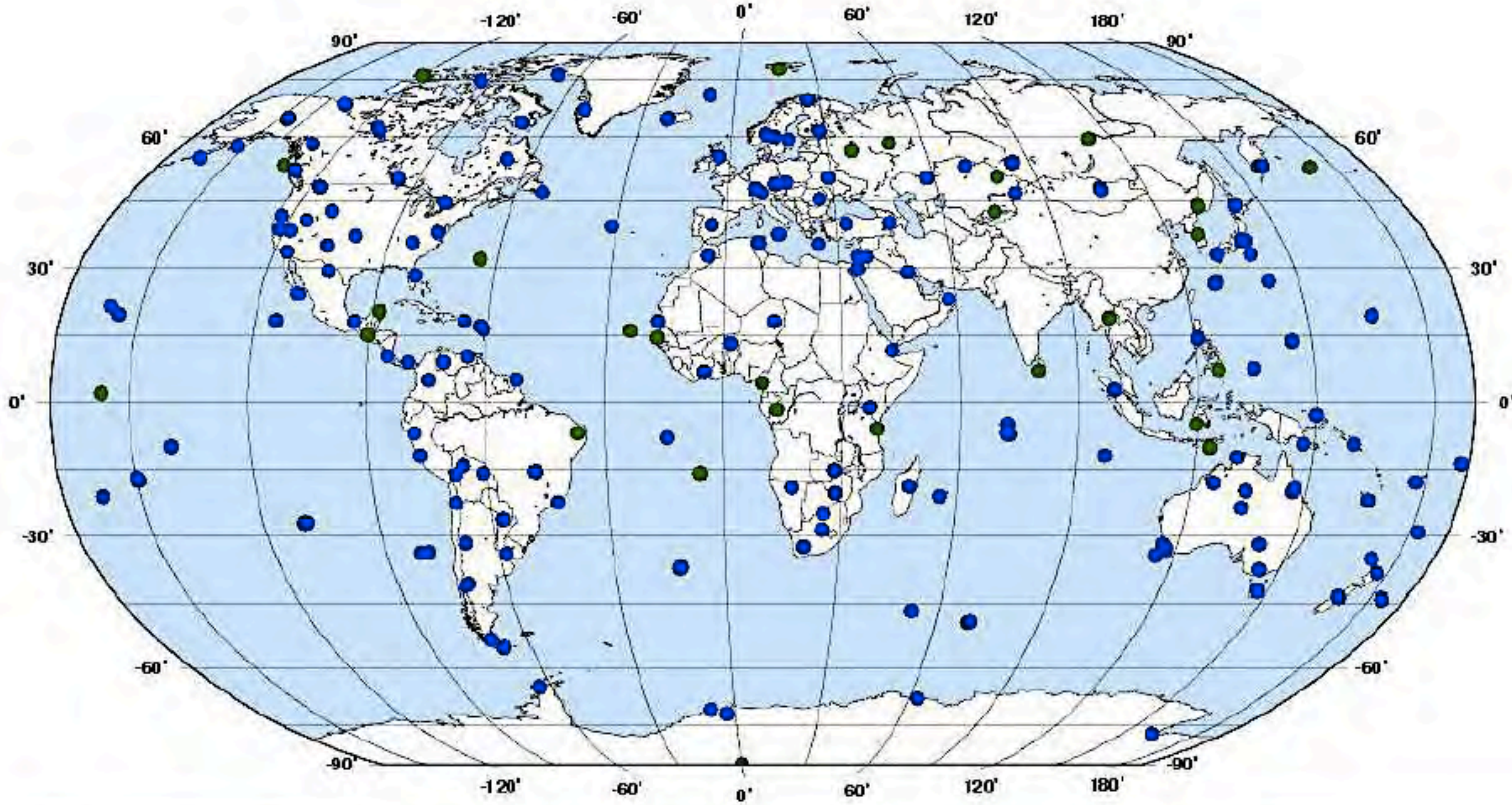




CTBTO
NORSAR

International Monitoring System today: 288 facilities

CTBTO
PREPARATORY COMMISSION



Comprehensive Nuclear Test-Ban Treaty International Monitoring System

50 primary and 120 auxiliary **seismic monitoring stations.**
11 **hydro-acoustic stations** detecting acoustic waves in the oceans.
60 **infra-sound** stations **stations** using microbarographs (acoustic pressure sensors) to detect very low-frequency sound waves.
80 **radionuclide stations** using air samplers to detect radioactive particles released from atmospheric explosions and/or vented from underground or under-water explosions.
16 **laboratories**

288 of these 337 facilities (85 %) are now built and certified or being certified; 21 are under construction and 28 are planned.

CTBT Monitoring Capability

Conventional Bomb to ~ 0.001 kt
Nuclear Bomb to ~ 10-1000 kt

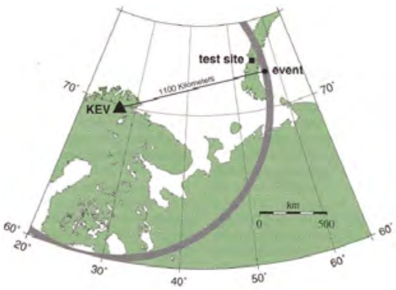
	Atmosphere	**Oceans**	**Land** (subsurface)
Sensitivity	**< 0.01 kt**	**< 0.001 kt**	**< 0.2 kt***
Detection	Satellites/cameras Radionuclides Infrasound/seismic	Satellites/cameras Acoustic/seismic Radionuclides	Seismic IMS NTM Public
Location	Satellites/cameras Infrasound/seismic On-site inspection	Satellites/cameras Infrasound/seismic On-site inspection	Seismic Satelites/InSAR
Characterization Nuclear explosion	Radionuclides Satellites/cameras	Radionuclides On-site inspection	On-site inspection Radionuclides
Explosion/Artificial	Infrasound/seismic	Acoustic/seismic	Seismic
Attribution	Satellite/cameras Nuclear forensics	Satellite/cameras Nuclear forensics	

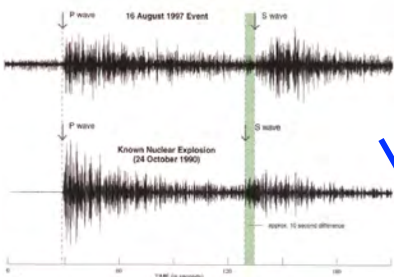
* < 0.01 (0.04) kt in regions of interest for hard (soft rock) + possible decoupling

IMS = International Monitoring System
NTM = National Technical Means

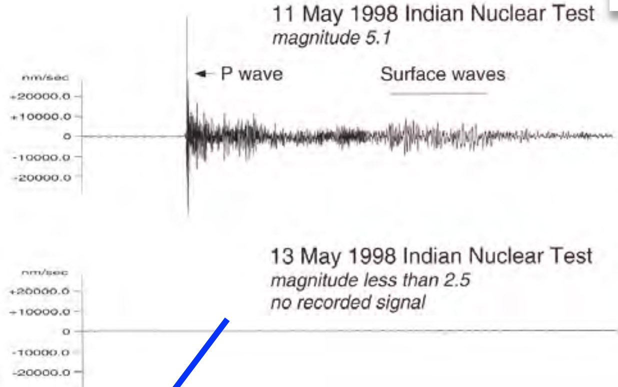
Monitoring

Validation with non-IMS stations



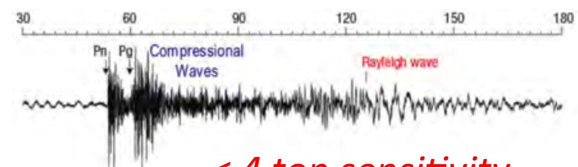


< 25 km, 500 km² resolution

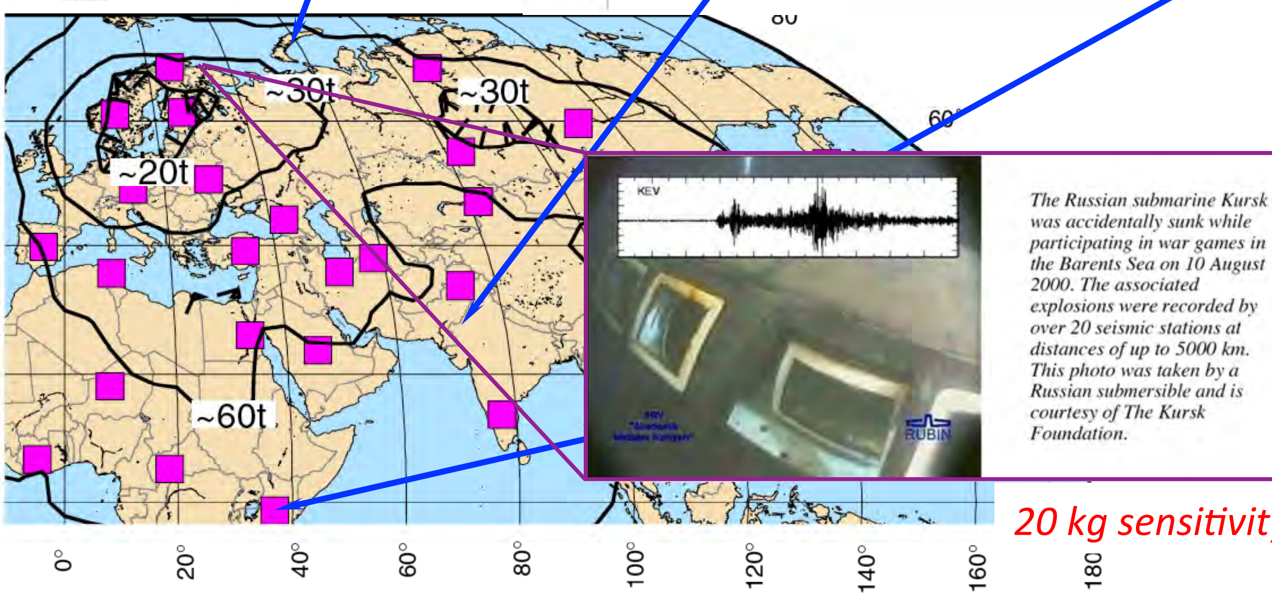


< 10-20 ton sensitivity

DPRK Tests 2006, 2009



< 4 ton sensitivity



The Russian submarine Kursk was accidentally sunk while participating in war games in the Barents Sea on 10 August 2000. The associated explosions were recorded by over 20 seismic stations at distances of up to 5000 km. This photo was taken by a Russian submersible and is courtesy of The Kursk Foundation.

20 kg sensitivity

The U.S. Embassy and surrounding buildings in the aftermath of the 7 August 1998 terrorist bombing in Nairobi, Kenya. The explosion was recorded on a seismometer just over 3 km away.

4 ton sensitivity

Planned IMS Sensitivity

Yield (tons TNT) detected at ≥ 3 IMS stations

2012 National Academy of Sciences Study

Evaluates explosion-monitoring and nuclear-weapons capabilities

Technical basis for US ratification

NAS, 2012

Seismic Monitoring

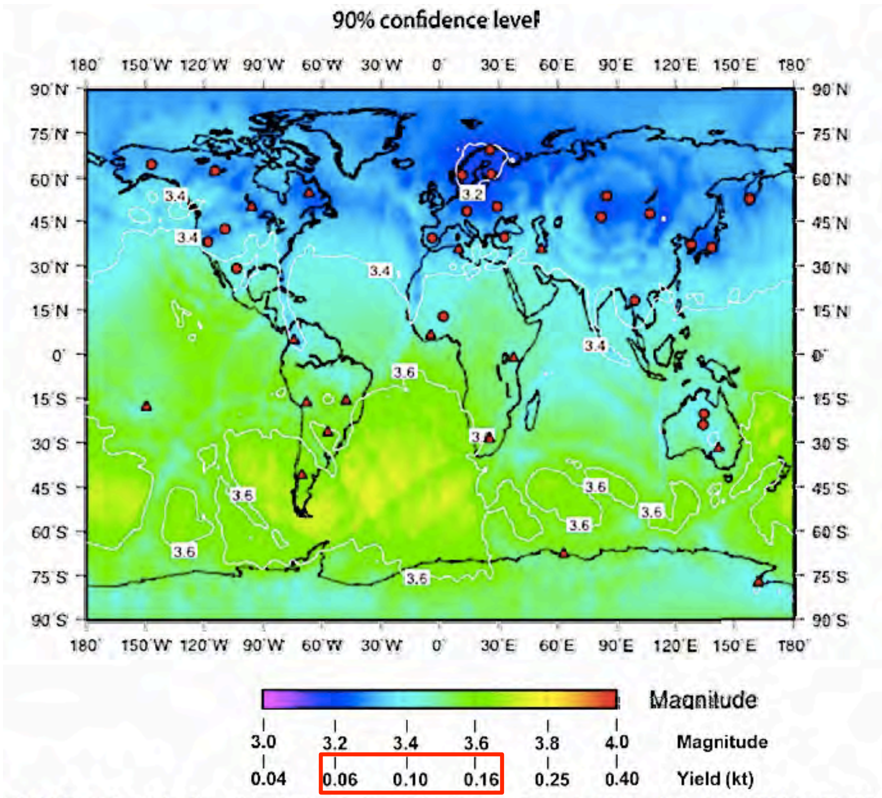


FIGURE 2-8: Detection Capability of the IMS Primary Seismic Network in late 2007, with 38 stations sending data to the IDC. Contours, indicate the magnitude of the smallest seismic event that would be detected with a 90 percent probability at three or more stations; that is, at enough stations to enable a location estimate. Red circles are seismic arrays, and triangles are single seismic stations. Completion of this network (to 50 stations) would reduce these magnitudes by about 0.1 or 0.2 units for Asia, much of Africa, and the Indian Ocean. The resulting capability, based extensively on operational experience, is quite similar to that described in the *2002 Report*, which was a calculation of how well the then far-from-complete primary network would eventually operate (The magnitude yield relationship comes from Box 2-1). SOURCE: Capability map prepared by Tormod Kværna and Frode Ringdal, NORSAR

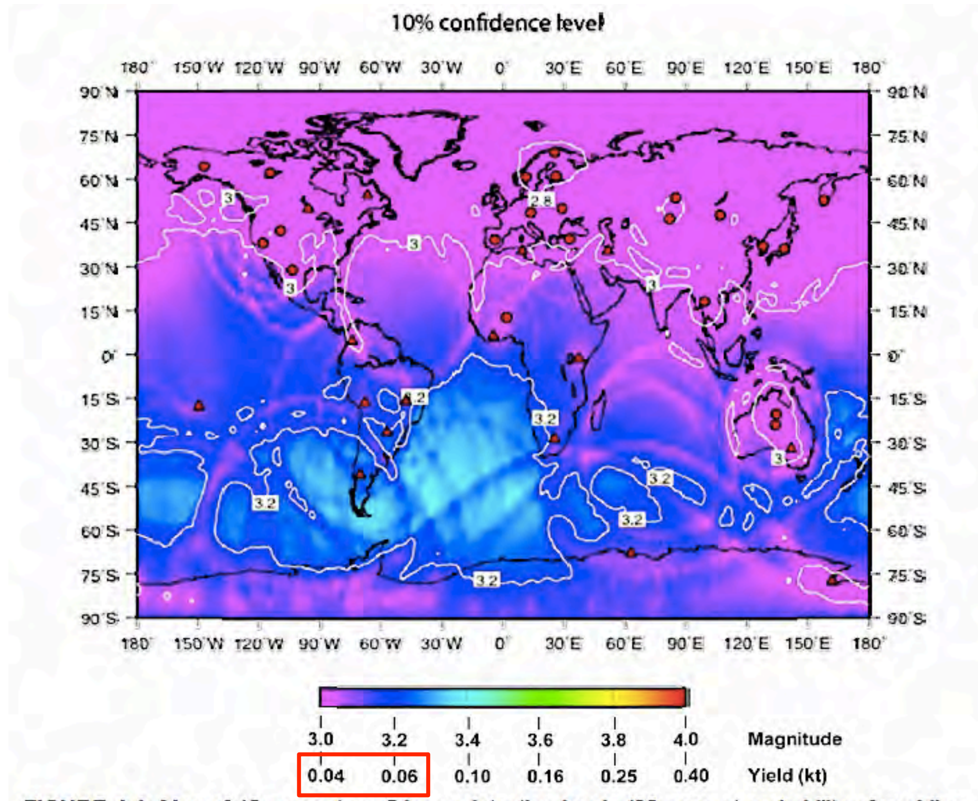


FIGURE 4-1: Map of 10 percent confidence detection levels (90 percent probability of avoiding detection) for the primary IMS Network (2007). The map represents detection capability of IMS primary seismic network, late 2007, with 38 stations sending data to the IDC. Contours indicate the magnitude of the smallest seismic event that would be detected with a 10 percent probability at three or more stations. Red circles are seismic arrays, and triangles are single seismic stations. This map is similar to Figure 2-8, except the probability of detection is 10 percent here rather than 90 percent in Figure 2-8. For reference, the magnitudes 2.8, 3.0, and 3.2 correspond to fully coupled device yields of 0.022 kt, 0.035 kt, and 0.056 kt respectively in regions of better propagation (The magnitude yield relationship comes from Box 2-1 in Chapter 2).
SOURCE: Capability map prepared by Tormod Kværna and Frode Ringdal, NORSAR

NAS, 2012

Monitoring Improvements

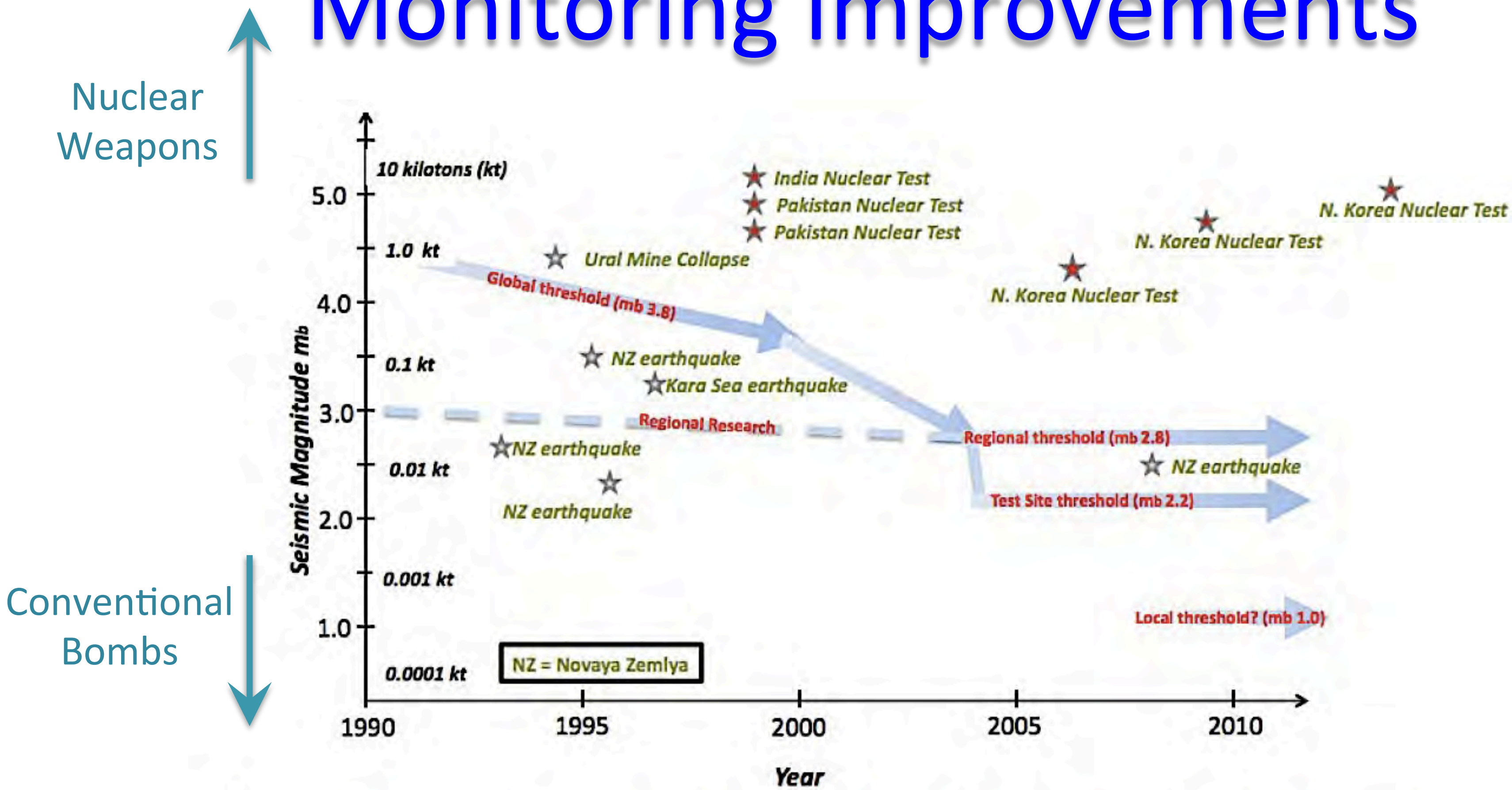
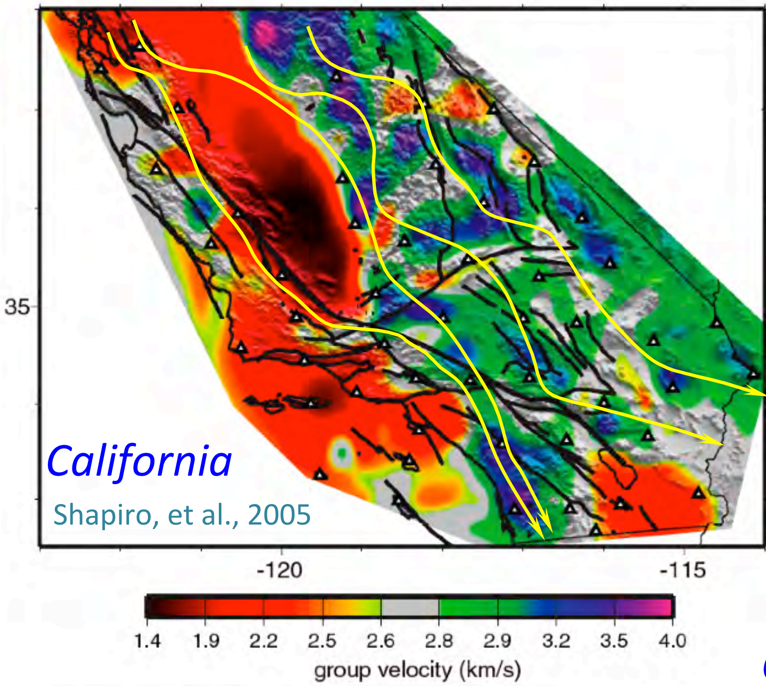
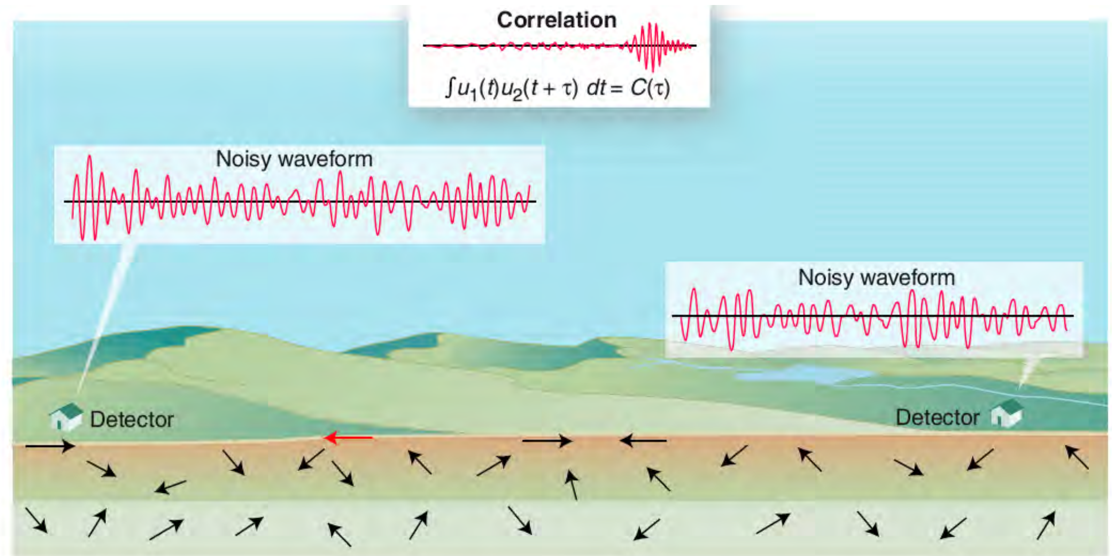


FIGURE 2-7: Improvement in seismic monitoring over the last 20 years. Threshold values indicate statistically significant confidence of detection. Note that yield and seismic magnitude scales are logarithmic; each unit of improvement is a factor of ten. Seismic sensitivity to nuclear explosions has improved significantly due to increased deployment of seismometers and improved data analysis. For locations of interest, this allows regional monitoring at distances less than about 1,600 km (1,000 miles), which has a much lower threshold (~ 20 tons or 0.020 kilotons explosive yield) than does global monitoring (~ 200 tons or 0.20 kilotons) recorded at distances typically greater than 2,000 miles. Monitoring at test sites (e.g., through transparency measures) can bring the sensitivity down to about 5 tons, or 0.005 kilotons.[10]

NAS, 2012

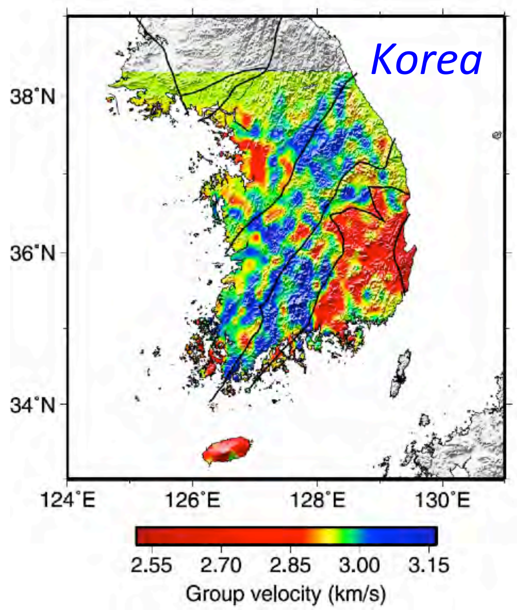
Seismic Wave-Velocities





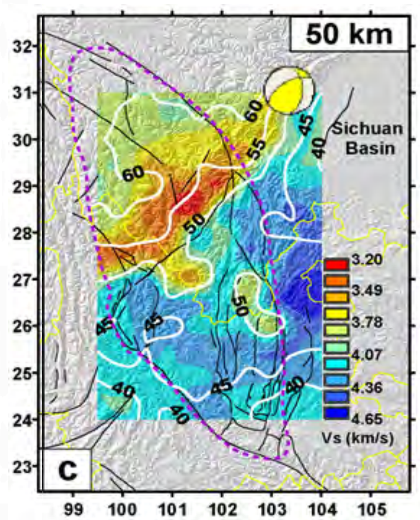
Using noise in seismology. When a diffuse wave field is generated by distant sources and/or by multiple scattering, detectors report random signals. Occasionally a ray (for example, the one shown in red) passes through both detectors. As a result, the signals are weakly correlated.

Weaver, 2005

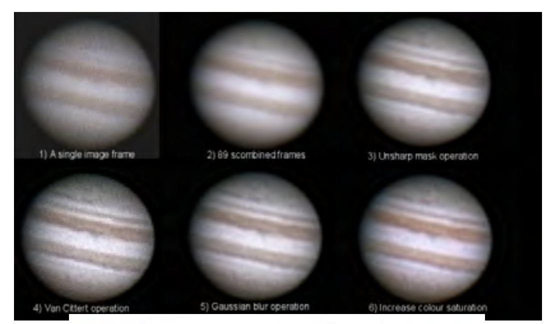


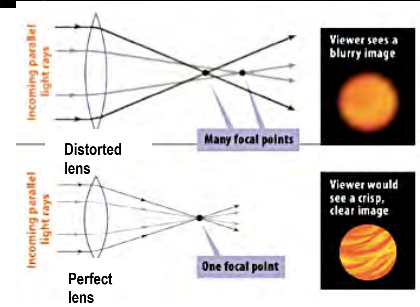
Kang & Shin, 2006

China



http://quake.mit.edu/~changli/wenchuan.html



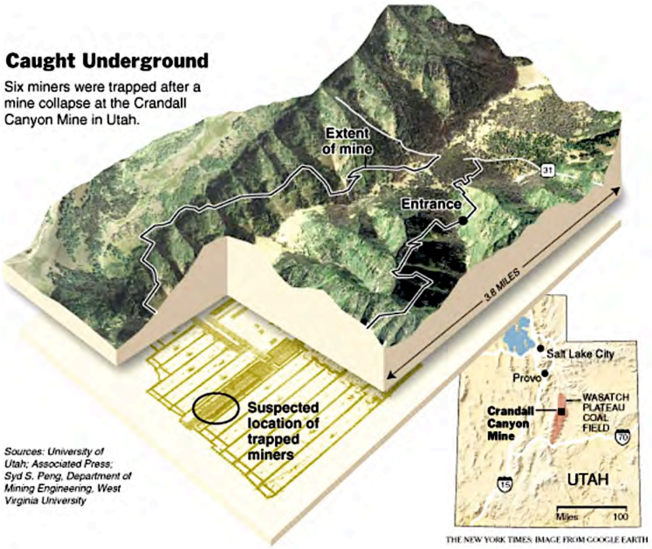


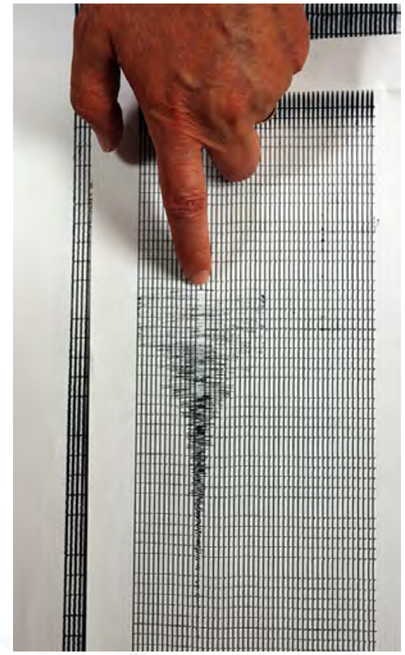
The New York Times
nytimes.com

August 7, 2007

Six Trapped After Collapse in a Utah Coal Mine

By MARTIN STOLZ





USA TODAY

Click to Print

Seismic readings at Utah mine do not point to quake

By William M. Welch, USA TODAY

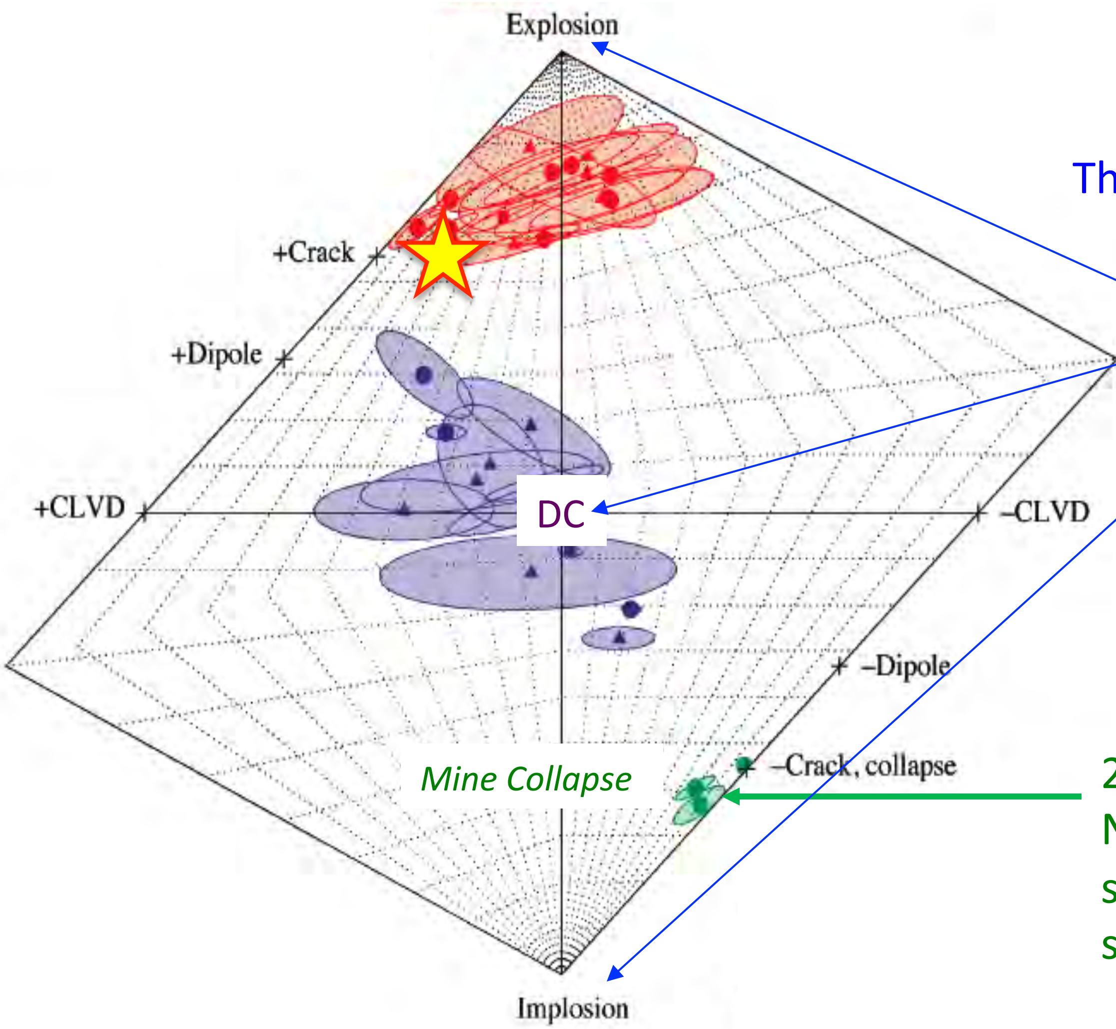
Scientists studying the collapse of a Utah mine that trapped six miners said Tuesday that "all of the evidence" from reviews of seismic readings overwhelmingly supports the conclusion that the collapse was caused by the mine and not an earthquake.

Douglas Dreger, associate professor of geophysics at the University of California, Berkeley, said comparisons of the Aug. 6 collapse with a blowout of the mine walls Aug. 16 that killed three rescue miners has buttressed the conclusion that the mine collapsed on its own.

Mining officials, among them Crandall Canyon Mine co-owner Robert Murray, have said the disaster was probably caused by an earthquake. Murray did not respond to a request for comment placed with his personal assistant.

Dreger said data from the blowout, or "bump" as it is known in mining parlance, showed the initial motion of the earth was the same, though smaller in force, to the initial collapse. He said that analysis confirmed that the mine collapse was triggered by shifting of rock in response to activity in the mine and not other seismic forces.

"All the evidence I've seen points to … (an) underground collapse, a reduction in volume source" inside the mine near Huntington, Dreger said in a phone interview.



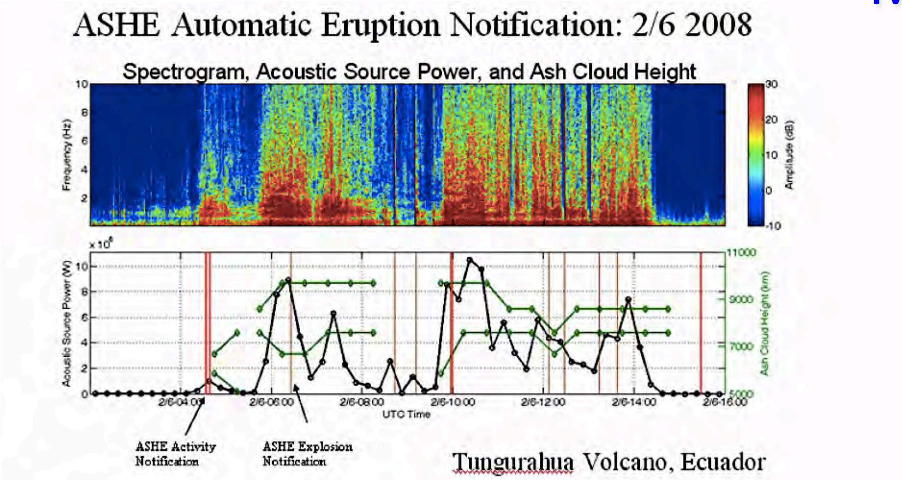
Dreger, et al. (2009)

The tragic Utah mine collapse was not an

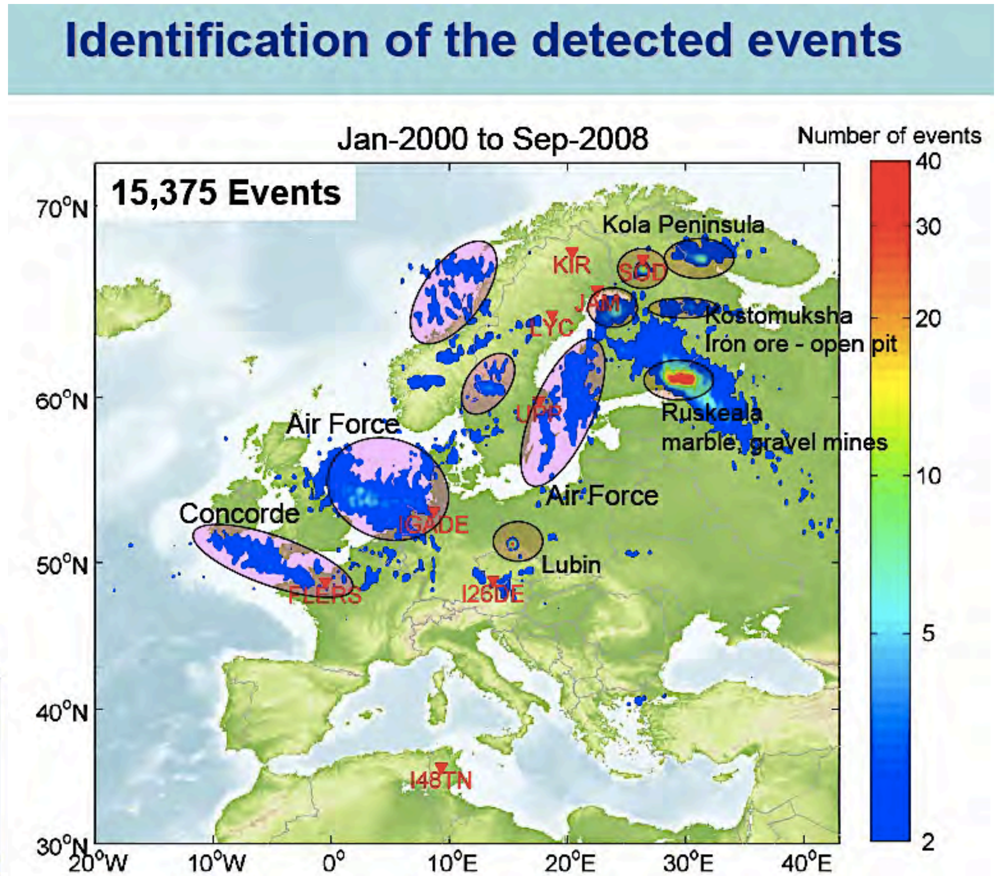
explosion
earthquake ("double-couple" DC)
or
implosion, but

2 flat surfaces slapping together:
Not any orientation but horizontal surfaces, like the roof of a chamber slamming onto the floor.

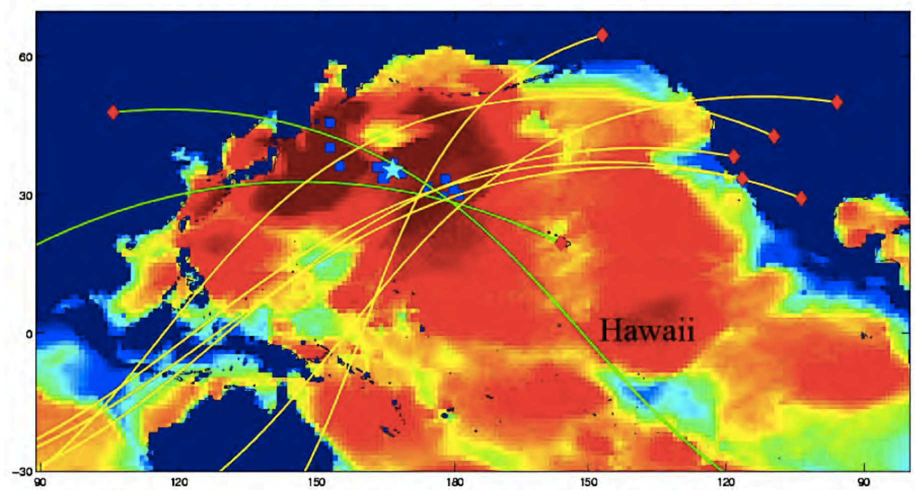
Major scientific & societal applications



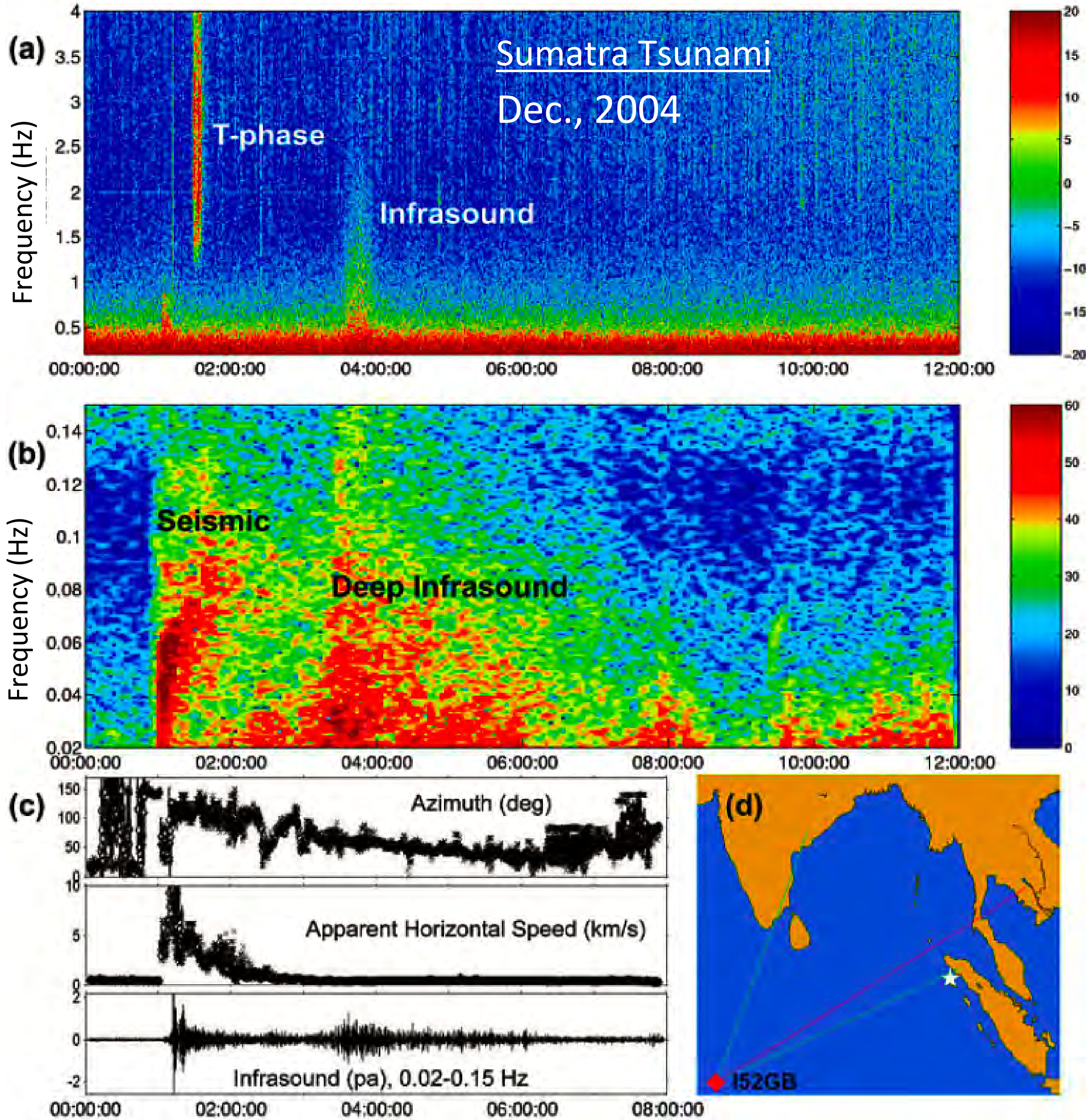
- Monitoring of volcanoes: Acoustic Surveillance for Hazardous Eruptions
- Monitoring of Tsunamis (Sumatra very strong signals)
- Study of atmospheric waves and global dynamics in relation with climate evolution



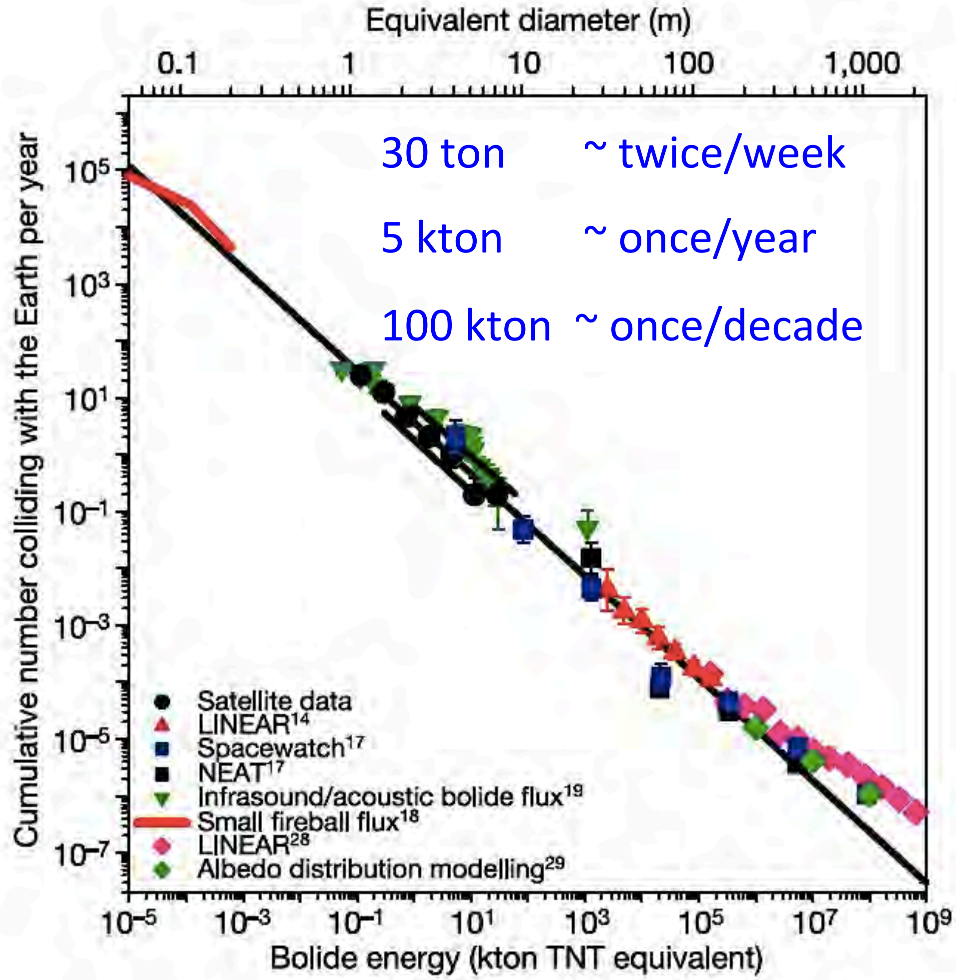
Monitoring Severe Weather (Hurricanes, Tornados)



USA-Canada project (UM, UH, UCSD, UAF, NRL, Canada)

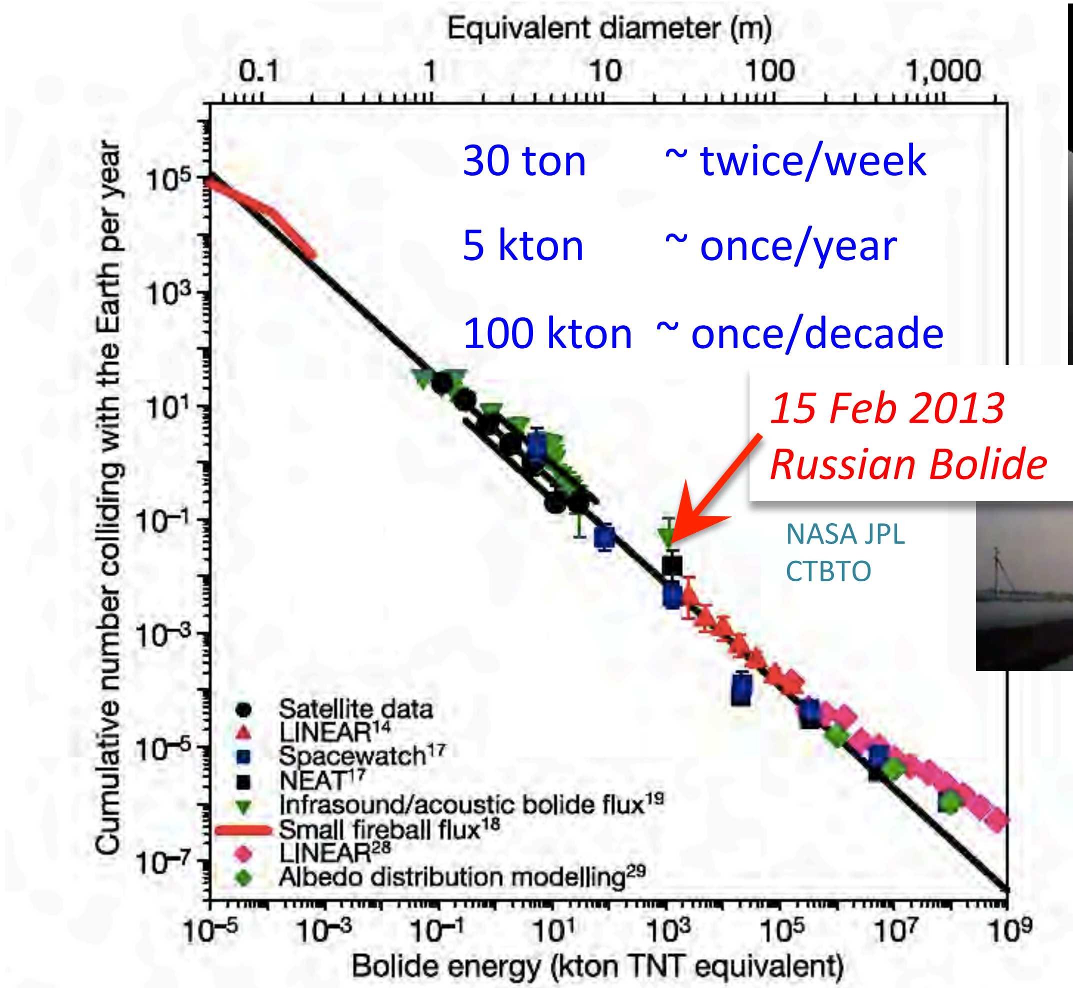


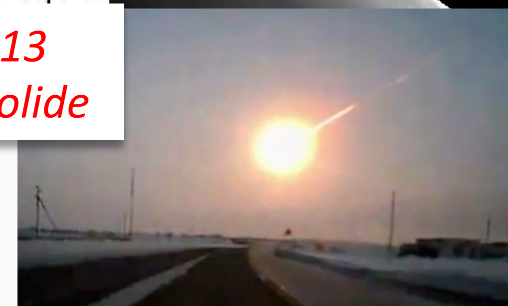
Garcés, et al. (2005)



The flux of small near-Earth objects colliding with the Earth. Data are shown over a range of 14 magnitudes of energy. In addition to data shown in Fig. 3, this plot also shows the Earth collision hazard in the 1,000 Mton and larger energy range, based on modelling the albedo distribution of near-Earth asteroids[29]. At smaller sizes, the power-law number distribution derived from a decade-long survey of ground-based observations of fireballs[18] is indicated.

Brown, et al (2002)



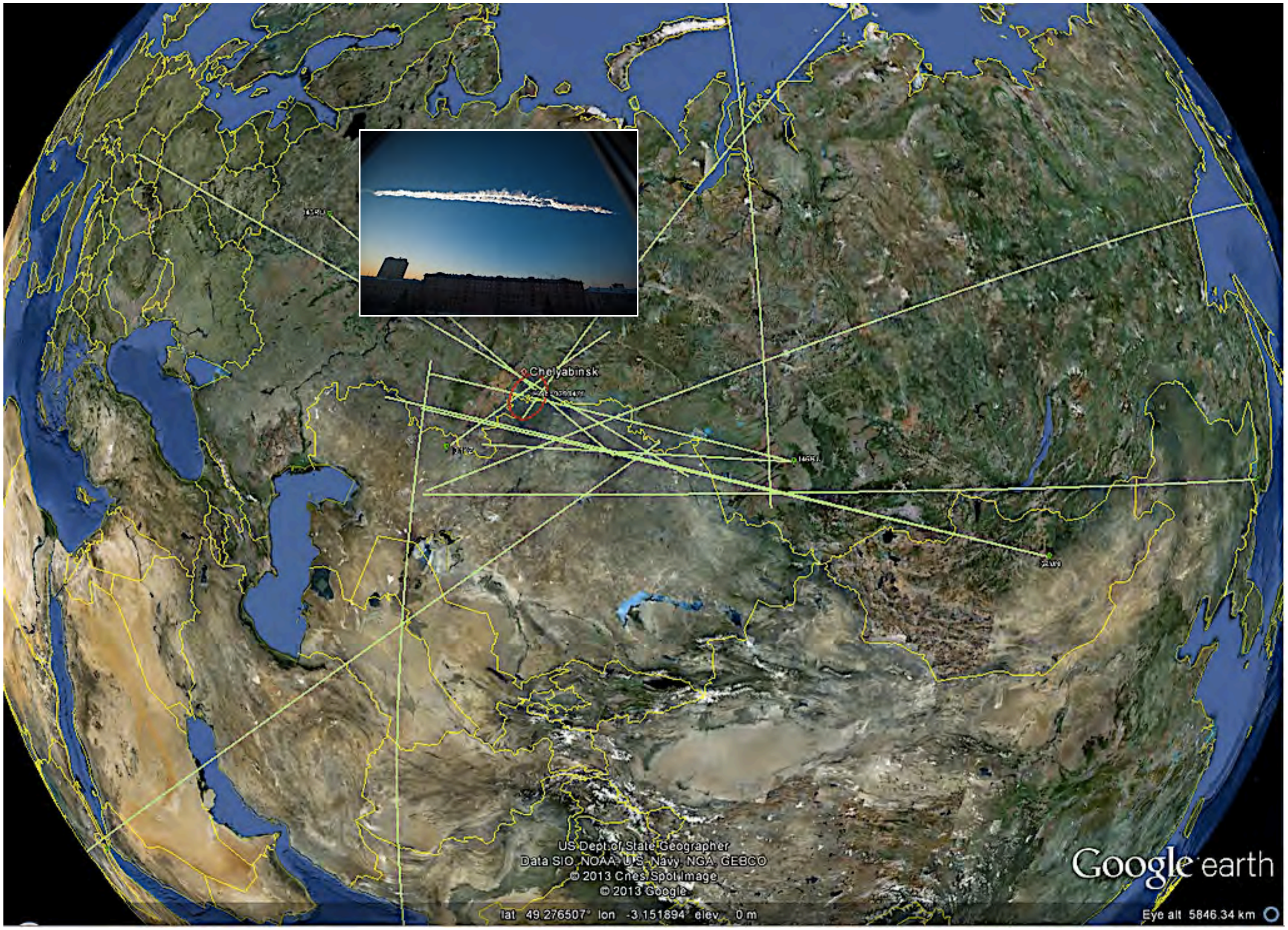


BBC
Chelyabinsk Region Police Department, via AFP — Getty Images

The flux of small near-Earth objects colliding with the Earth. Data are shown over a range of 14 magnitudes of energy. In addition to data shown in Fig. 3, this plot also shows the Earth collision hazard in the 1,000 Mton and larger energy range, based on modelling the albedo distribution of near-Earth asteroids[29]. At smaller sizes, the power-law number distribution derived from a decade-long survey of ground-based observations of fireballs[18] is indicated.

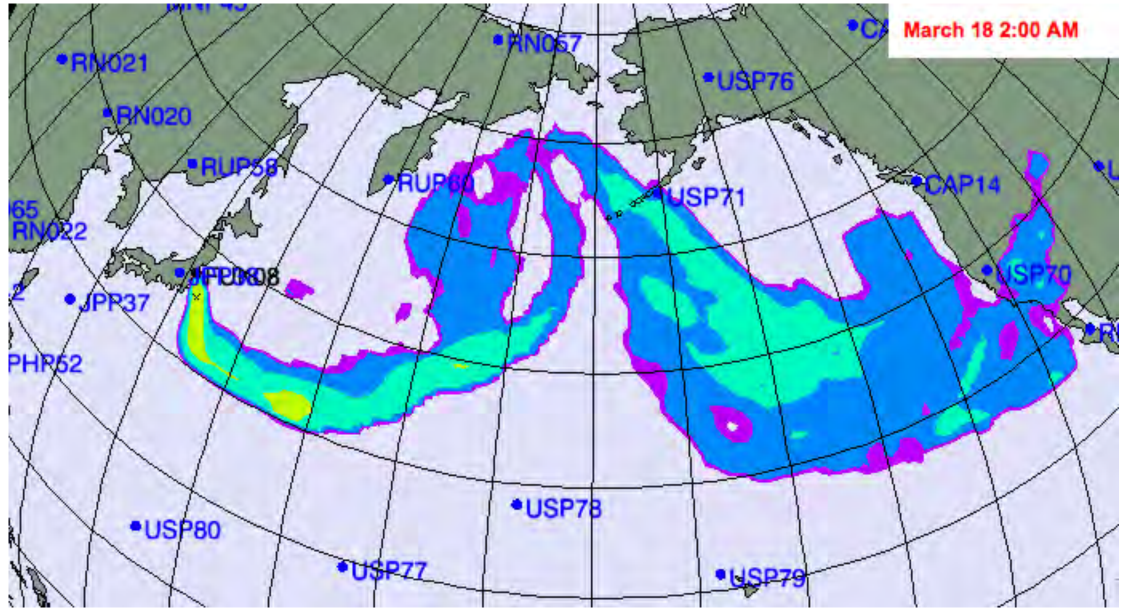
Brown, et al (2002)

15 February, 2013 Bolide



CTBTO
Yekaterina Pustynnikova/Chelyabinsk.ru,
via Associated Press

Tracking Radioactive Fallout



Then…

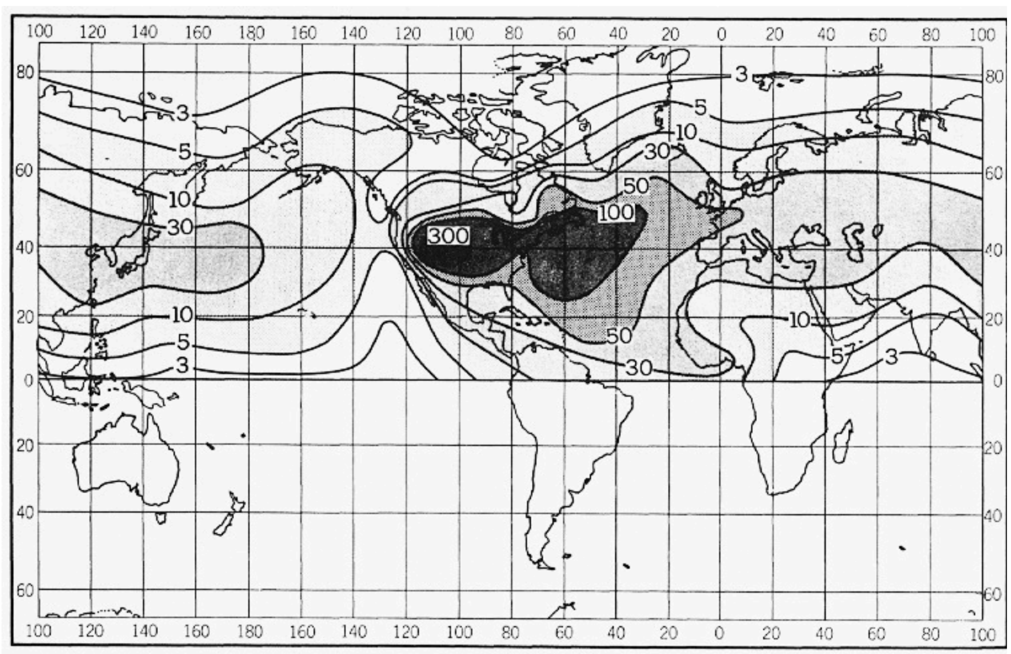


FIGURE 9-15 Worldwide radioactive fallout from nuclear weapons tests in Nevada in 1953. The explosions were in the kiloton range of yields, and debris was confined to the troposphere. The intensity of fallout is shown in relative units. [Reprinted with permission from Machta, L., List, R. J., and Hubert, L. F. (1956). World-wide travel of atomic debris. *Science* **124**, 474–477. Copyright 1956 American Association for the Advancement of Science.]

2011
Fukushima

Now

1953
NTS Tests

CTBTO
Machta, et al., 1956

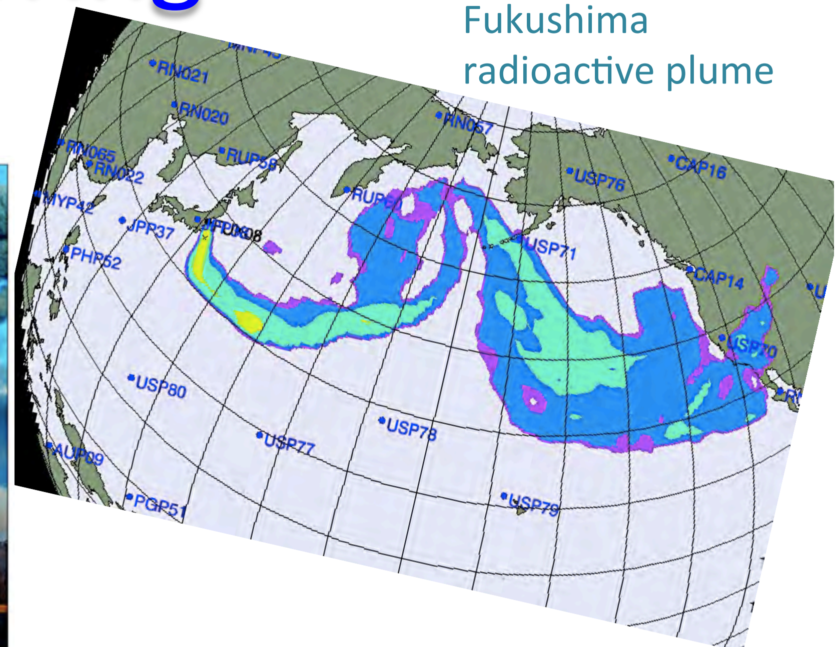
Non-Treaty Applications of Monitoring

Comprehensive Nuclear Test-Ban Treaty
International Monitoring System

Advanced Science Course
CTBTO, Dec. 2011

volcanic eruptions

Fukushima
radioactive plume



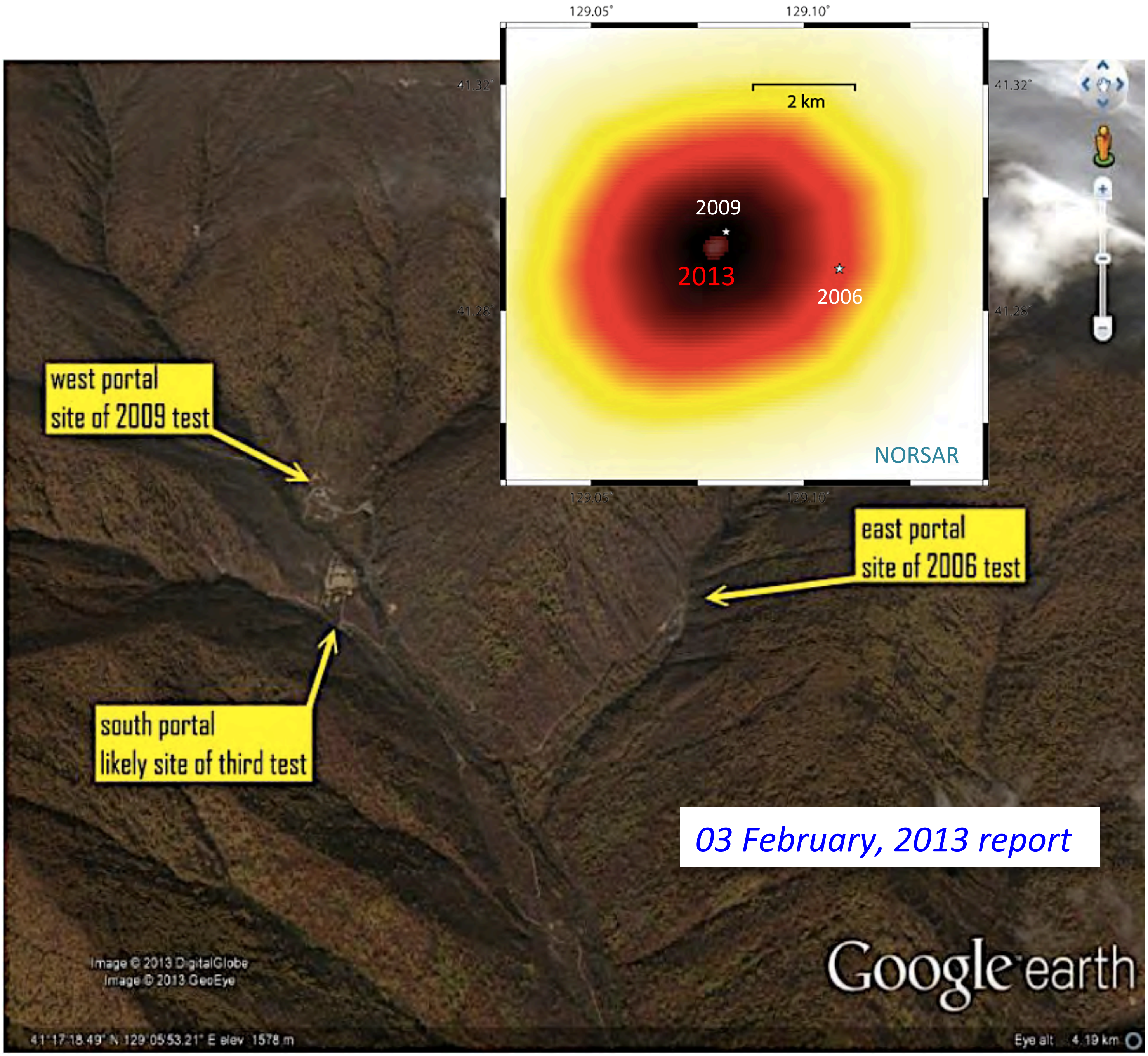
Indian Ocean
tsunami warning

ctbto.org

North Korean Test Site

Commercial Imagery

Albright & Brannan (2006)


129.05°
129.10°
41.32°
41.28°
2 km
2009
2013
2006
NORSAR
west portal
site of 2009 test
east portal
site of 2006 test
south portal
likely site of third test
03 February, 2013 report
Image © 2013 DigitalGlobe
Image © 2013 GeoEye
41°17'18.49" N 129°05'53.21" E elev 1578 m
Google earth
Eye alt 4.19 km

Non-Treaty Applications

Pervasive monitoring of the environment

Relevant to
- climate change
- resource management (water)
- environmental quality (pollution)
- public health (epidemiology)
- natural hazards mitigation (tsunami)
- natural catastrophe response (earthquakes)

Opportunity: Greatly enhance atmospheric monitoring

gases (e.g., greenhouse gases)
particulates
use data to improve weather/climate, pollution tracking, forecasting

… and for arms control

Recommendations

1) Acknowledge non-treaty applications of monitoring
   - helps implement and practice monitoring
   - provides platform for developing, vetting technologies
   - maintains long-term motivation for monitoring regime
   - *hazard mitigation, avoidance*

2) Develop and implement plans to use non-treaty monitoring

3) Take leadership through bi-lateral cooperation

POLICYFORUM

ARMS CONTROL

Beyond Arms-Control Monitoring

Raymond Jeanloz,[1,2]* Inez Fung,[1] Theodore W. Bowyer,[3] Steven C. Wofsy[4]

Environmental monitoring can become a useful long-term objective of arms-control treaty verification.

In some sense, nontreaty applications should be viewed as one of the ultimate long-term objectives of an arms-control monitoring regime. Without such applications, monitoring may not be sustainable. With such applications, however, monitoring can be enhanced through implementation of new technologies, engagement of more participants and—more generally—through improvements in transparency among nations.

The HIAPER aircraft approaching Deadhorse, Alaska.

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