GPS Precision Monitoring of Geologic Hazards

USTTI Seminar: Global Positioning System Applications for Disaster Management and Societal Benefits

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U.S. Geological Survey

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U.S. Department of the Interior
U.S. Geological Survey

Acknowledgement

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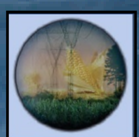
USGS

Facing Tomorrow's Challenges – USGS Science in the Decade 2007-2017

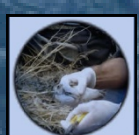
Understanding Ecosystems and Predicting Ecosystem Change

Climate Variability and Change

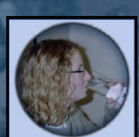


Energy and Minerals for America's Future

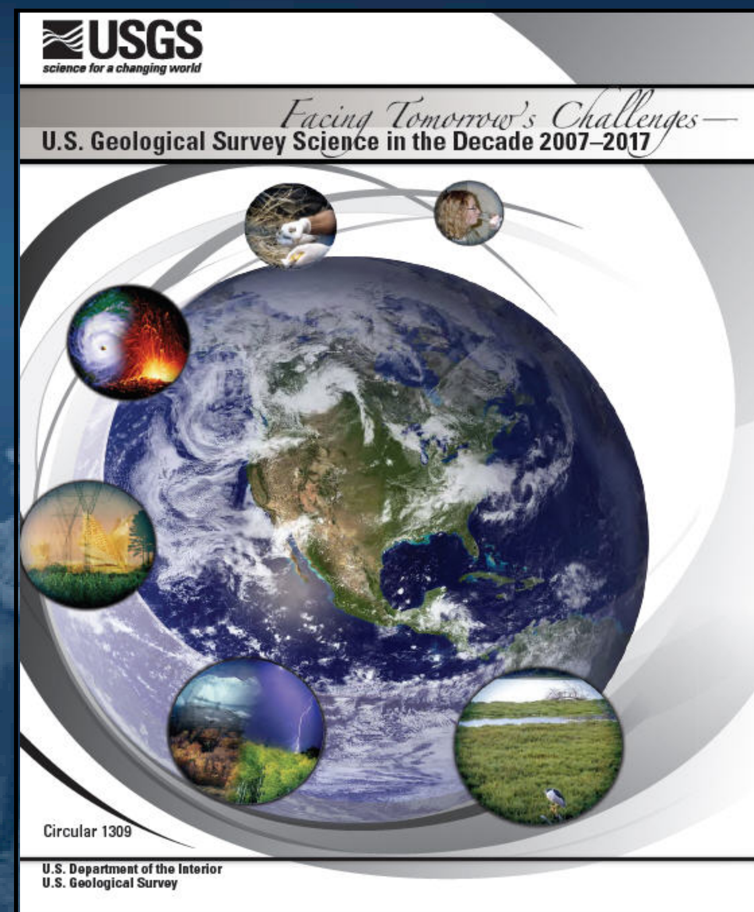
A National Hazards, Risk, and Resilience Assessment Program



The Role of Environment and Wildlife in Human Health



A Water Census of the United States



U.S. Geological Survey Natural Hazards Science Strategy – Promoting the Safety, Security, and Economic Well-Being of the Nation

Published April 2013

Contents

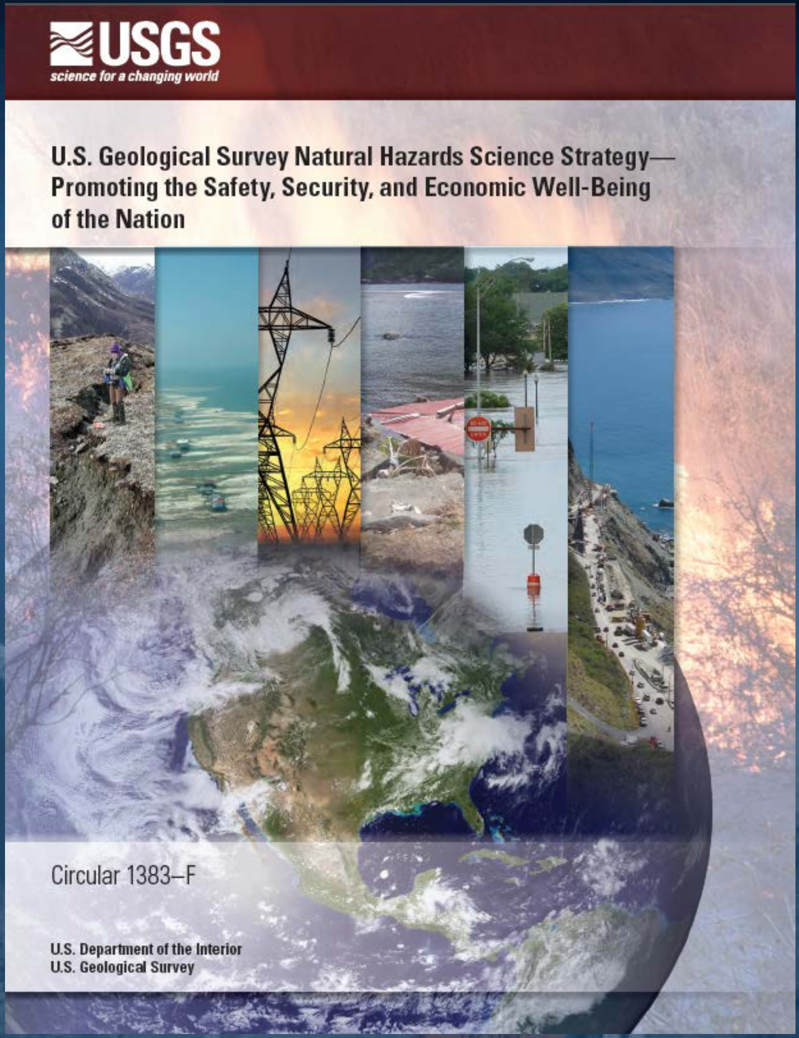
Identifies four primary goals:

1. Enhanced Observations
2. Fundamental Understanding of Hazards and Impacts
3. Improved Assessment Products and Services
4. Effective Situational Awareness

A Vision of the Future

Opportunities and Challenges

Planning and Interconnections Across the USGS Mission Areas



USGS Natural Hazards Mission Area Headquarters Staff Structure

Associate Director for Natural Hazards

Science Strategy Planning Team

Deputy AD

Emergency Response Coordinator

- **Management/Budget**
- **Emergency Management**

Non-program Hazard Coordinators

- Flood
- Geospatial Response
- Storm Team
- Wildfire
- Chemical & Biological Threats

Chief of Staff

Coastal & Marine Geology Program

Earthquake Hazards, GSN & Geomagnetism Programs

Landslide Hazards Program

Volcano Hazards Program

Science Applications for Risk Reduction (SAFRR) Project

USGS

USGS hazard roles and responsibilities

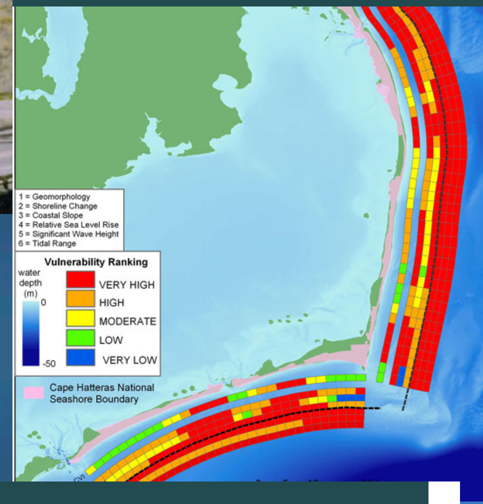
- Delegated federal responsibility to provide notifications and warnings for earthquakes, volcanic eruptions, and landslides.
- Seismic networks support NOAA's tsunami warnings.
- Streamgages and storm surge monitors support NOAA's flood and severe weather (including hurricane) warnings.
- Geomagnetic observatories support NOAA and AFWA geomagnetic storm forecasts.
- USGS has key role in tracking chemical and biological threats, in particular zoonotic diseases.
- Geospatial information supports response operations for wildfire and many other disasters.

USGS

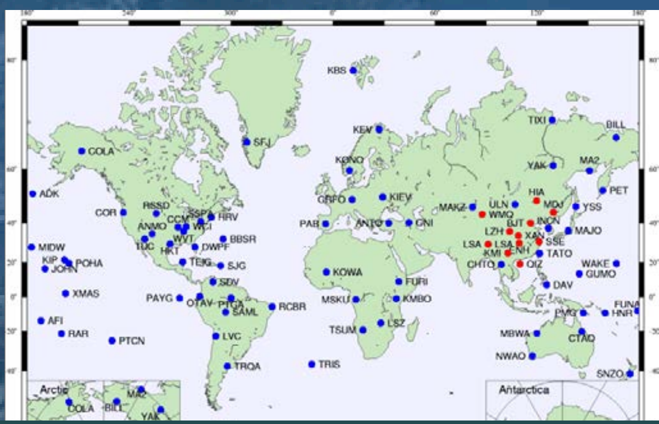
Natural Hazards Mission Area programs

Earthquake Hazards

Coastal & Marine Geology

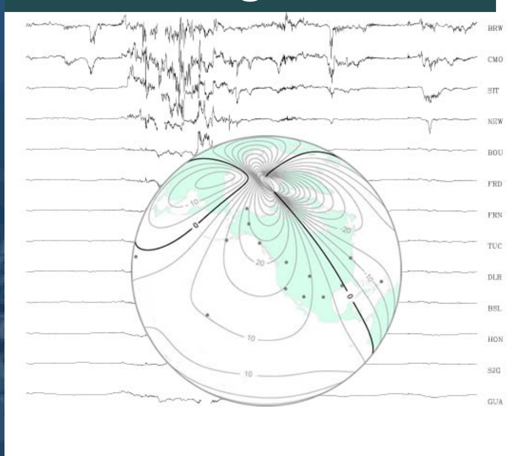


Volcano Hazards



Global Seismographic Network

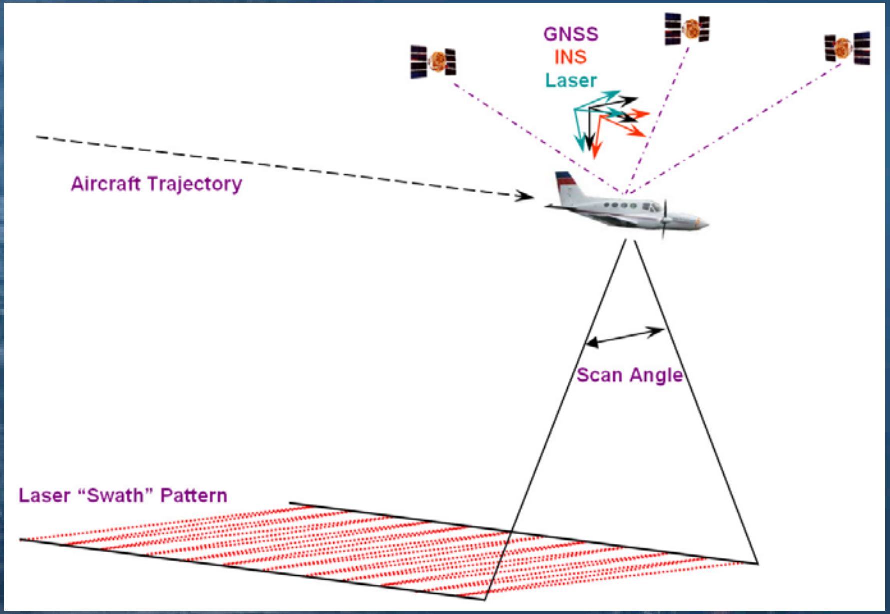
Geomagnetism

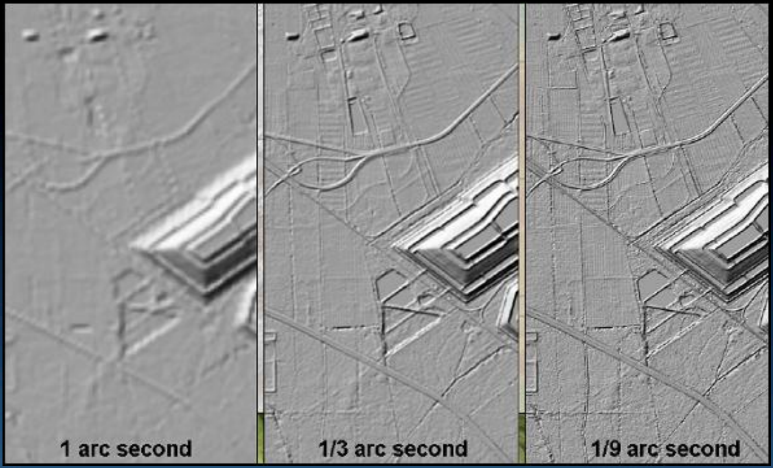


Landslide Hazards

GPS used for high-accuracy base geospatial data products

GPS provides precise positions of airborne sensors so that highly accurate base geospatial data products such as high resolution terrain (elevation) data and orthorectified imagery can be produced efficiently.



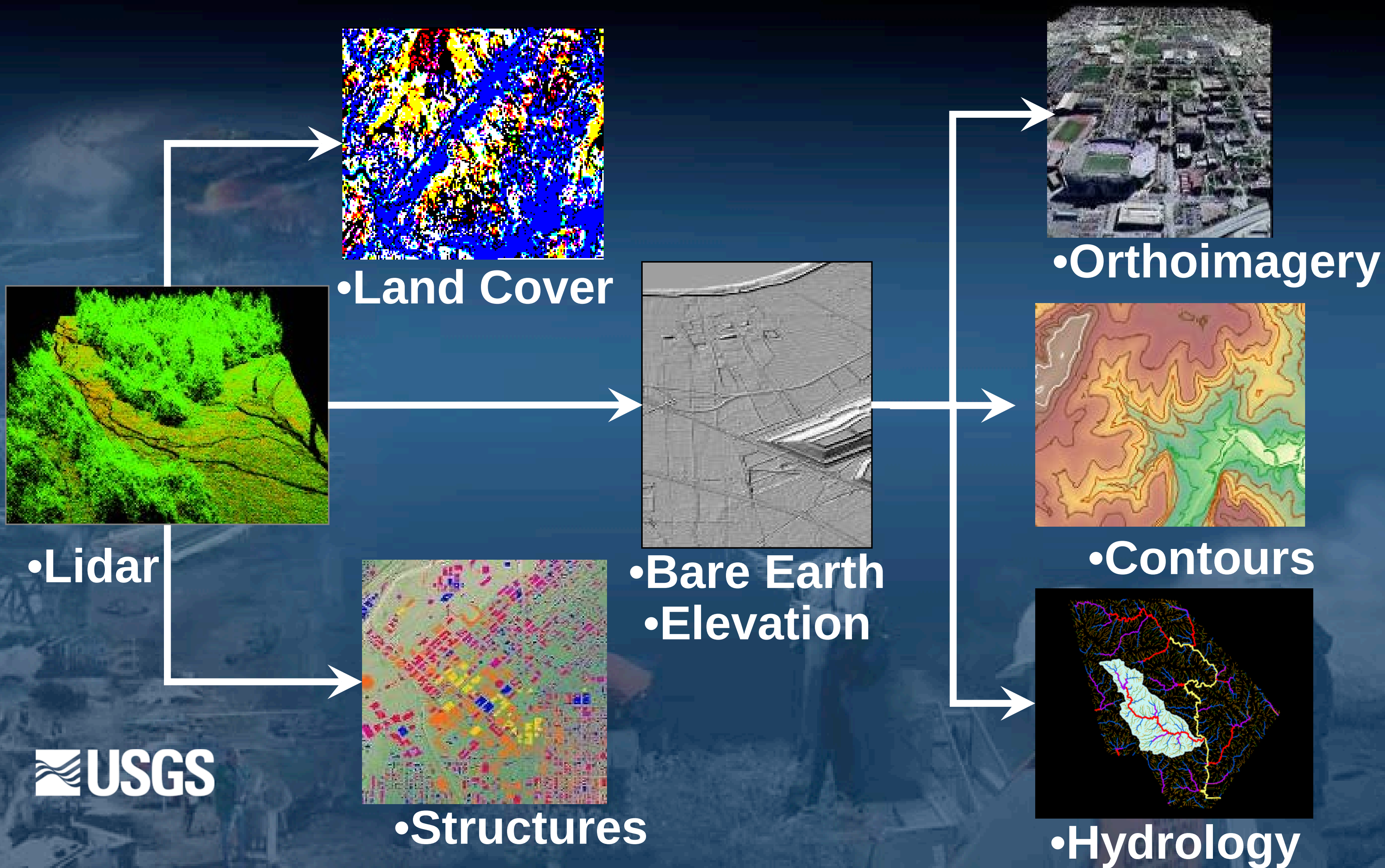


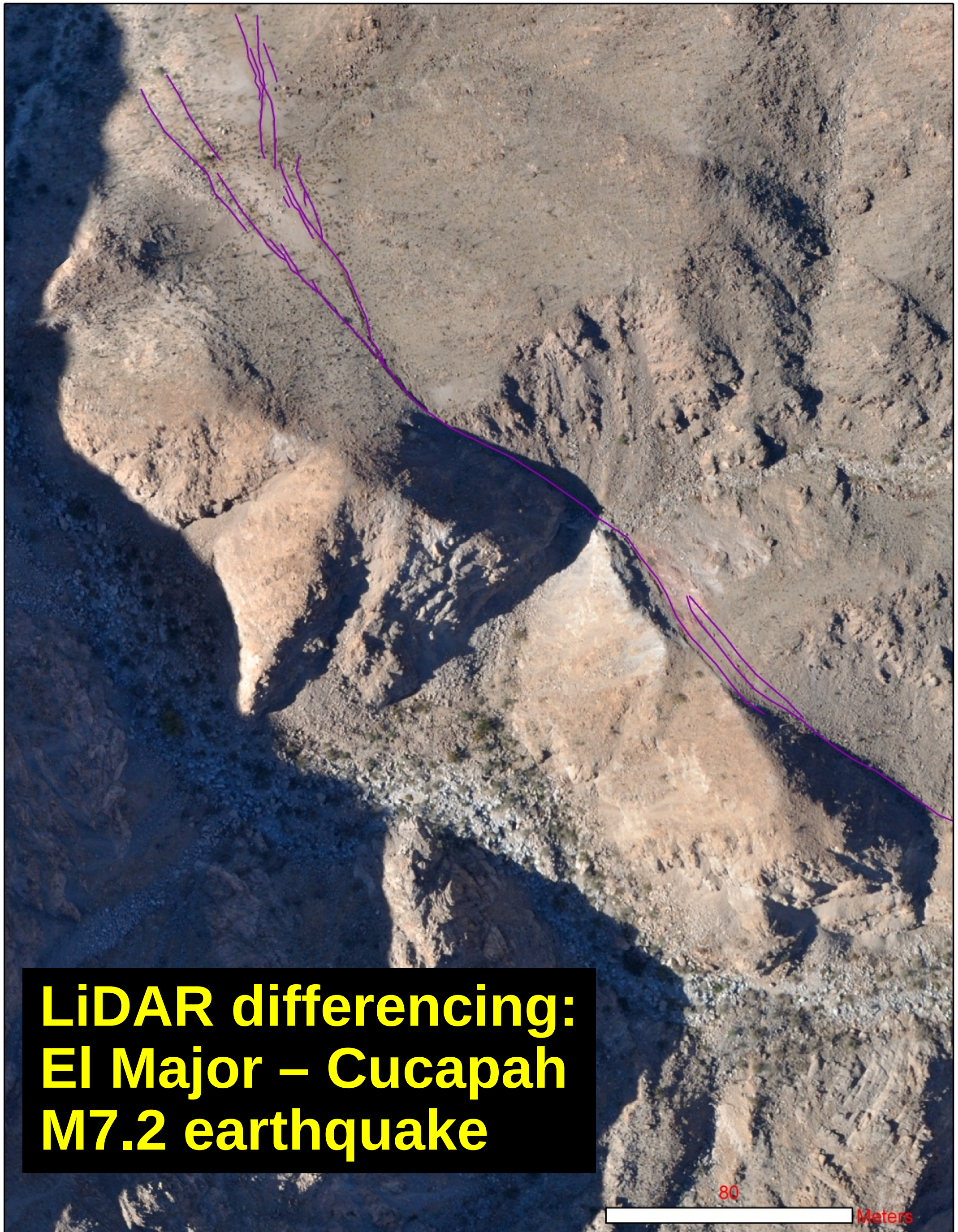
Highly accurate terrain elevation data is replacing older, lower resolution data

Example of high resolution orthorectified imagery acquired in partnership with other Fed, state, and local agencies

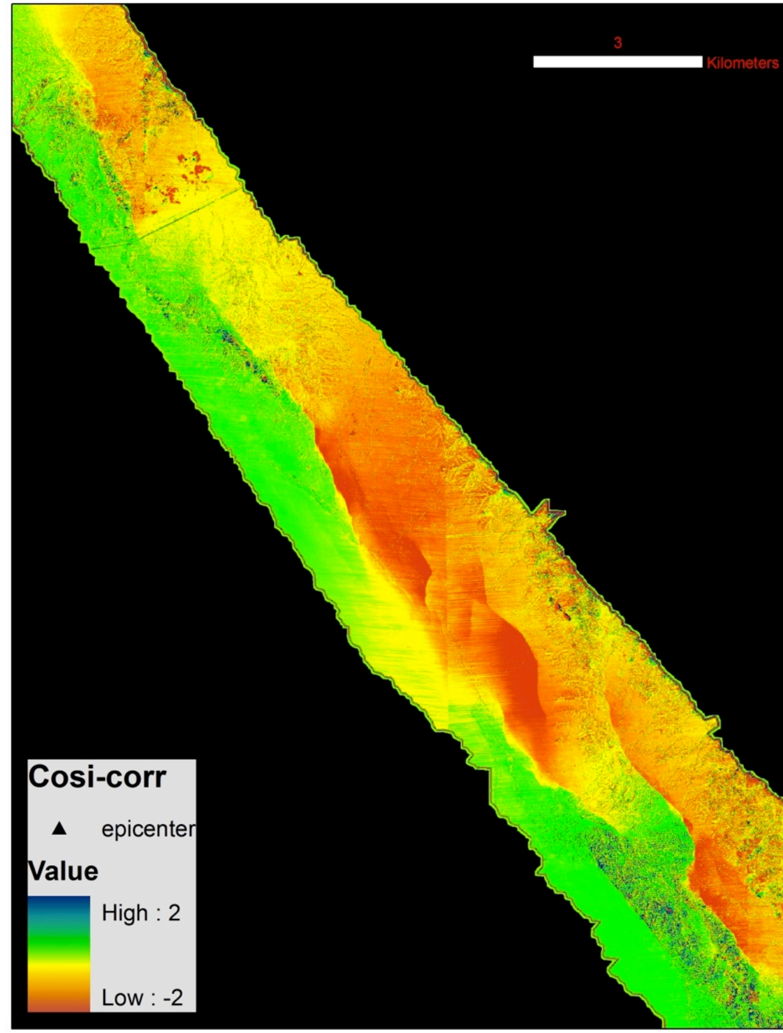
USGS

Accurate Lidar mapping is highly relevant to several data layers of The National Map





LiDAR differencing: El Major – Cucapah M7.2 earthquake

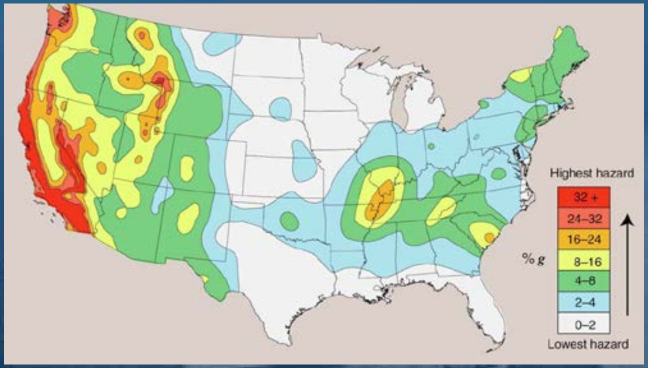


GPS enables ultra-high-precision geo-ref for fault mapping using repeat-pass imagery

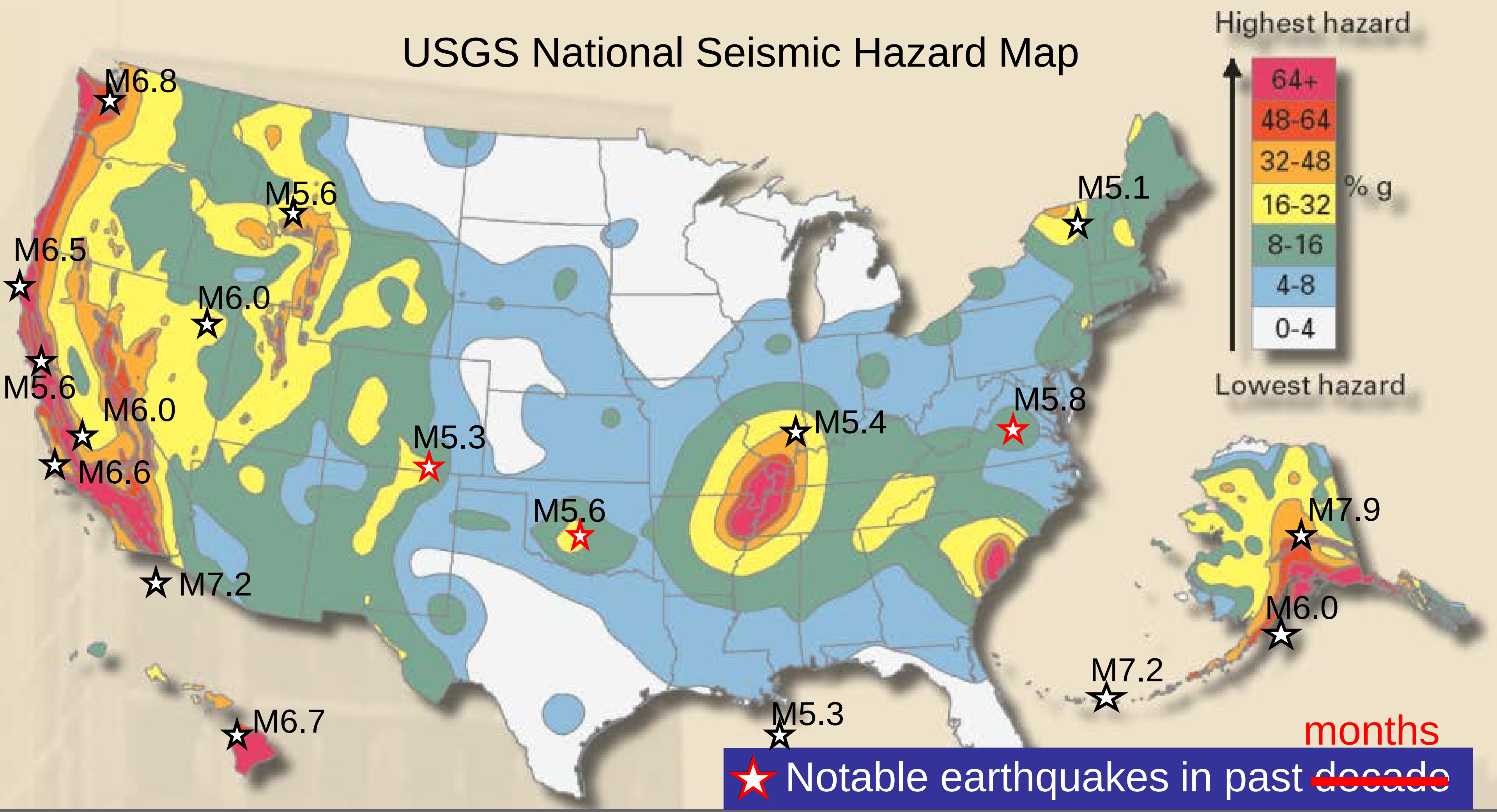
- **LiDAR**
- **3D stereo**

The USGS role in the National Earthquake Hazard Reduction Program partnership

- Provide earthquake monitoring and notifications,
- Assess seismic hazards,
- Conduct targeted research needed to reduce the risk from earthquake hazards nationwide, and
- Work with NEHRP agencies and many other partners to support public awareness of earthquake hazards and impacts.



Earthquakes are a national hazard



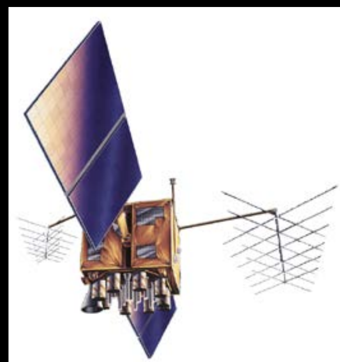
Notable earthquakes in past ~~decade~~ months

national earthquake hazards reduction program

SCIGN

SOUTHERN CALIFORNIA INTEGRATED GPS NETWORK

GPS



A network of GPS/GNSS stations measures plate tectonic motions to an accuracy of better than

1 mm/yr

We can see whether the motion is 'slow and steady,' or perhaps more interestingly, it may sometimes accelerate or decelerate

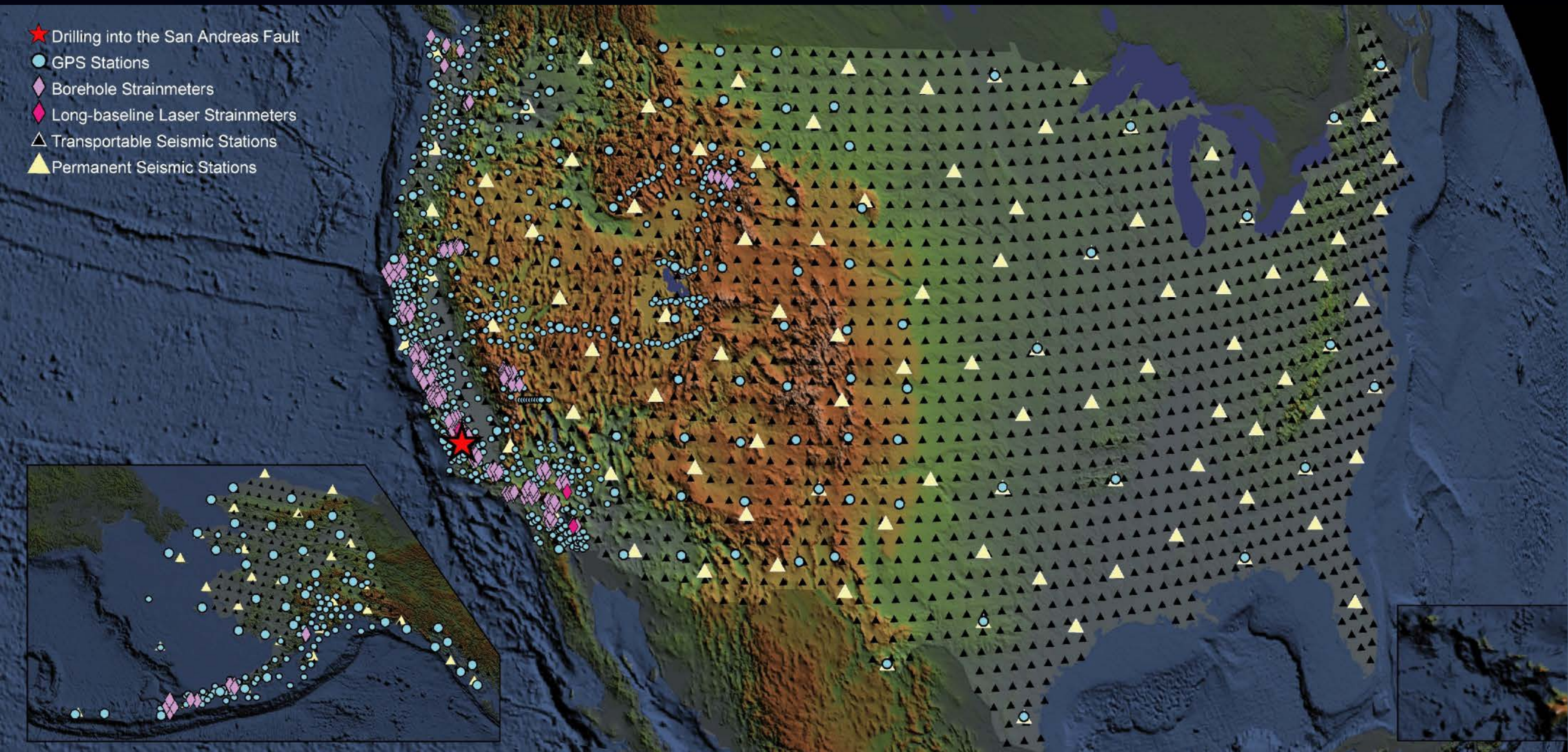
W. M. Keck Foundation

NASA

NSF

USGS science for a changing world

earth scope PROJECT



USGS

National Science Foundation
WHERE DISCOVERIES BEGIN

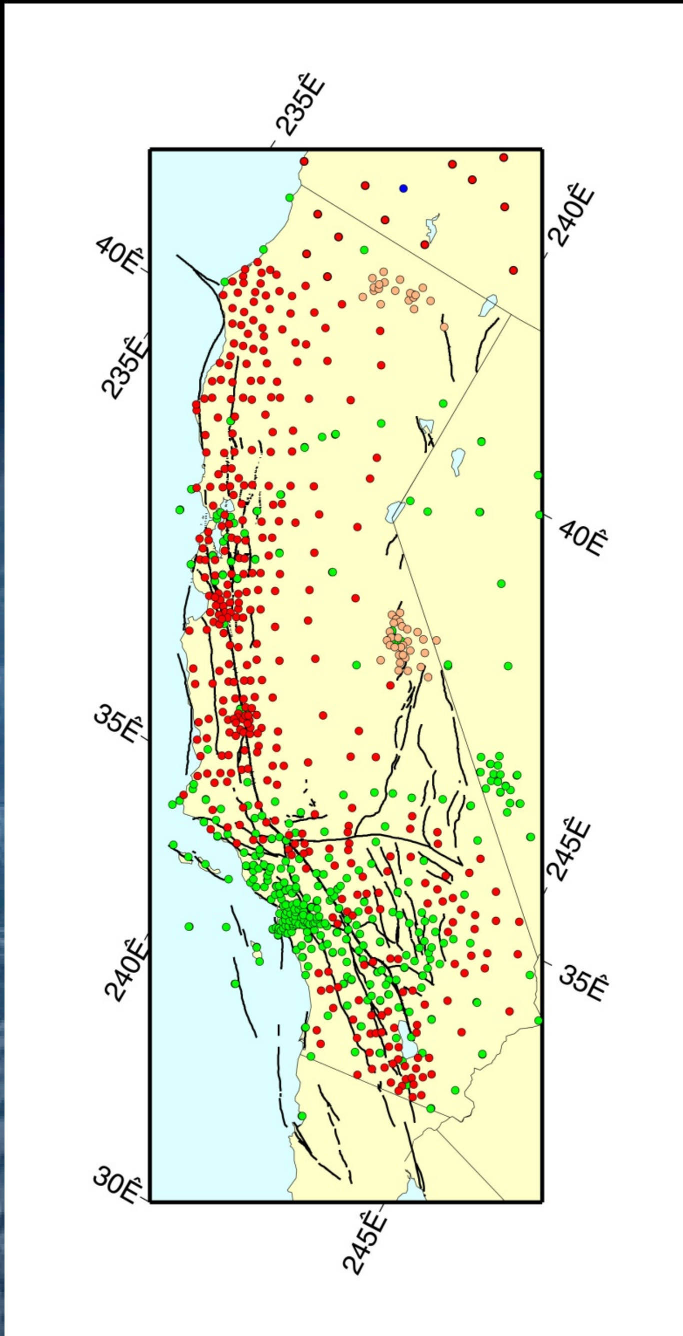
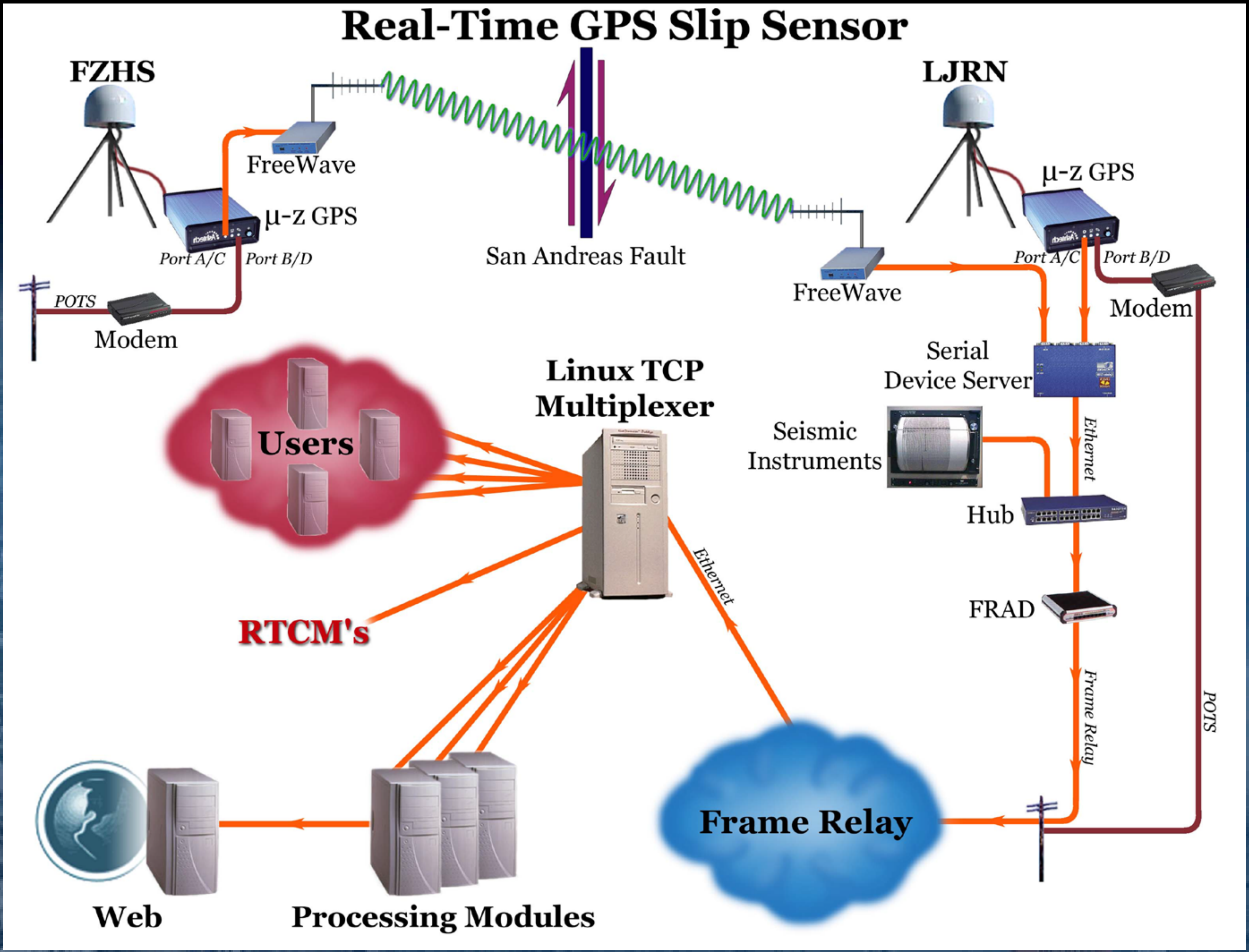


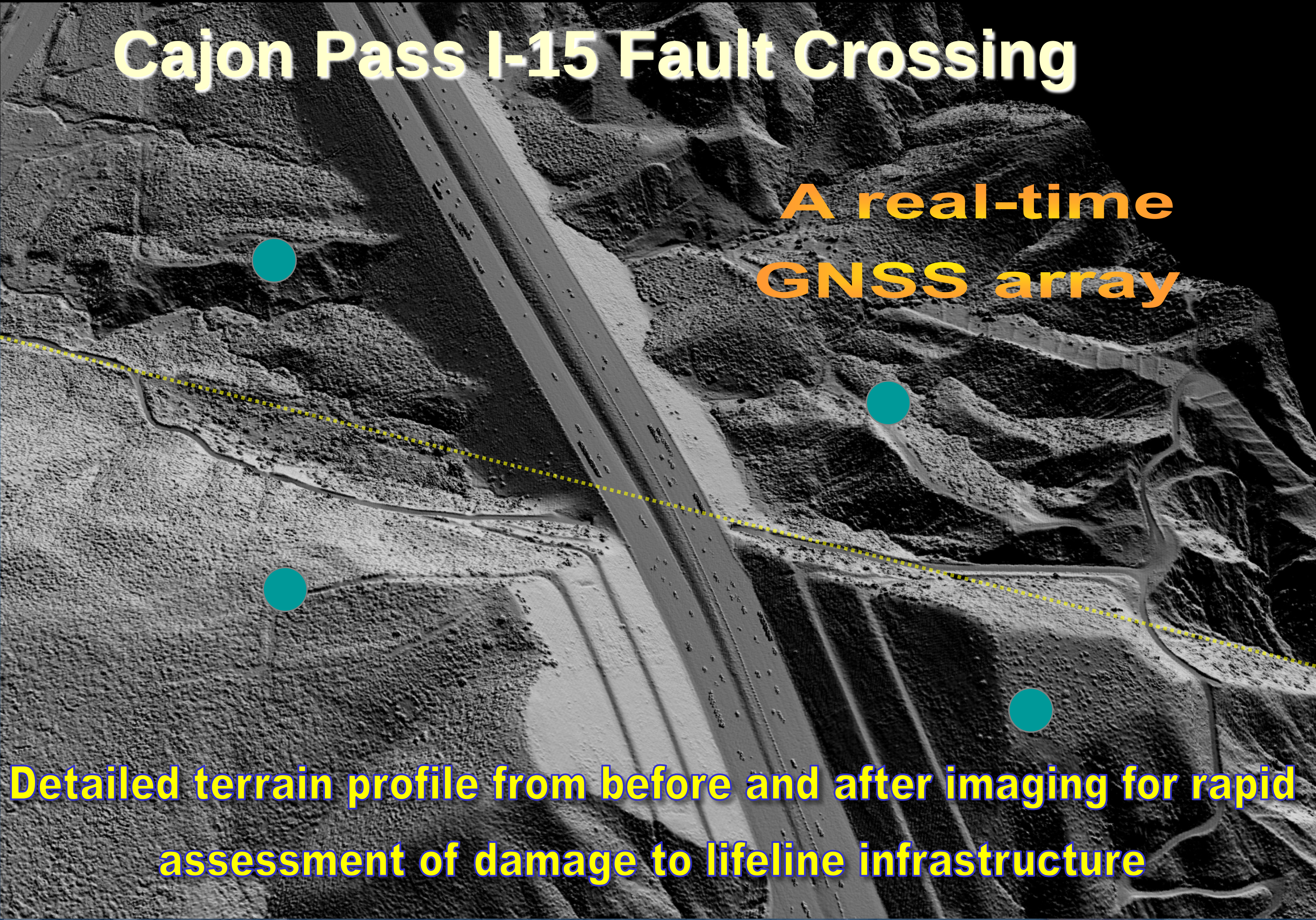
Plate Boundary Observatory

San Andreas plan

GNSS station clusters along San Andreas fault, especially along transitions from creeping to locked sections

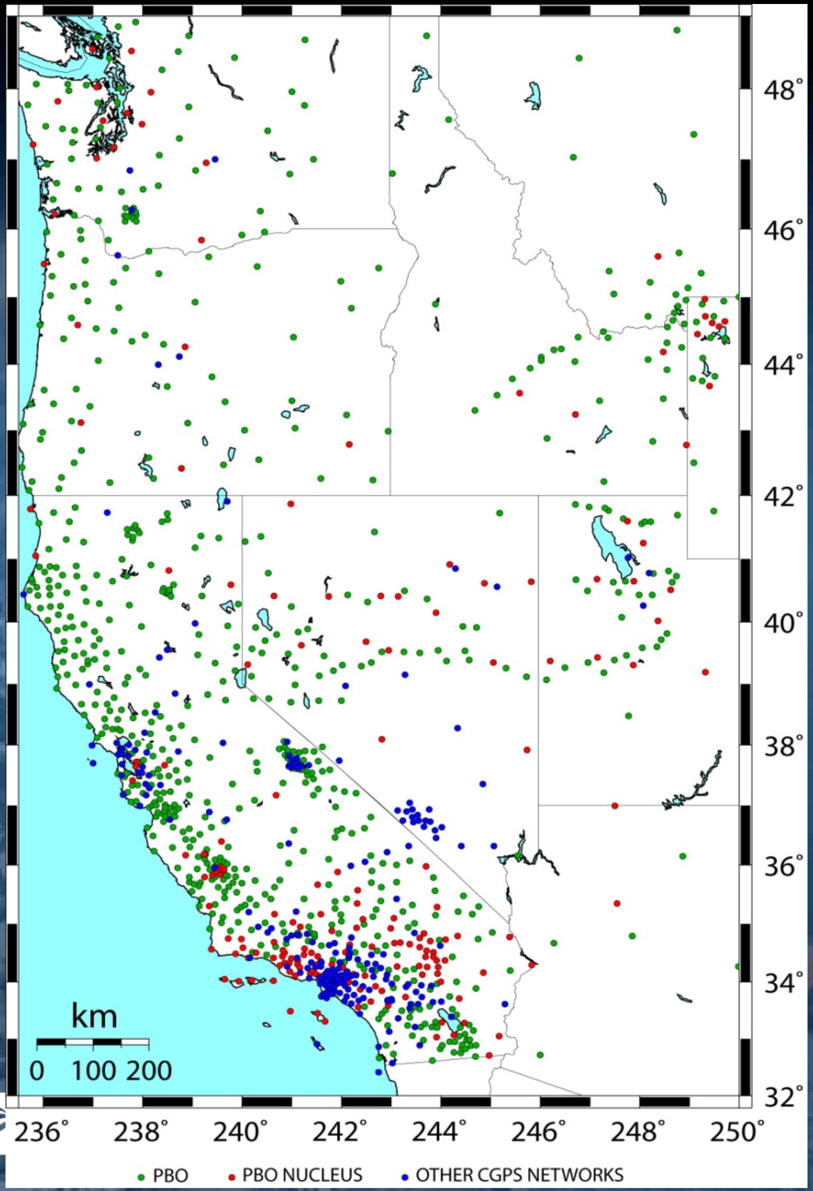


Real-Time GPS Slip Sensor
FZHS
LJRN
FreeWave
μ-z GPS
Port A/C
Port B/D
POTS
Modem
San Andreas Fault
FreeWave
μ-z GPS
Port A/C
Port B/D
Modem
Serial Device Server
Linux TCP Multiplexer
Users
Seismic Instruments
Ethernet
Hub
FRAD
RTCM's
Ethernet
Frame Relay
POTS
Frame Relay
Web
Processing Modules

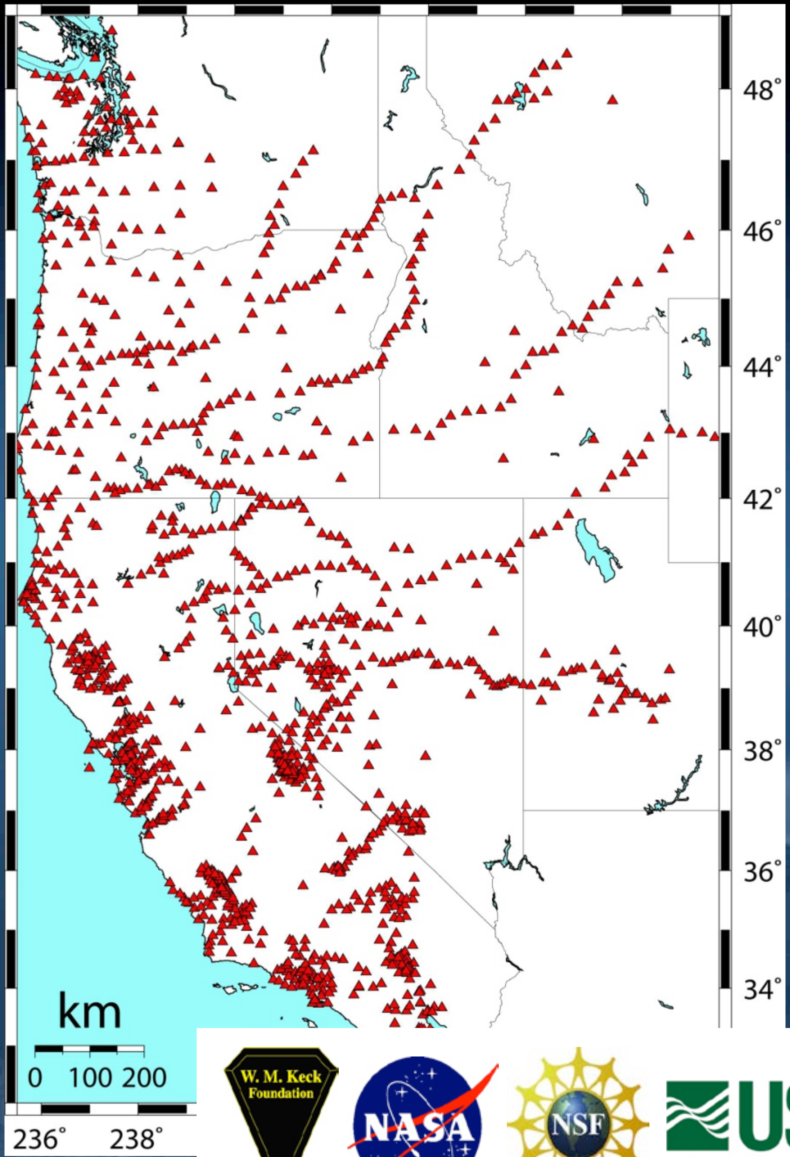

Cajon Pass I-15 Fault Crossing
A real-time
GNSS array
Detailed terrain profile from before and after imaging for rapid
assessment of damage to lifeline infrastructure

Continuous and campaign GPS arrays

Continuously Operating GPS Stations



Campaign Survey GPS Points



W. M. Keck Foundation NASA NSF USGS science for a changing world

Virginia Earthquake of August 23, 2011

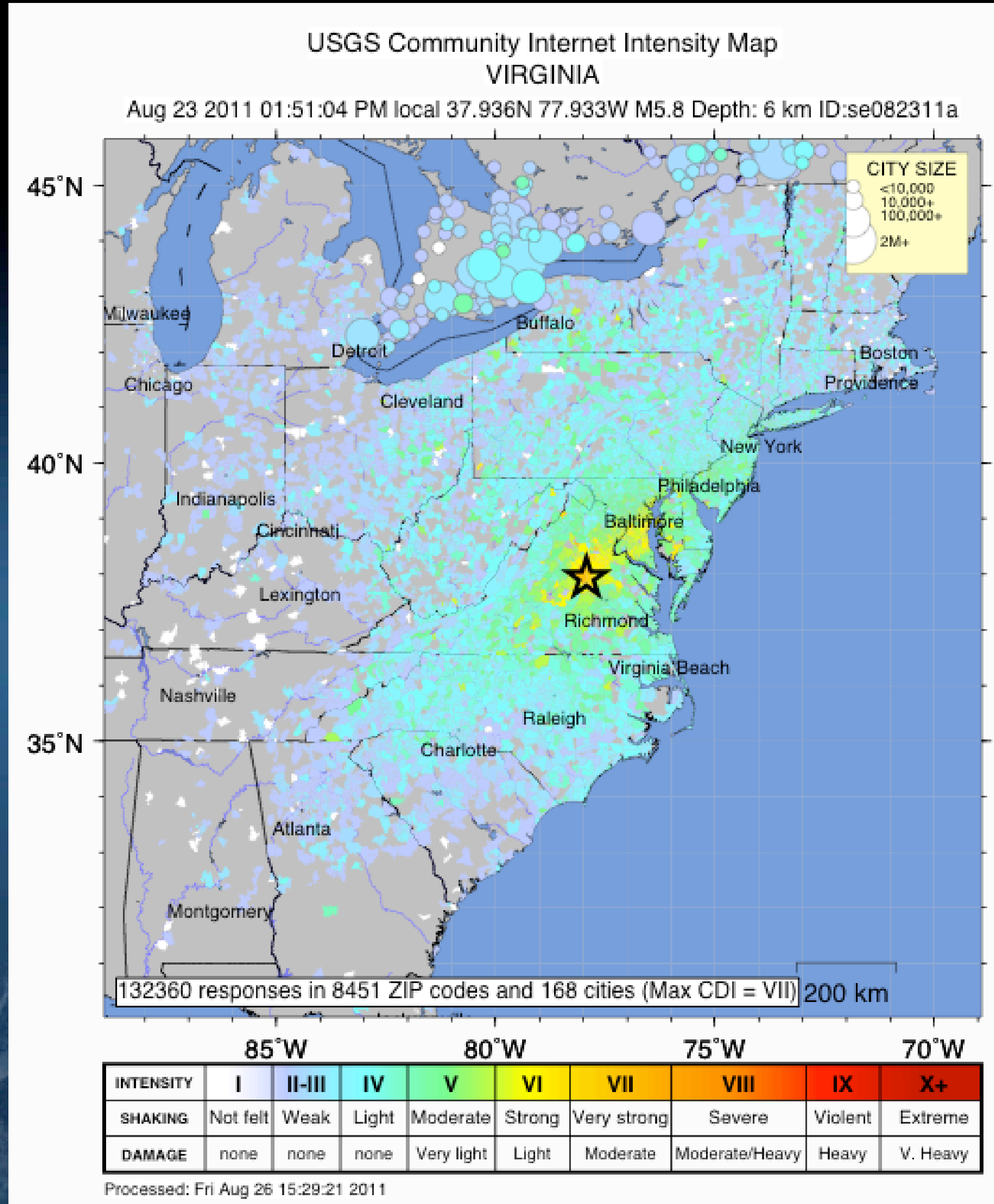
Largest earthquake in Virginia In 114 years

Centered in low-population area between Richmond and Charlottesville

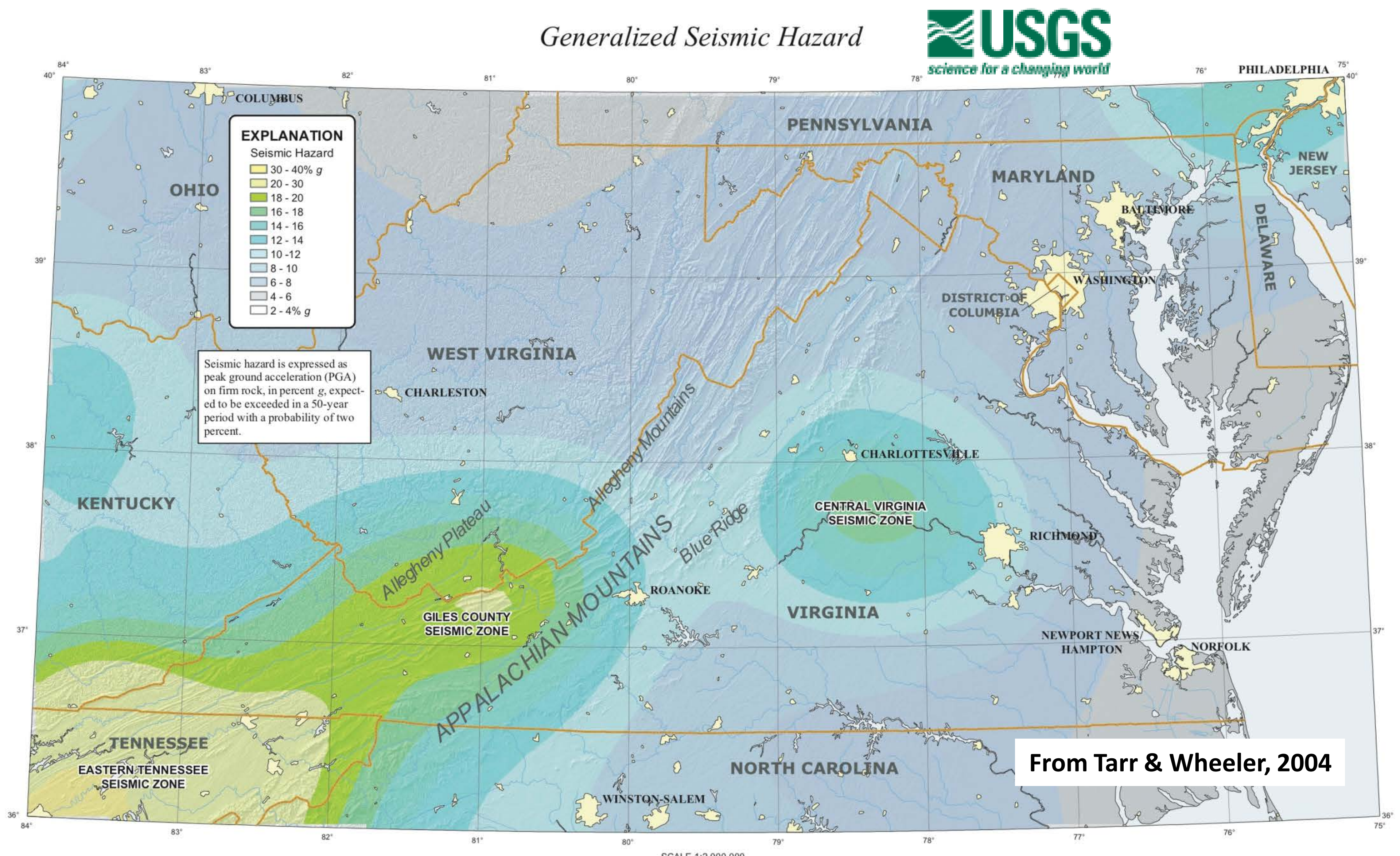
No fatalities. Estimated Damages >$100M

Felt from Florida to Maine to Missouri (>140,000 reports)

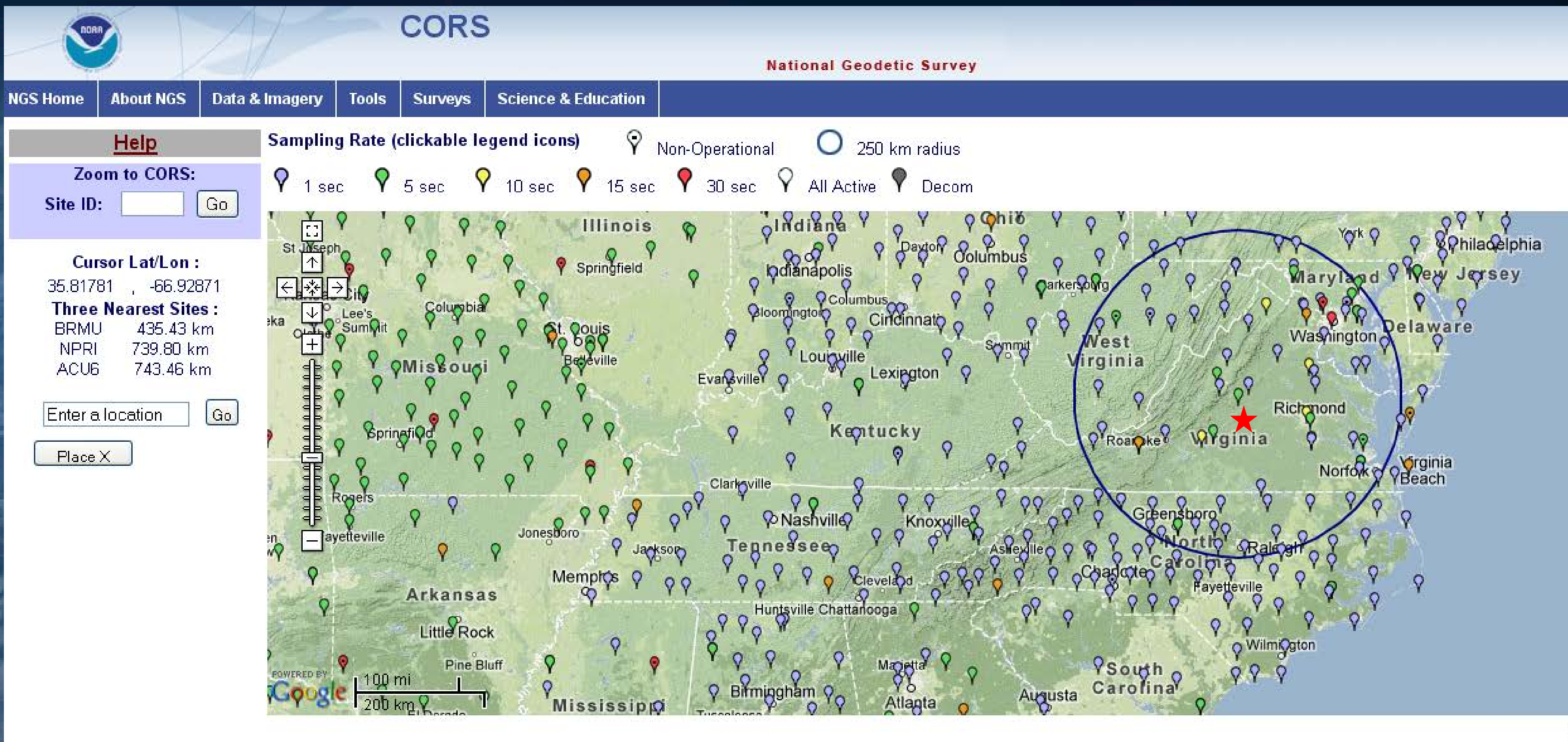
Caused evacuations across Washington DC metropolitan area, and damage to historic structures.



The August earthquake struck in a recognized zone of elevated hazard



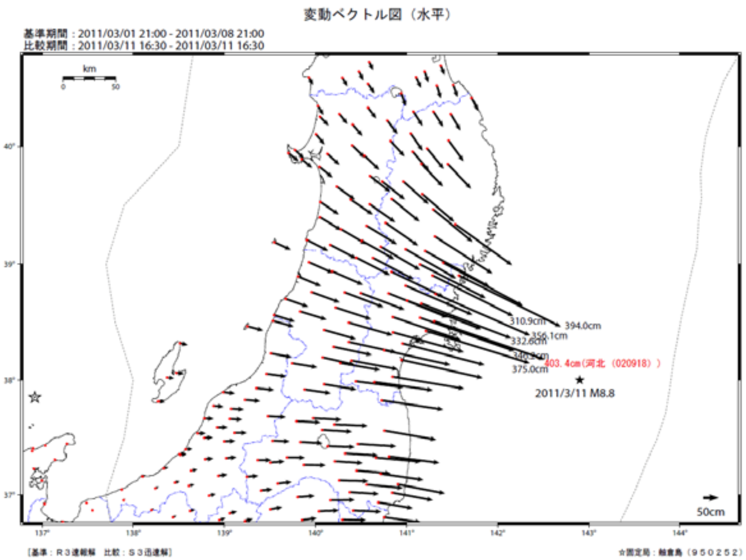
Continuous Operating Reference Stations (CORS)



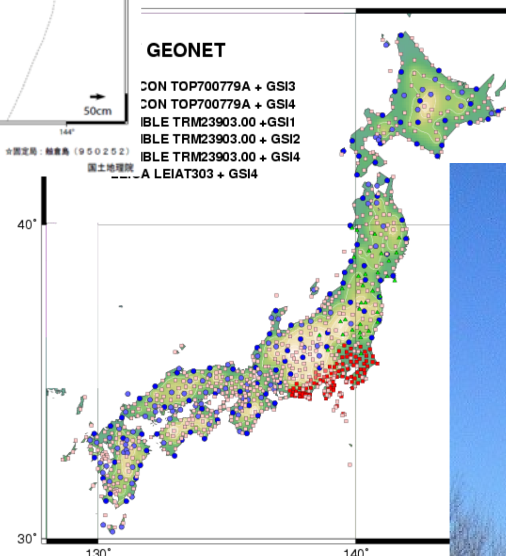
★ Magnitude 5.8 Virginia Earthquake, August 23, 2011

March 11, 2011 Japan earthquake

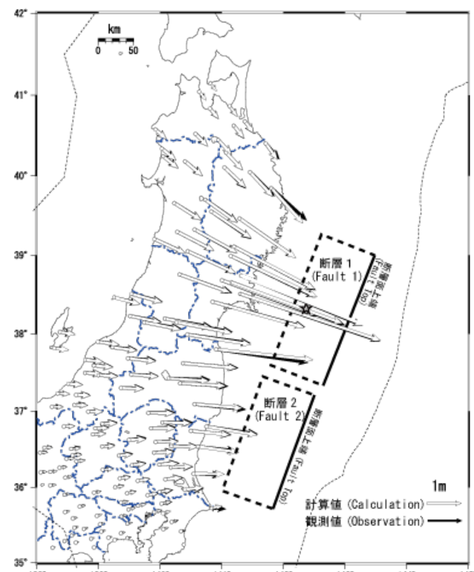
Initial GPS results from GSI showed 2.6 meters shift; later results gave maximum GPS offset of 4.034 m (13.2 feet)



Since 1990, US advised Japan on construction of continuously-operating GPS stations (like ones we built in Southern California). They built a network of over 1000 GPS stations called GEONET.



Data were openly available and other groups quickly confirmed these results and made movies of the displacements to help visualize the information



星印は USGS の震央（142.369°，38.322°）
A Star indicates an epicenter released from USGS (142.369°, 38.322°)

矩形断層２枚での推定結果
Two rectangular faults with uniform slip are assumed.

西側に傾き下がる逆断層．モーメントマグニチュードは北側（断層1）が 8.7，南側（断層２）が 8.2．２つ合わせて 8.8（暫定）．
West-dipping reverse fault. Total moment magnitude: Mw8.8. (Northern segment: Mw=8.7, Southern segment: Mw=8.2)

断層の長さは南北に約 200km の断層 1 と約 180km の断層 2 で合計約 380km．総延長はおよそ 400km．
Total major rupture length: ～400 km (Fault Length: Northern segment ～200 km / Southern segment ～180 km)

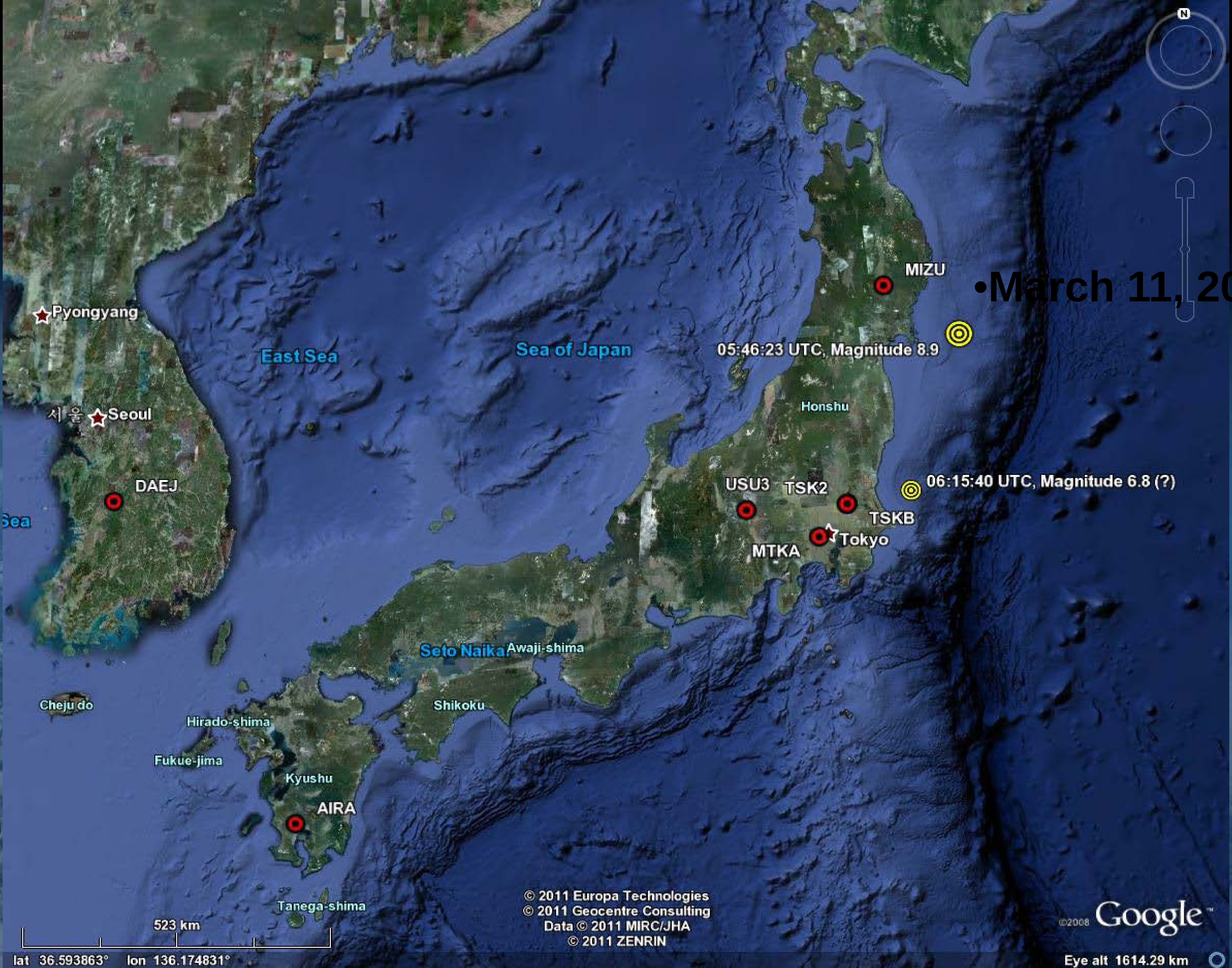
	緯度 Lat	経度 Lon	上端深さ Depth (Fault top) km	長さ Length km	幅 Width km	走向 Strike	傾斜角 Dip	すべり角 Rake	すべり量 Slip m	Mw
断層 1	39.00°	143.49°	10.0	199	85	202°	18°	97°	27.7	8.7
断層 2	37.21°	142.51°	10.1	176	82	201°	15°	81°	5.9	8.2

国土地理院資料
Geospatial Information Authority of Japan

Post-seismic:

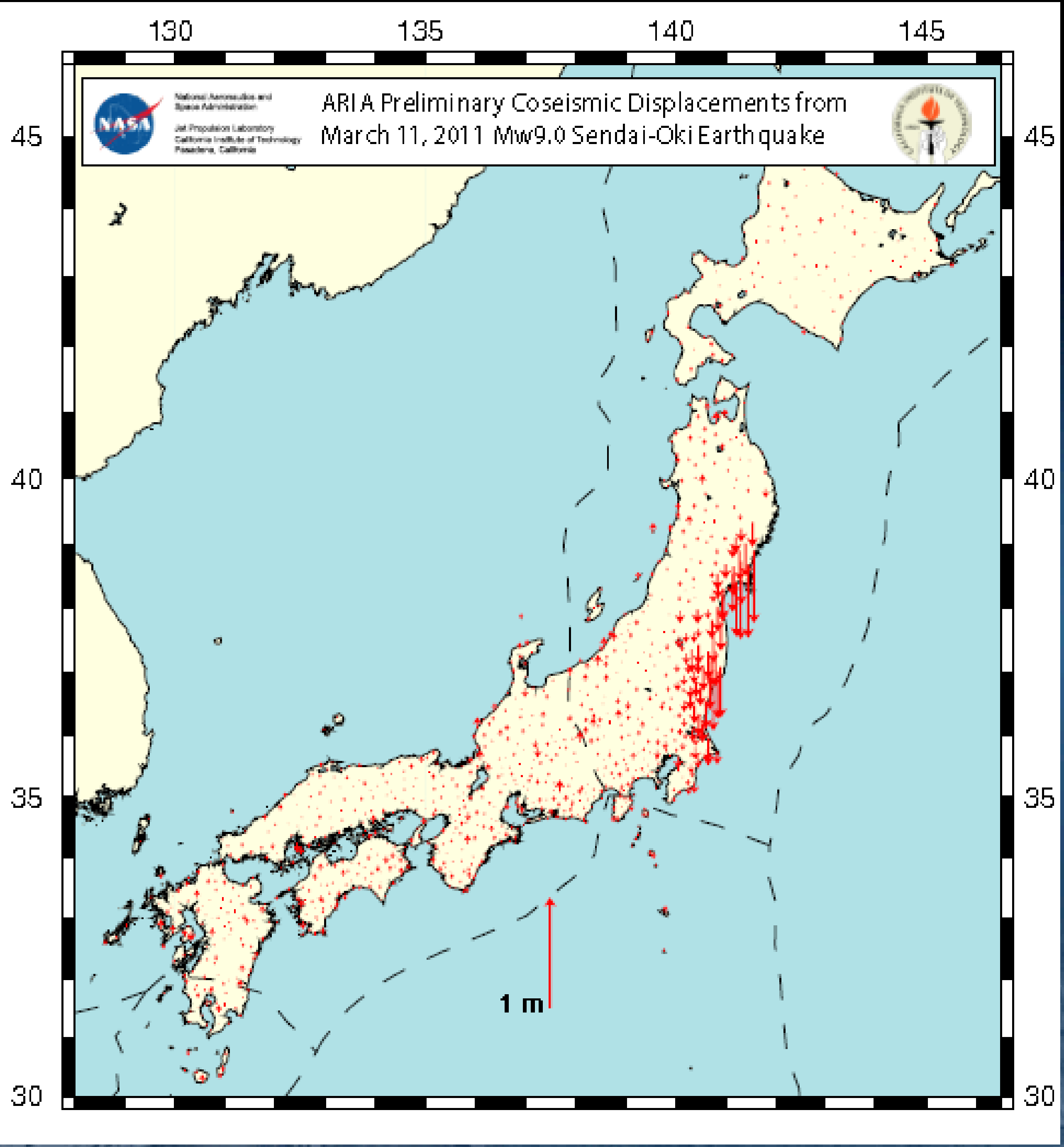
re-adjustments will go on for years, GPS is the best way to examine it

USGS
science for a changing world



MIZU
05:46:23 UTC, Magnitude 8.9
06:15:40 UTC, Magnitude 6.8 (?)
Pyongyang
East Sea
Sea of Japan
Honshu
서 울 Seoul
DAEJ
USU3
TSK2
TSKB
Tokyo
MTKA
Sea
Seto Naikai
Awaji-shima
Cheju do
Hirado-shima
Shikoku
Fukue-jima
Kyushu
AIRA
Tanega-shima
523 km
© 2011 Europa Technologies
© 2011 Geocentre Consulting
Data © 2011 MIRC/JHA
© 2011 ZENRIN
Google
lat 36.593863° lon 136.174831°
Eye alt 1614.29 km

- March 11, 201

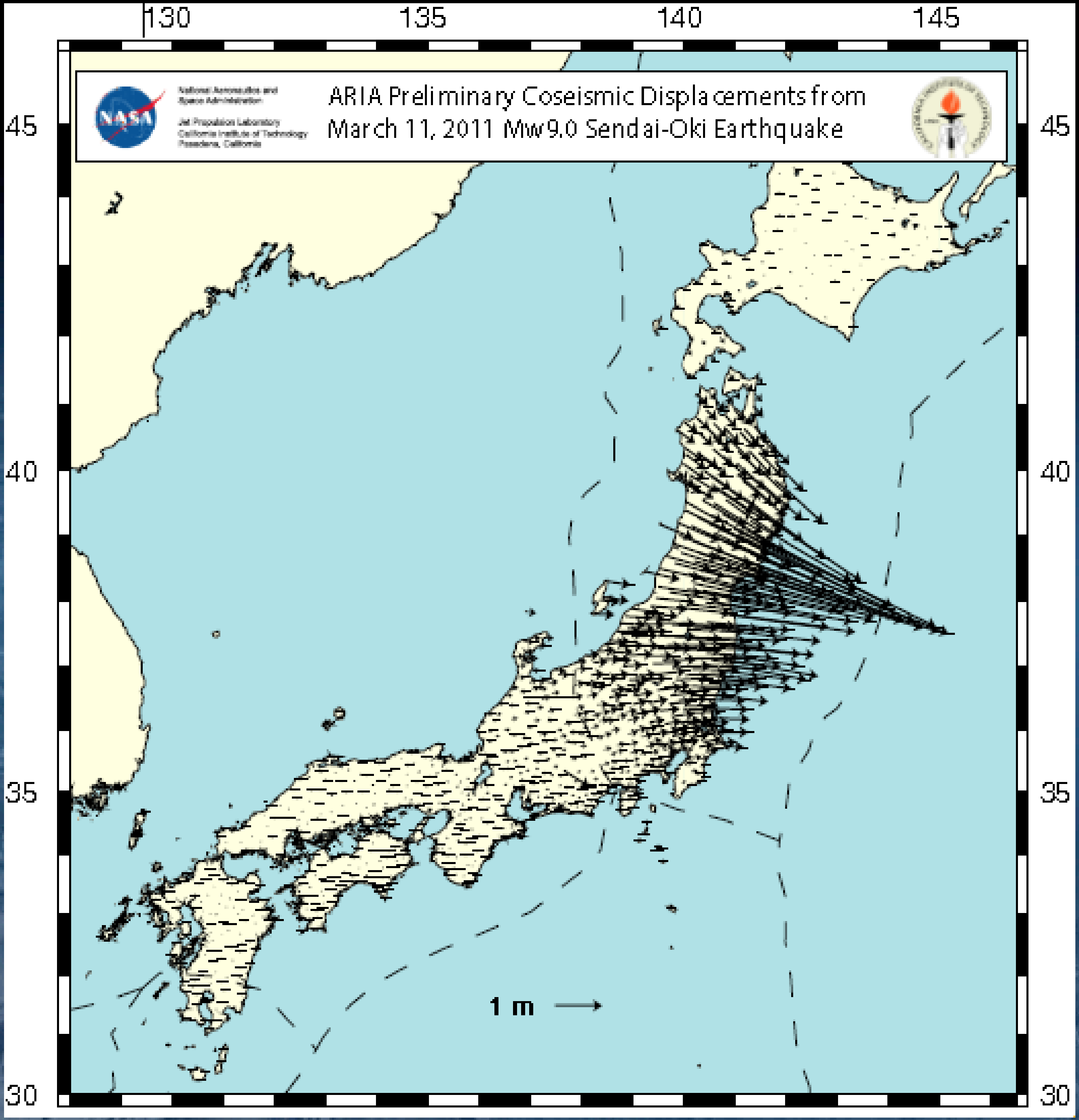


Vertical Displacements

Difference between estimated positions of GEONET stations at 05:00 and 06:30 UTC on March 11, 2011

Solutions by JPL and Caltech.

GPS 1 Hz data in RINEX format provided by the Geospatial Information Authority (GSI) of Japan.



Horizontal Displacements

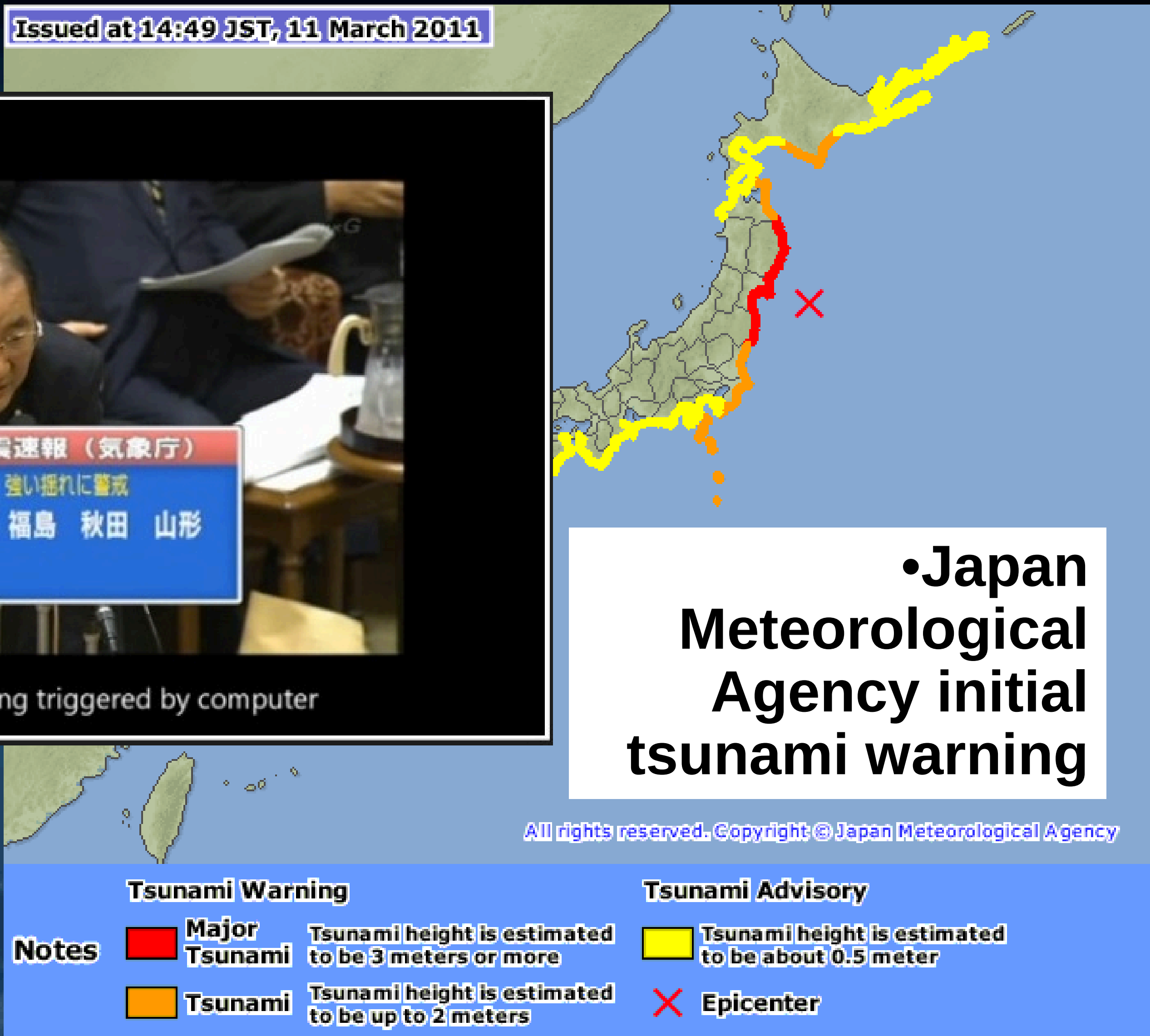
Difference between estimated positions of GEONET stations at 05:00 and 06:30 UTC, March 11, 2011

Bars at end of vector show 95% error estimate.

Solutions by JPL and Caltech.

GPS 1 Hz data in RINEX format provided by the Geospatial Information Authority (GSI) of Japan.

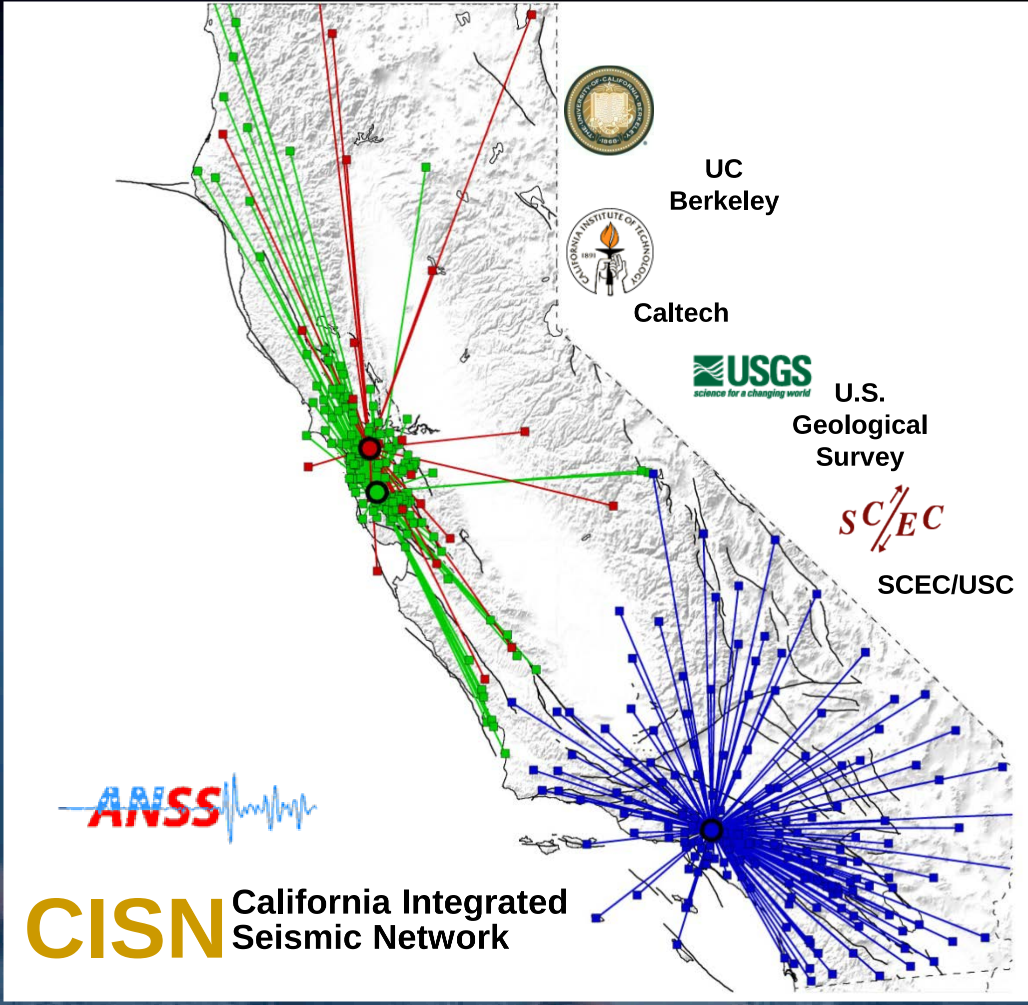
•Japanese early warning systems



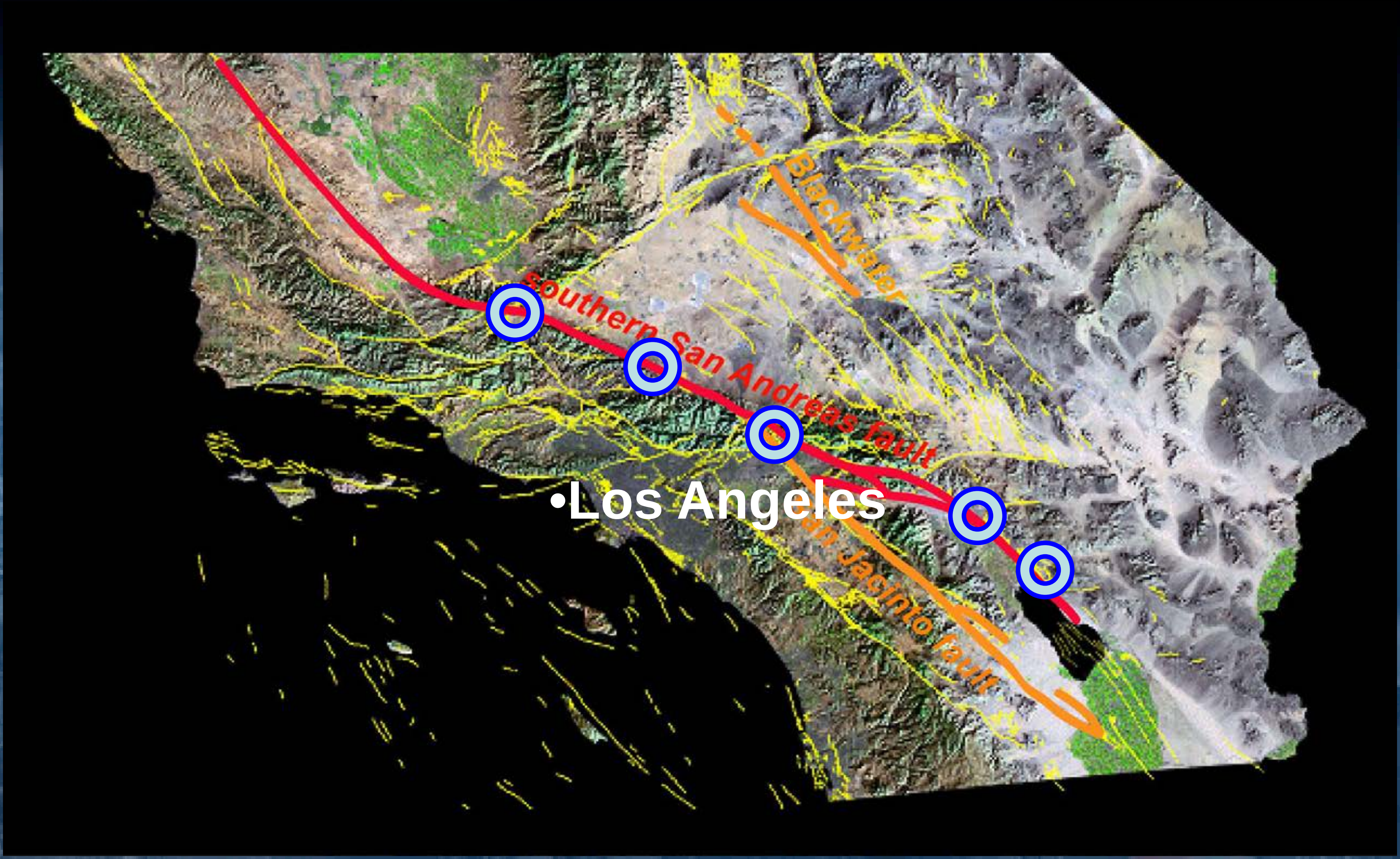
•Japan Meteorological Agency initial tsunami warning

Earthquake early warning – getting ahead of strong ground shaking

- **USGS/CISN Phase I (2007-2009) cooperative agreement supported algorithm testing**
- **Phase II (2010-2012) supports prototype development and identifies test users**
- **ARRA funding used to reduce datalogger delays**
- **EEW requirements:**
- **-- rapid earthquake detection**
- **-- early magnitude estimation**
- **-- ground shaking prediction**
- **-- robust monitoring networks**
- **-- well-defined user community**



San Andreas Fault lifeline crossings

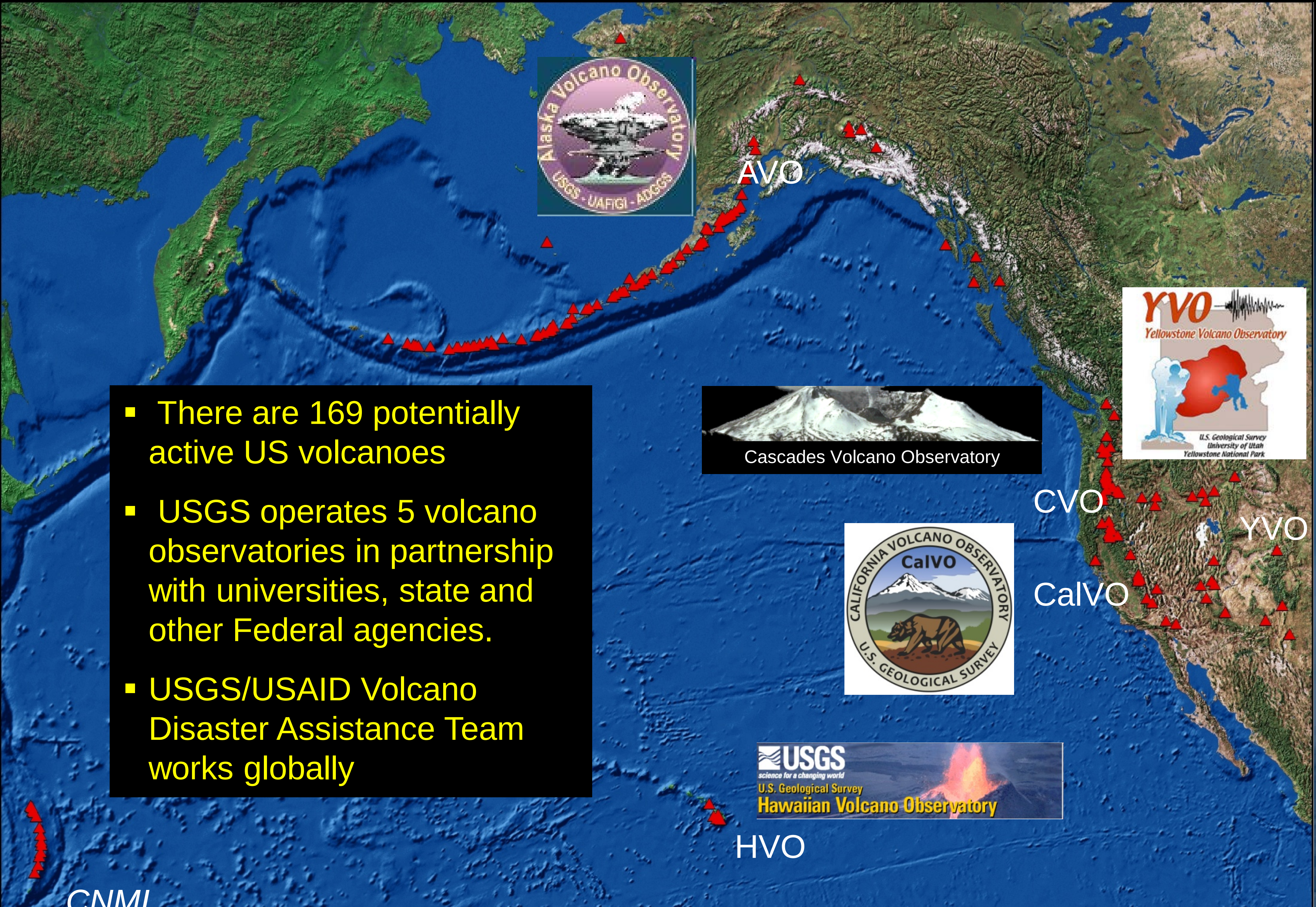


USGS

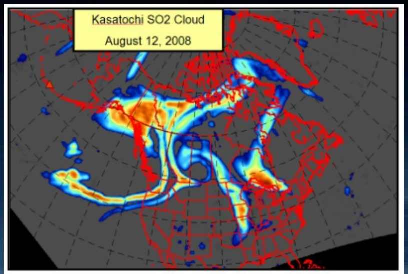
GPS & accelerometer arrays are being explored as part of a fully operational earthquake early warning system

USGS volcano monitoring responsibility

- There are 169 potentially active US volcanoes
- USGS operates 5 volcano observatories in partnership with universities, state and other Federal agencies.
- USGS/USAID Volcano Disaster Assistance Team works globally

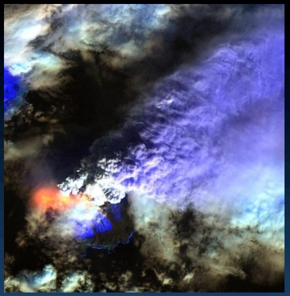


USGS volcano observatories combine an array of real time data streams to interpret behavior and forecast eruptions

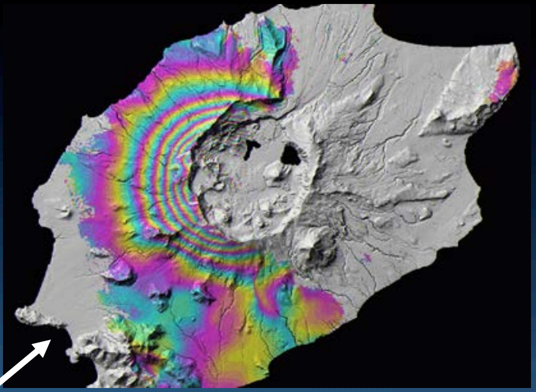


Gas cloud from satellite UV sensor

AVO operations room

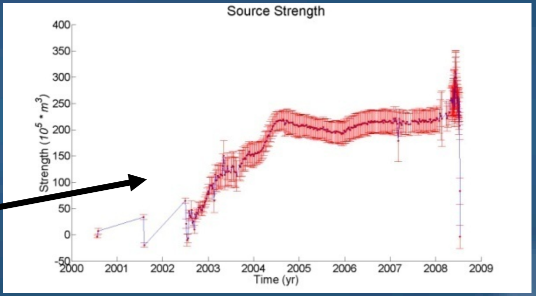


Satellite surveillance for hotspots and ash

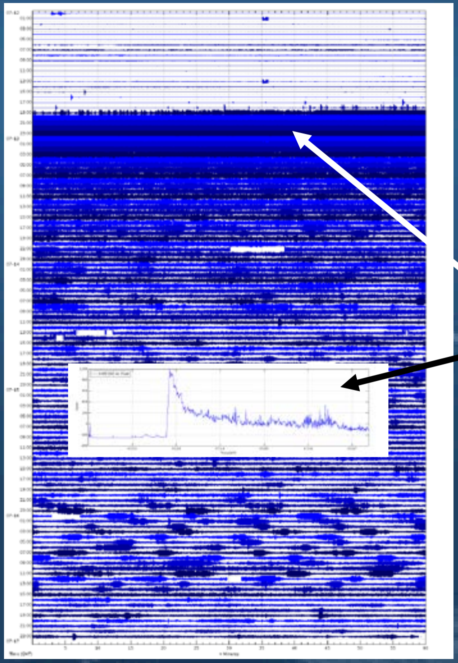


Volcano deformation from radar satellites

Volcano deformation from GPS

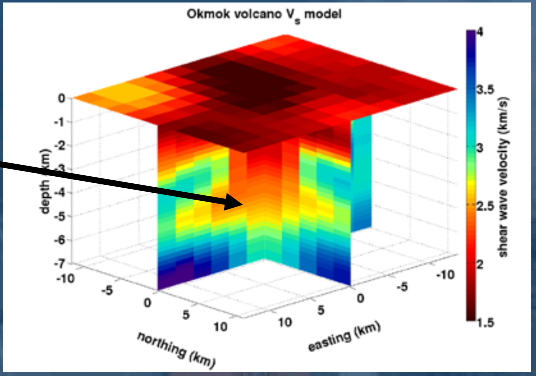


AVO field installation



Eruption onset from seismic network

Magma chamber location from seismic tomography

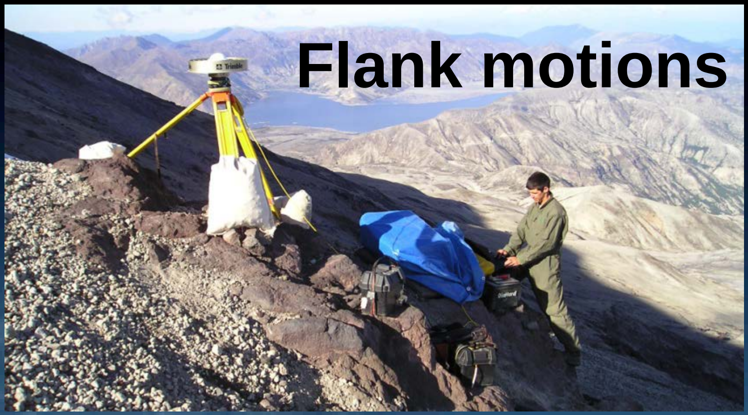


GPS uses by USGS Volcano Hazards Program

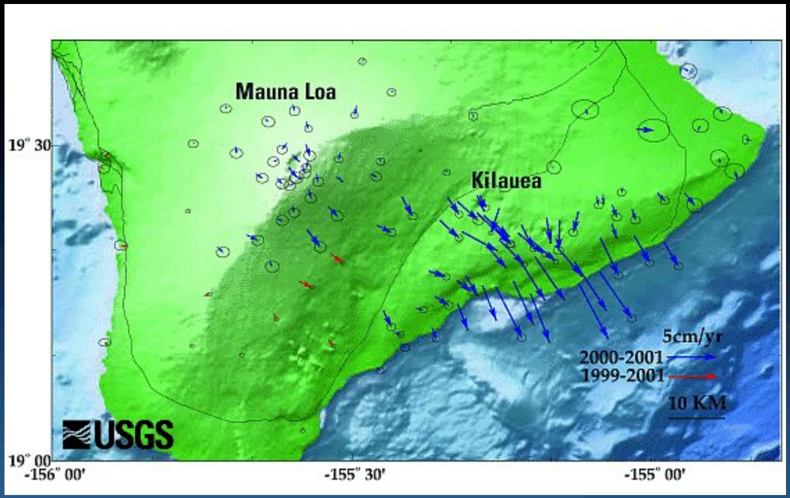
- **Key component of volcano monitoring for flank movements and lava dome growth**
- **Integral part of National Volcano Early Warning System plan for monitoring modernization and expansion**
- **Over 300 continuous GPS units are currently in use by USGS volcano observatories (nearly all of these are telemetered precise dual-frequency GPS stations; many are Plate Boundary Observatory stations operated by UNAVCO with NSF funding)**

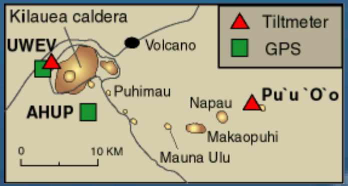
USGS

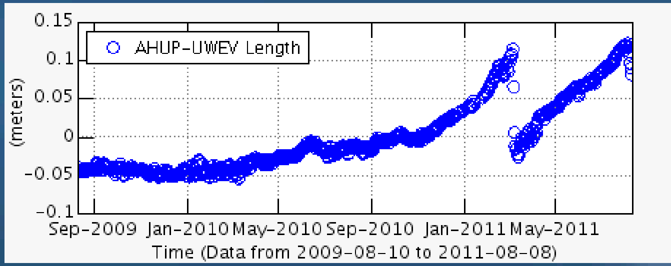
USGS uses precise GPS for eruption monitoring



Motions of volcanoes' flanks can indicate the arrival of new magma; **GPS is used to monitor changes in activity.**







USGS

National Volcano Early Warning System (NVIEWS): Closing the monitoring gap

Based on systematic threat ranking of 169 U.S. Volcanoes

NVEWS Goals:

- Robust real-time monitoring of the most threatening volcanoes.
- 24/7 Volcano Watch Office.
- Support for collaborative research and communication projects with State, Local and Academic partners.

Authorization bill pending before Senate Energy and Natural Resources Committee

NVEWS TARGETS	MONITORING GAP
Kilauea, HI	1 ERUPTION
St. Helens, WA	1 ERUPTION
Rainier, WA	3
Hood, OR	3
Shasta, CA	3
South Sister, OR	3
Lassen, CA	3
Mauna Loa, HI	2
Redoubt, AK	2
Makushin. AK	2
Glacier Peak, WA	4
Akutan, AK	2
Baker, WA	3
Spurr, AK	2
Newberry Volcano,OR	3
Augustine, AK	2
Crater Lake, OR	4
Inyo Craters., CA	3
Adams, WA,	2

USGS

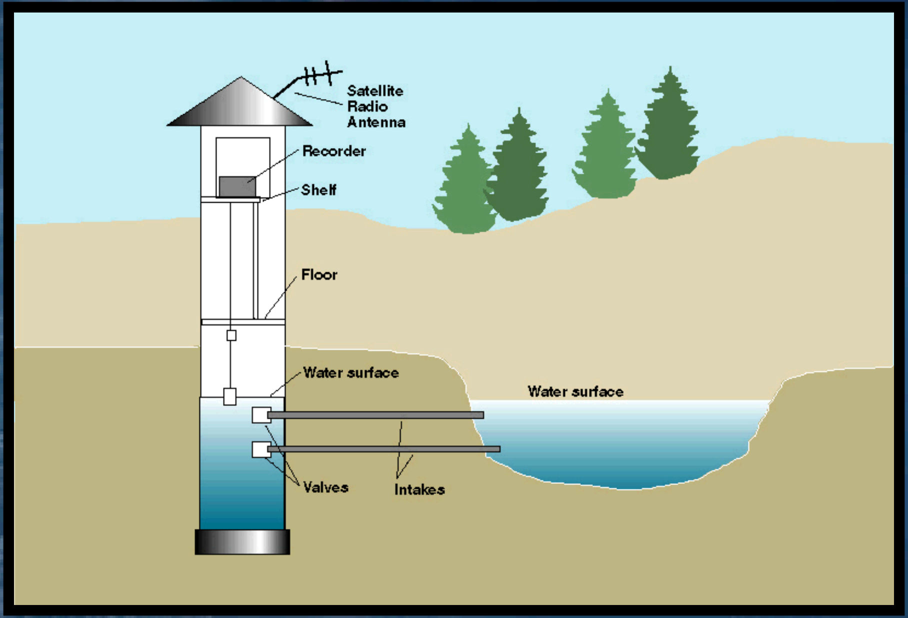
- **GPS used for Streamgaging**

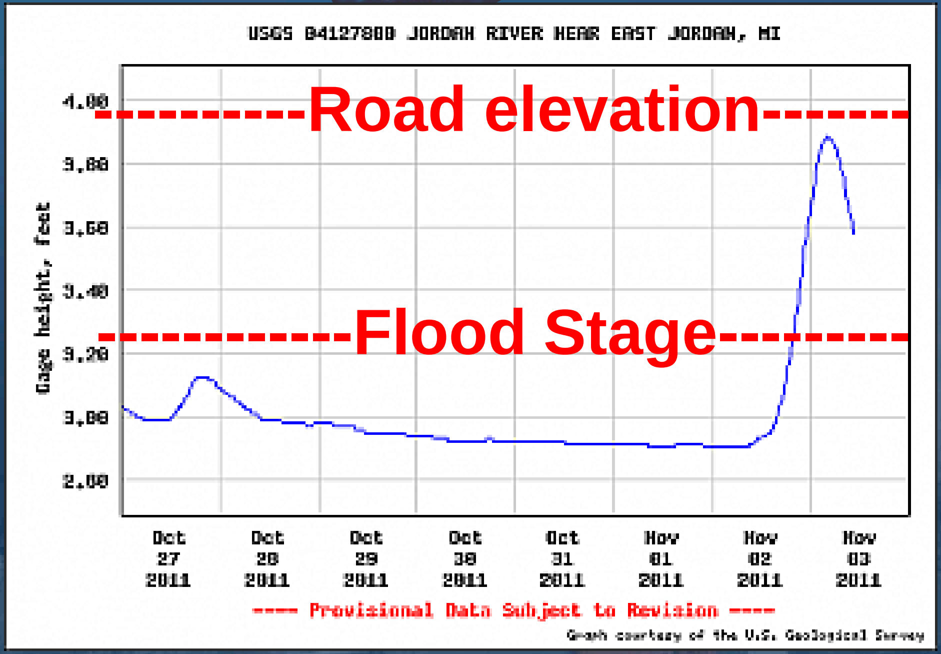
- **9,000 USGS streamgages and water-quality monitoring sites use GPS timing for satellite communications**

USGS WaterAlert

Text message or e-mail

customized alerts





http://water.usgs.gov/wateralert/

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GPS/GNSS for hazards management

- **GPS/GNSS is an essential enabling technology for the mapping and precise monitoring needed to accomplish science missions in support of hazard warnings.**
- **In the aftermath of a significant disaster event, GPS/GNSS is critical in support of new mapping and geopositioning incident features - essential in support of immediate response (e.g., support Urban Search & Rescue) as well as for long-term recovery (e.g., organizing debris removal).**

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Questions?