GPS Precision Monitoring of Natural Hazards

USTTI 2015 Course:
GPS Applications for Disaster Management

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USGS Natural Hazards Science Strategy

- **Goal 1**: Enhanced observations
  - GPS/GNSS, optical, LiDAR, InSAR and seismic

- **Goal 2**: Fundamental understanding of hazards and impacts

- **Goal 3**: Improved assessment products and services

- **Goal 4**: Effective situational awareness
• Responsible for providing assessments 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

• Coastal and marine geologic surveys and research support assessments of earthquake and tsunami hazards, and coastal impacts from storms, hurricanes and sea-level rise
Natural Hazards Mission Area programs

Earthquake Hazards

Global Seismographic Network

Volcano Hazards

Coastal & Marine Geology

Landslide Hazards
USGS Emergency Management

• The **Natural Hazards Mission Area** is responsible for overseeing the USGS's emergency management activities.

• Function includes the USGS **Hazard Response Executive Committee**, which provides executive direction, oversight, and support to USGS managers in responding to major hazard events.

• During incidents of national significance, the USGS provides support to certain **National Response Framework** emergency support functions.
A network of GPS/GNSS stations measures plate tectonic motions and land surface deformation to an accuracy of better than 1 mm/yr.

We can see whether the motion is ‘slow and steady,’ or perhaps more interestingly, is it sometimes accelerating or decelerating.
How does the USGS use GPS/GNSS to measure fault motion?

- **Objective:** determine how stations near active faults move relative to each other.
- **Occupy stations simultaneously.**
- **Relative positions and possible motion are determined** between stations separated by up to several 100 km to a precision of better than a few millimeters.
- **Months or years later we reoccupy the same stations.**
- **Determine the change in relative position between stations.**
- **Calculate accumulated strain and slip between faults.**
National Seismic Hazard Map, 2014

USGS

science for a changing world

Highest hazard

Lowest hazard

Map showing seismic hazard levels across the United States.
Earthquakes are a national hazard

USGS National Seismic Hazard Map

Notable earthquakes in past decade

M6.8
M6.5
M6.0
M6.0
M6.0
M6.6
M6.7
M5.6
M5.3
M5.1
M5.6
M5.4
M5.3
M5.1
M5.8
M7.9
M6.0
M7.2

4 years
decade

Notable earthquakes in past decade
Plate Boundary Observatory

San Andreas plan

GNSS station clusters along San Andreas fault, especially along transitions from creeping to locked sections
Continuous and campaign GPS arrays

**Continuously Operating GPS Stations**

**Campaign Survey GPS Points**
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.
San Andreas Fault lifeline crossings

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

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

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

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

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

- Earthquake early warning systems are currently in use in Japan and a number of other countries.
- Magnitude-6.0 South Napa earthquake provided the first major and successful test of the prototype *ShakeAlert* system in California.
- Potential to provide additional situational awareness for critical infrastructure operators.

Image Source: UC Berkeley
GPS is used for high-accuracy base geospatial data products

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

LiDAR (Light Detection and Ranging) - a remote sensing technology

High accuracy terrain elevation data is replacing older, lower resolution data

High resolution orthorectified imagery
Accurate LiDAR mapping is highly relevant to several data layers of The National Map.
GPS enables ultra-high-precision georeferencing for fault mapping using repeat-pass imagery
- LiDAR
- 3D stereo
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
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
Monitoring Volcano Ground Deformation
Changes at the Surface Tell us about the Subsurface

Most volcano deformation can only be detected and measured with precise surveying techniques.

GPS/GNSS
Precision Monitoring at individual ground locations

Tilt
Measuring tiny changes in the slope angle or "tilt" of the ground

InSAR
Mapping ground deformation of large areas using radar images from Earth-orbiting satellites.

EDM
Measuring the distance between benchmarks placed on a volcano tens to thousands of meters apart.
Volcano observatories combine an array of real time data streams to interpret behavior and forecast eruptions.
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 uses precise GPS for eruption monitoring

Flank motions

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

Dome growth
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

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<thead>
<tr>
<th>NVEWS TARGETS</th>
<th>MONITORING GAP</th>
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<tr>
<td>Kilauea, HI</td>
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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/
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).
Questions?