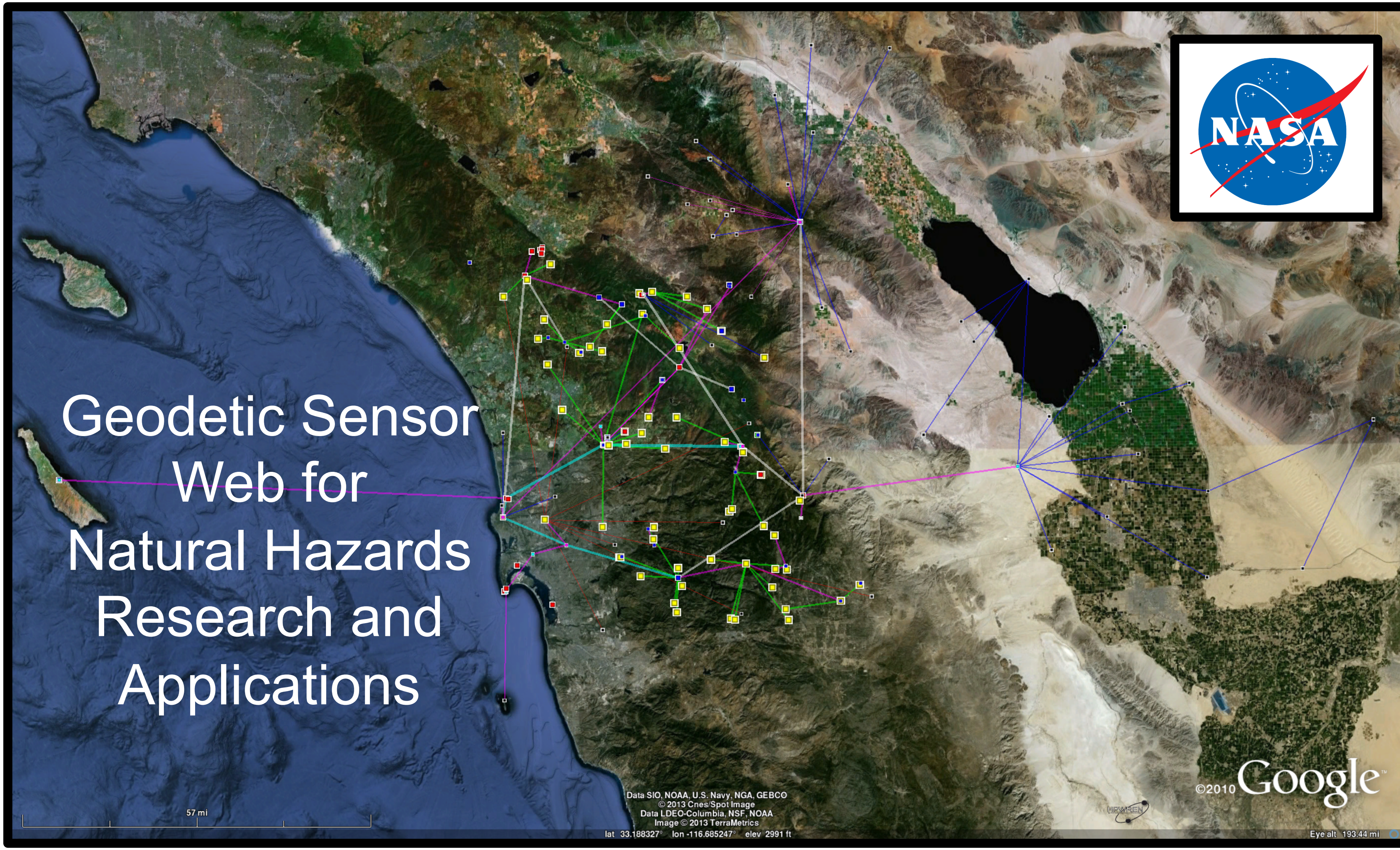
Geodetic Sensor Web for Natural Hazards Research and Applications



J.S. Haase, Y. Bock, J. Geng, A. Moore, G. Offield, M. Squibb, I. Small, S. Gutman, J. Laber, E. Yu, R. Clayton, S. Kedar

Scripps Institution of Oceanography

Jet Propulsion Laboratory, NOAA National Weather Service, Caltech

Earth Science Technology Office

AIST-11-0072

Objectives

- Develop and deploy SIO Geodetic Modules that transform ground based Global Positioning System (GPS) receivers into a web of sensors that provide advanced geophysical products to users for rapid response to natural hazards.

- To better forecast, assess, and mitigate risk for natural hazards, including earthquakes, tsunamis, and extreme storms and flash flooding to save lives and reduce damage to critical infrastructure.

Data Fusion: Enhance GPS technology with low-cost sensors to mitigate risk for natural hazards

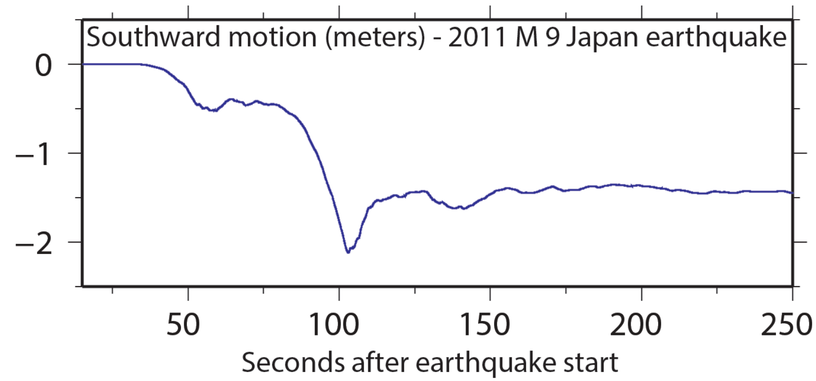
GPS
(in field)

+

Accelerometer

=

Continuous measure of seismic motions

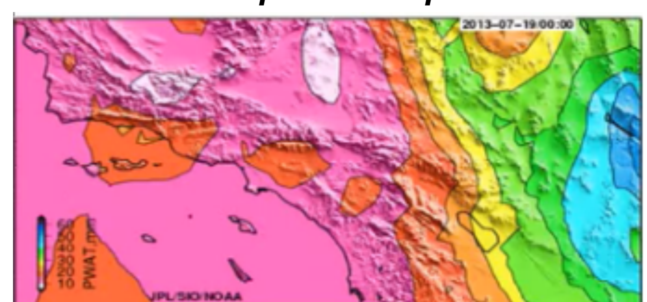


+

Meteorological Sensors
(pressure, temperature)

=

Continuous atmospheric water vapor maps



ESTO
Earth Science Technology Office

Geodetic Sensor Web

- Traditional Paradigm
  - Sensors transmit data to central processing facility
  - Advanced analysis to derive geophysical parameters
  - Transmission of results and alerts from central processing facility to users

- New Paradigm
  - Advanced analysis carried out a remote site
  - Transmission of results and alerts directly from remote sites to central facility and to users

Project Phases

- Develop a power-efficient, low-cost, plug-in Geodetic Module to interface with MEMS accelerometer, met sensors, and other low-cost instruments (e.g. gyroscope)
- Generate on-the-fly millimeter-level ground motions and precipitable water ***within*** the geodetic module
- Develop a real-time autonomous sensor web to transmit and receive information among regional nodes, including directly to users
- Transfer capabilities to NOAA and California Integrated Seismic Network (CISN) as part of a technology infusion, for decision support and rapid response to earthquakes, tsunamis, severe storms and flash flooding

ESTO Earth Science Technology Office

Technology Demonstration – Earthquake and Tsunami Hazards

M 7.9 at 9 min

Estimated Population Exposed to Earthquake Shaking

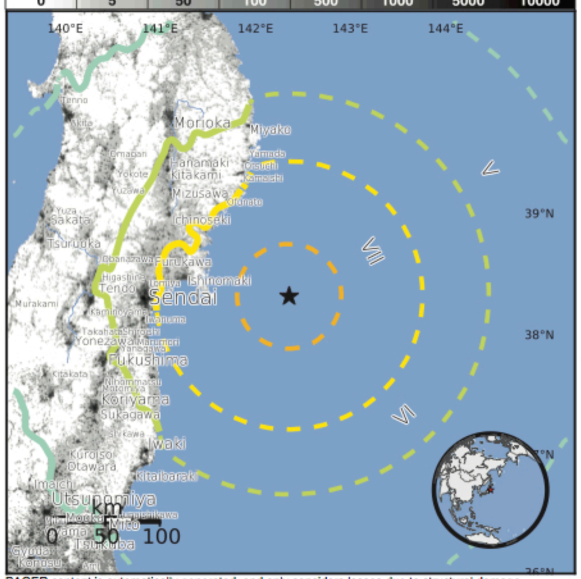
ESTIMATED POPULATION EXPOSURE (k = x1000)		--*	--*	3,227k*	6,192k	2,918k	719k	0	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0 | 5 | 50 | 100 | 500 | 1000 | 5000 | 10000



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The predominant vulnerable building types are ductile reinforced concrete frame and heavy wood frame construction.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1998-06-14	363	5.7	VII(428k)	0
1994-12-28	263	7.7	VII(132k)	3
1983-05-26	369	7.7	VII(174k)	104

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and fires that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VII	**Ishinomaki**	117k
VII	Yamoto	32k
VII	Shiogama	60k
VII	Kogota	20k
VII	Rifu	35k
VI	**Ofunato**	35k
VI	**Sendai**	1,038k
VI	Yamagata	255k
V	**Morioka**	295k
V	**Fukushima**	294k
IV	**Utsunomiya**	450k

bold cities appear on map (k = x1000)

Event ID: usc0001xgp

M 8.9 at 2.5 hrs

Estimated Population Exposed to Earthquake Shaking

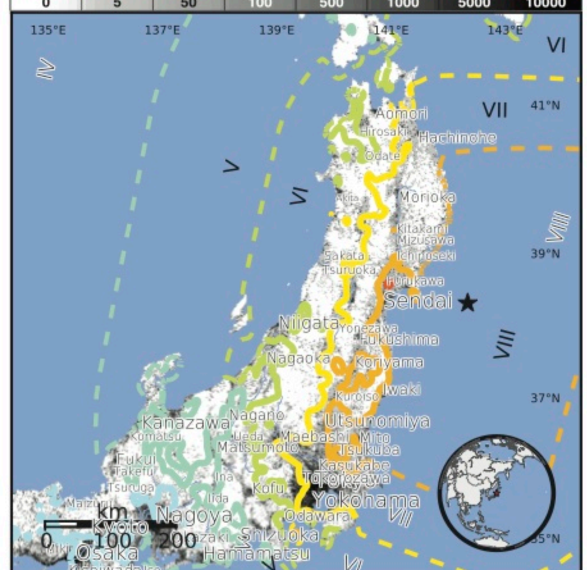
ESTIMATED POPULATION EXPOSURE (k = x1000)		--*	13,068k*	21,353k*	8,612k*	10,080k*	34,125k*	6,009k*	251k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0 | 5 | 50 | 100 | 500 | 1000 | 5000 | 10000



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The predominant vulnerable building types are non-ductile reinforced concrete frame and heavy wood frame construction.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1998-06-14	363	5.7	VII(428k)	0
1994-12-28	263	7.7	VII(132k)	3
1983-05-26	369	7.7	VII(174k)	104

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and fires that might have contributed to losses.

Selected City Exposure

from GeoNames.org

MMI	City	Population
IX	Furukawa	76k
IX	Iwanuma	42k
IX	Hitachi	186k
IX	Kogota	20k
VIII	Shiogama	60k
VIII	Sukagawa	69k
VII	**Tokyo**	8,337k
VII	**Yokohama**	3,574k
IV	**Nagoya**	2,191k
III	**Osaka**	2,592k
III	Kobe	1,528k

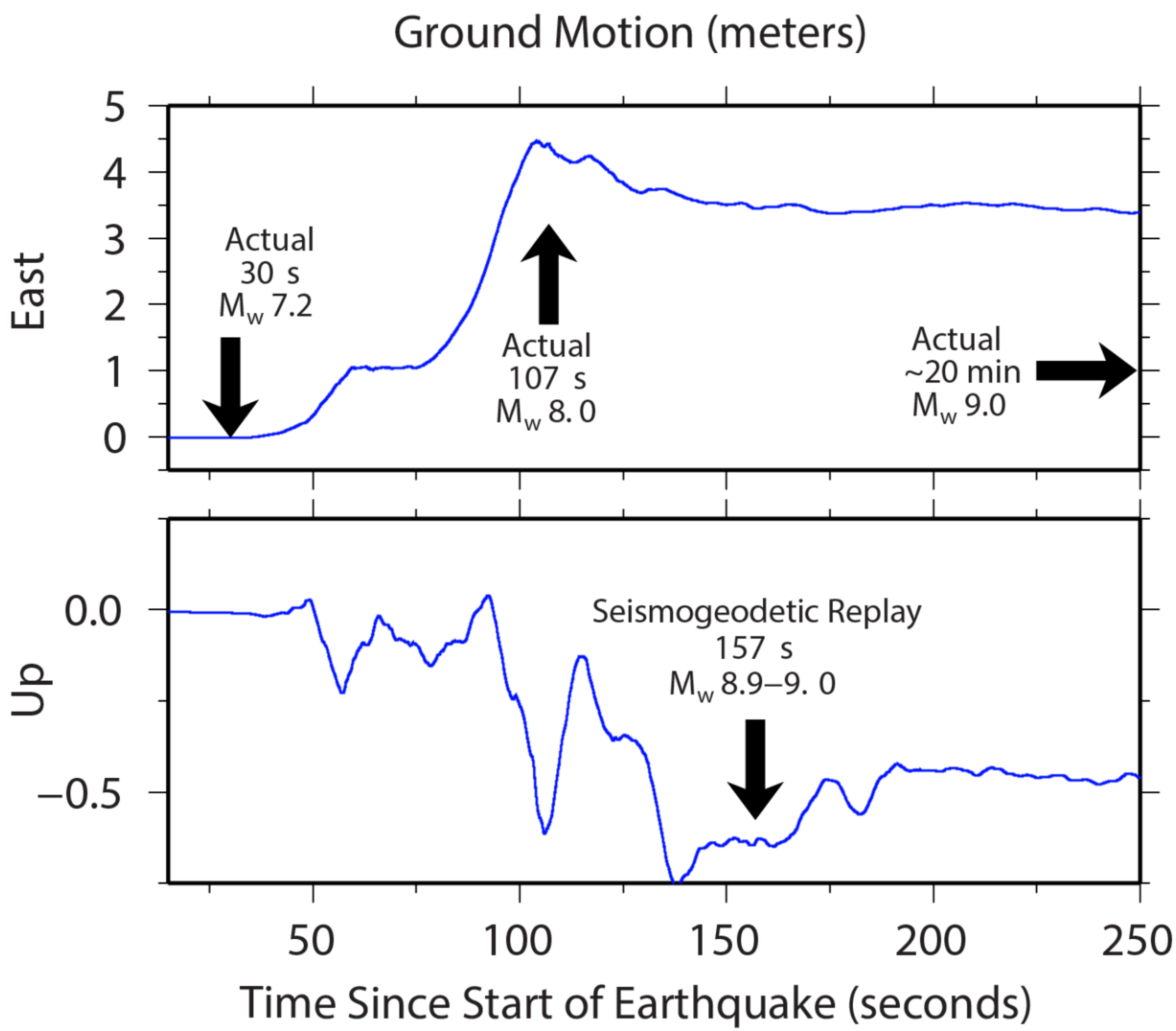
bold cities appear on map (k = x1000)

Event ID: usc0001xgp

2011 Mw 9.0 Tohoku-oki earthquake was underestimated by traditional seismic methods

ESTO Earth Science Technology Office

GPS + accelerometer sensors = seismogeodetic waveforms



Permanent displacement is DIRECTLY related to size of rupture and slip on fault, therefore earthquake size

Our system improves on traditional seismic monitoring by estimating ground acceleration ***and permanent displacements***

Source: Melgar et al., GRL, 2013

Technology Demonstration – Earthquake and Tsunami Hazards

M 7.9 at 9 min
Traditional seismic – point source

M 9 at 2.6 minutes
Seismogeodetic – extended source

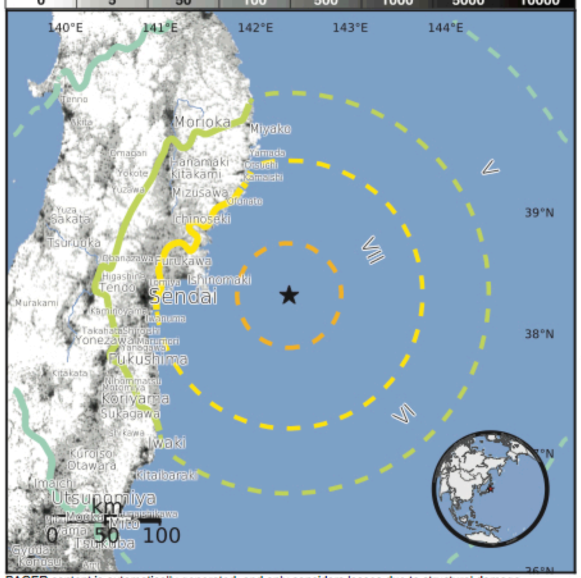
Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	3,227k*	6,192k	2,918k	719k	0	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan



PAGER content is automatically generated, and only considers losses due to structural damage.
Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The predominant vulnerable building types are ductile reinforced concrete frame and heavy wood frame construction.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1998-06-14	363	5.7	VII(428k)	0
1994-12-28	263	7.7	VII(132k)	3
1983-05-26	369	7.7	VII(174k)	104

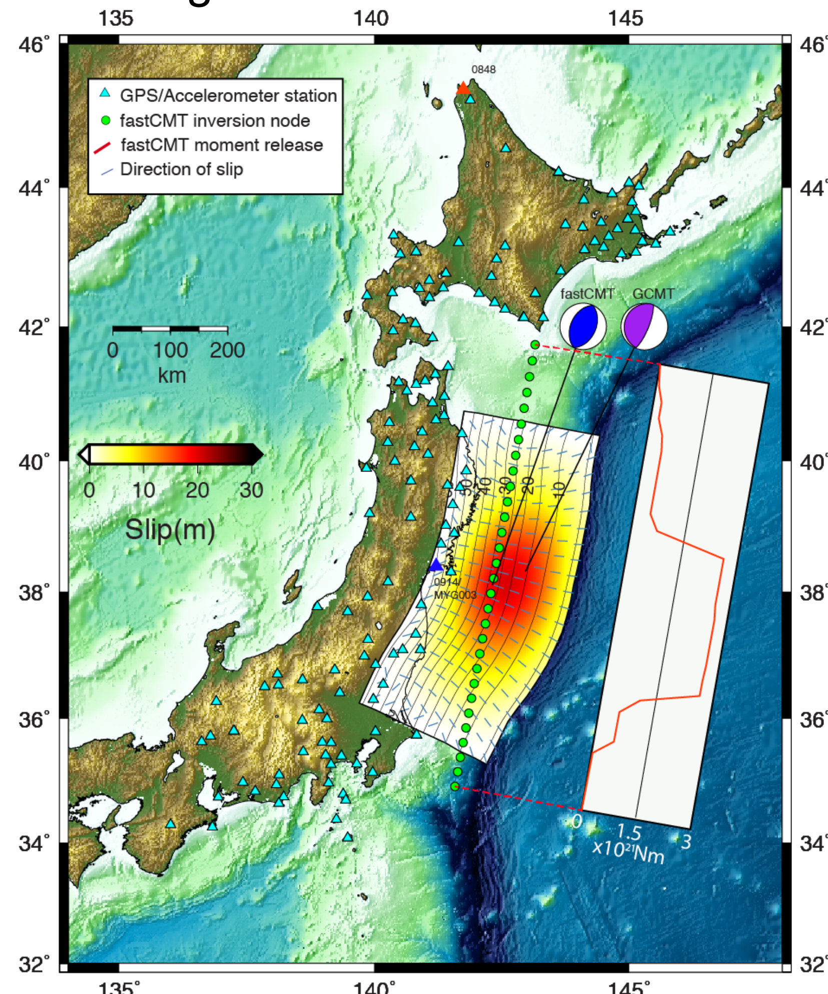
Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and fires that might have contributed to losses.

Selected City Exposure
from GeoNames.org

MMI	City	Population
VII	**Ishinomaki**	**117k**
VII	Yamoto	32k
VII	Shiogama	60k
VII	Kogota	20k
VII	Rifu	35k
VI	**Ofunato**	**35k**
VI	**Sendai**	**1,038k**
VI	Yamagata	255k
V	**Morioka**	**295k**
V	**Fukushima**	**294k**
IV	**Utsunomiya**	**450k**

bold cities appear on map (k = x1000)

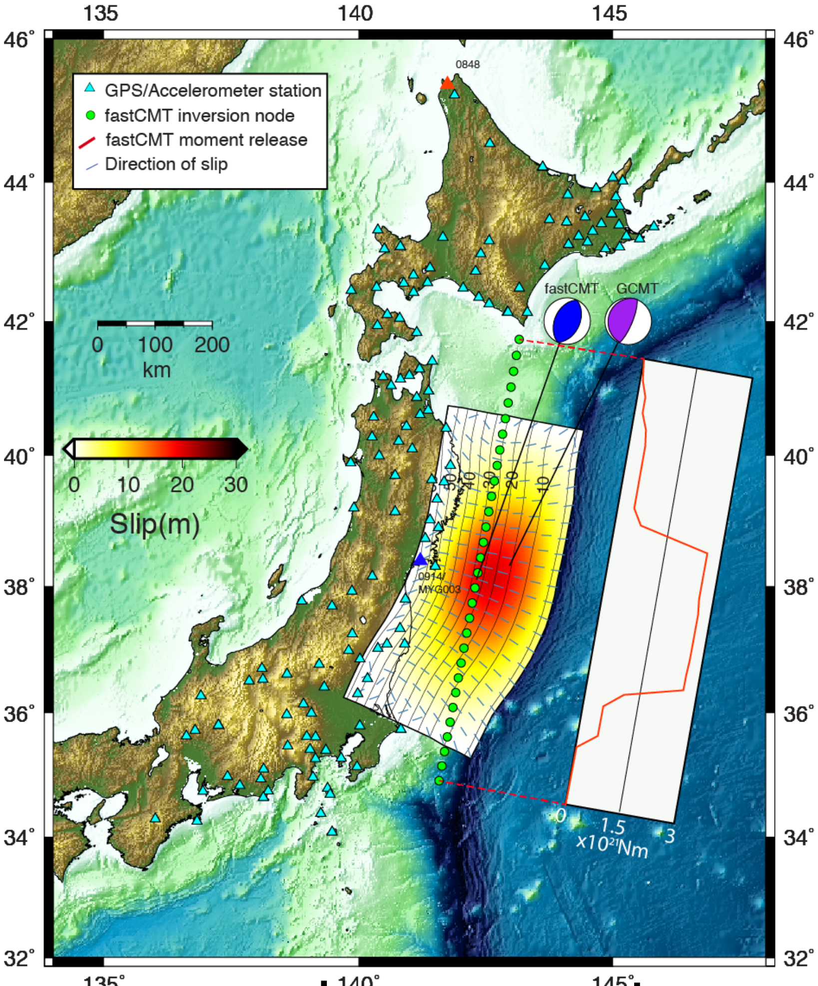
Event ID: usc0001xgp



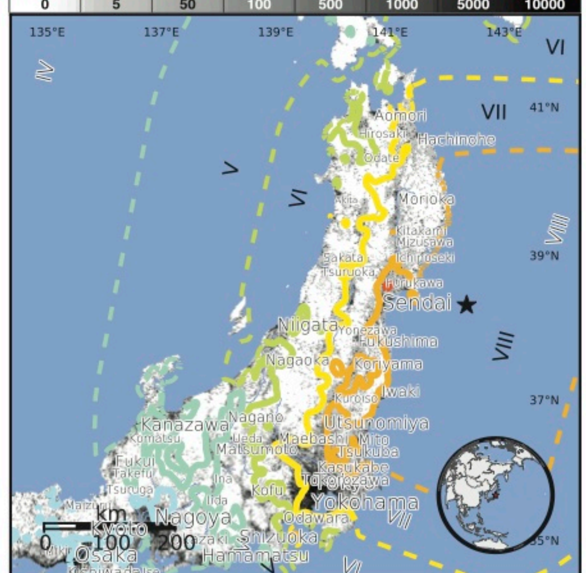
Seismogeodetic data provides better estimates of finite extent of earthquake

Technology Demonstration – Earthquake and Tsunami Hazards

M 9 at 2.6 min



M 8.9 at 2.5 hrs



Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		--*	13,068k*	21,353k*	8,612k*	10,080k*	34,125k*	6,009k*	251k	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure population per ~1 sq. km from Landscan

0 | 5 | 50 | 100 | 500 | 1000 | 5000 | 10000

Structures:
Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist. The predominant vulnerable building types are non-ductile reinforced concrete frame and heavy wood frame construction.

Historical Earthquakes (with MMI levels):

Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
1998-06-14	363	5.7	VII(428k)	0
1994-12-28	263	7.7	VII(132k)	3
1983-05-26	369	7.7	VII(174k)	104

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides, and fires that might have contributed to losses.

Selected City Exposure
from GeoNames.org

MMI	City	Population
IX	**Furukawa**	76k
IX	Iwanuma	42k
IX	Hitachi	186k
IX	Kogota	20k
VIII	Shiogama	60k
VIII	Sukagawa	69k
VII	**Tokyo**	8,337k
VII	**Yokohama**	3,574k
IV	**Nagoya**	2,191k
III	**Osaka**	2,592k
III	Kobe	1,528k

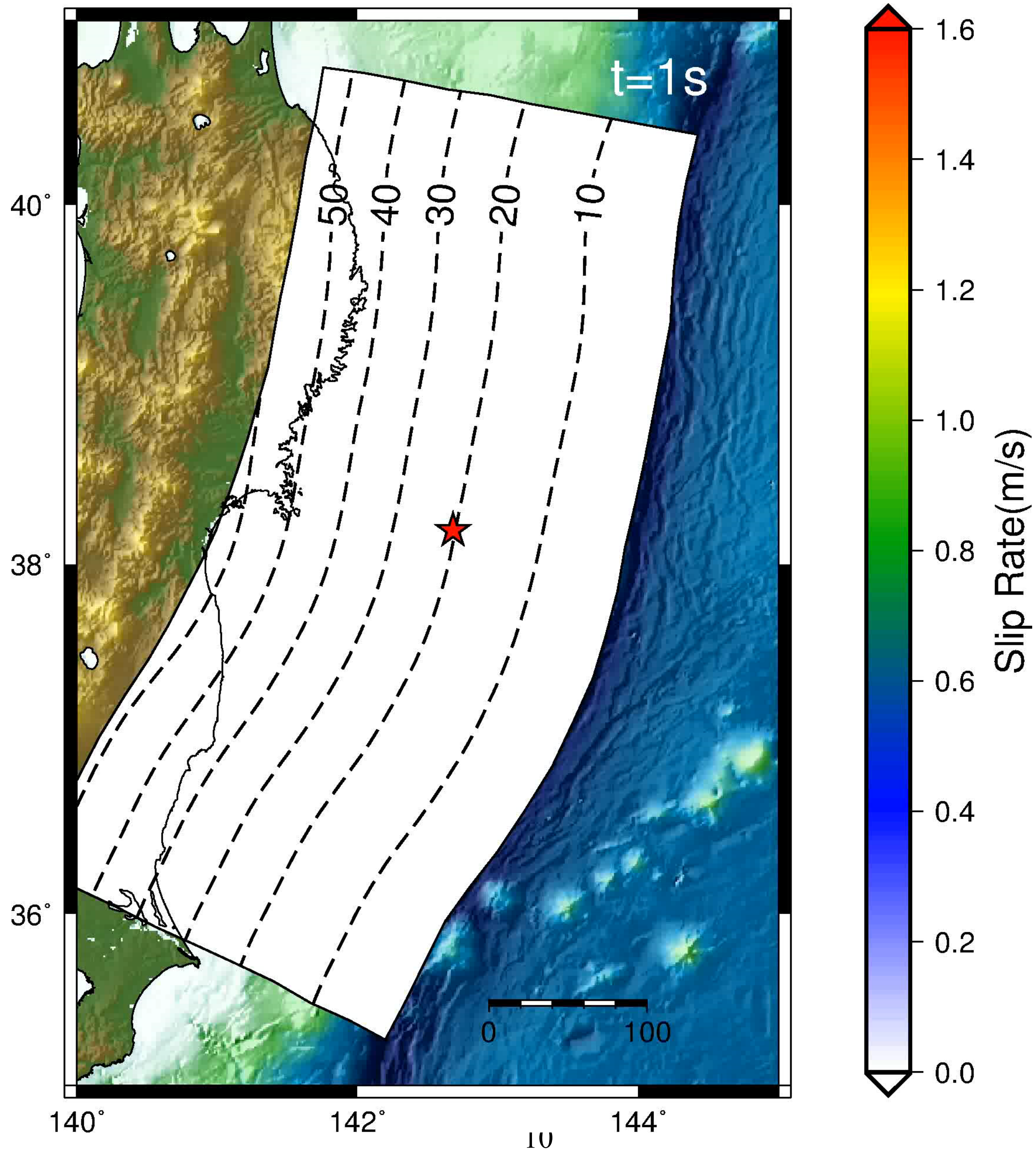
bold cities appear on map (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

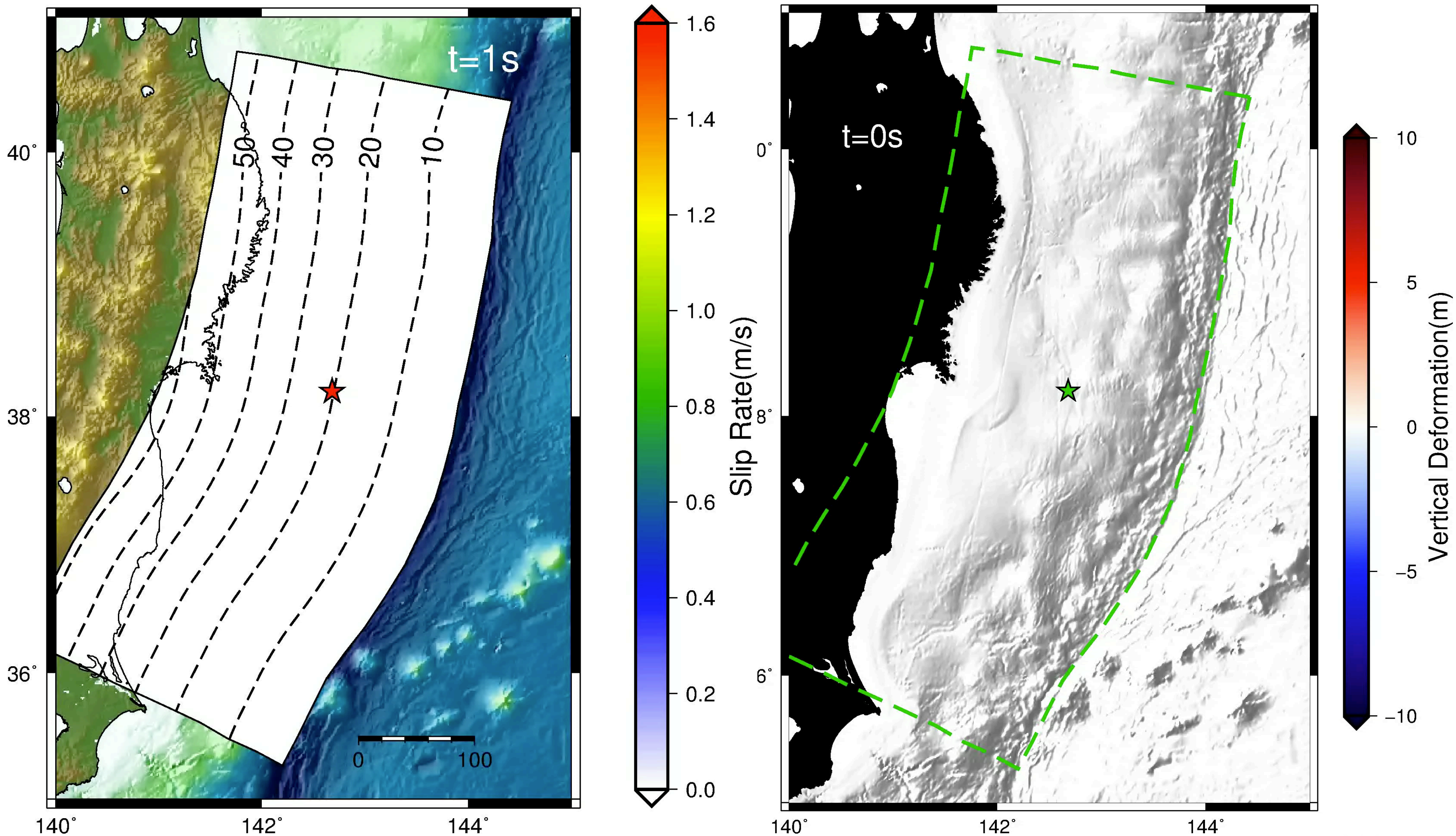
Event ID: usc0001xgp

Seismogeodetic data provides better estimates of finite extent of earthquake

Technology Demonstration – Kinematic Source Inversion

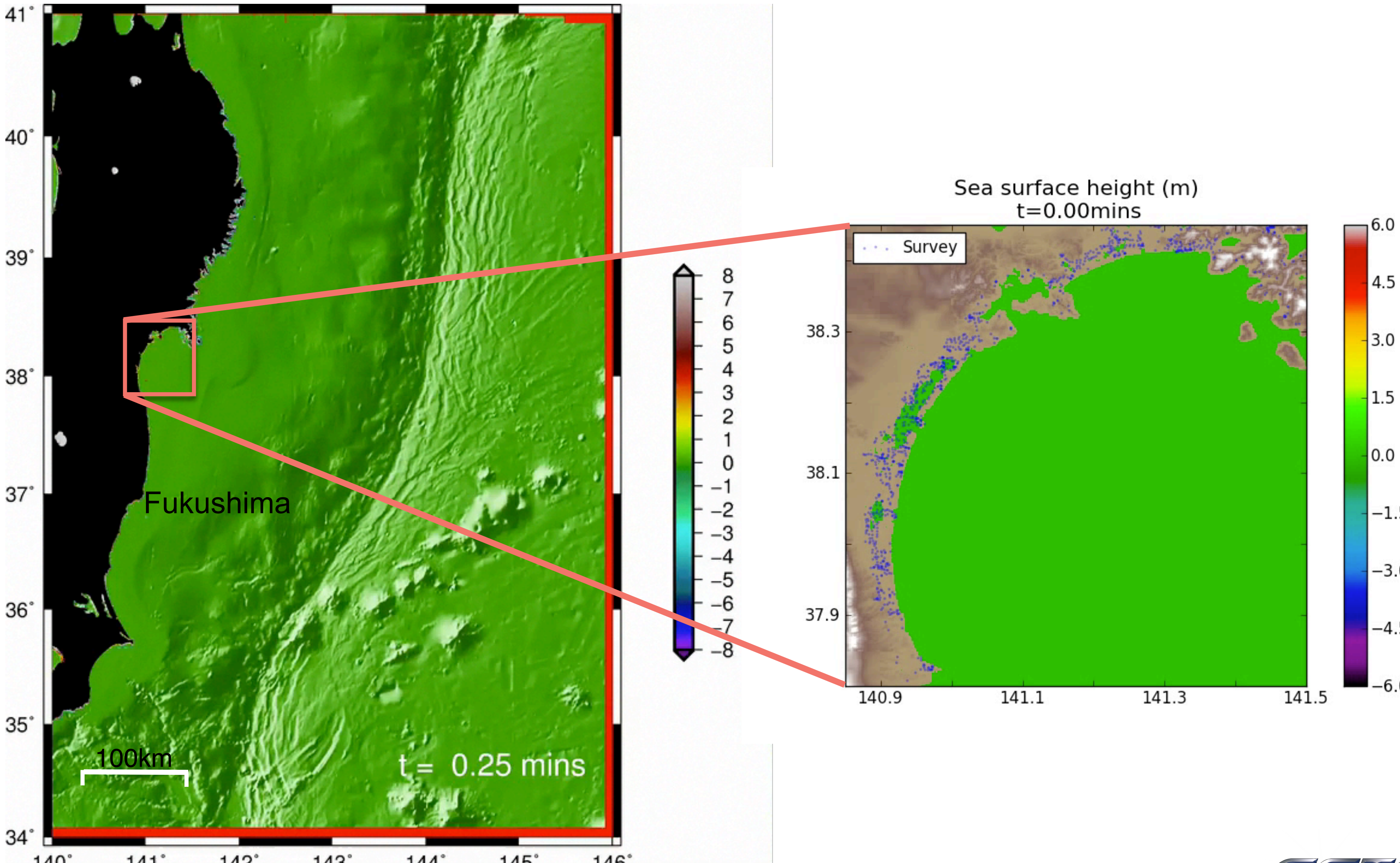


Time dependent deformation of the seafloor



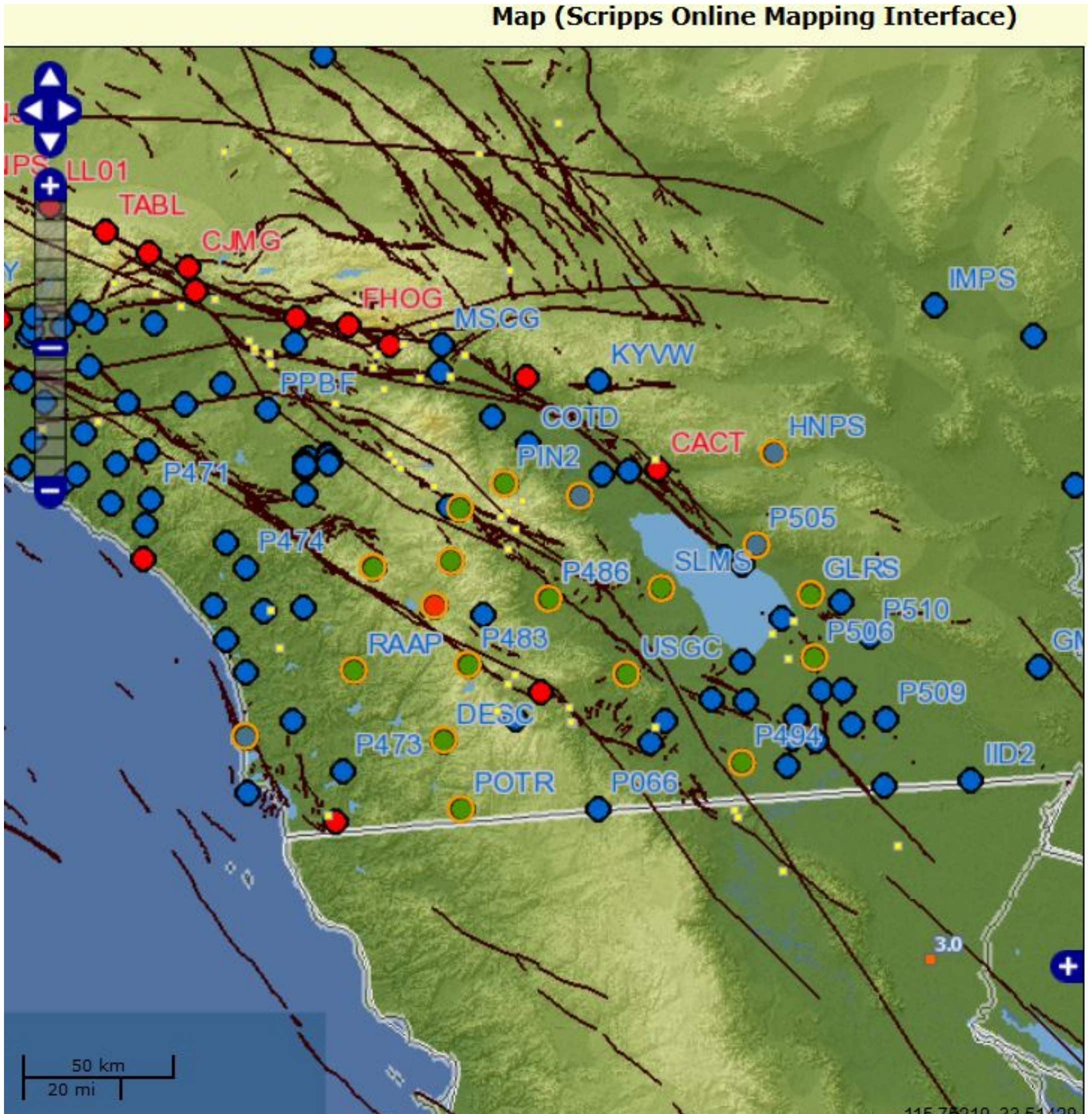
Melgar et al., in prep

Inundation prediction compared to post-event land survey



Melgar et al., in prep

Technology Implementation – San Andreas Fault



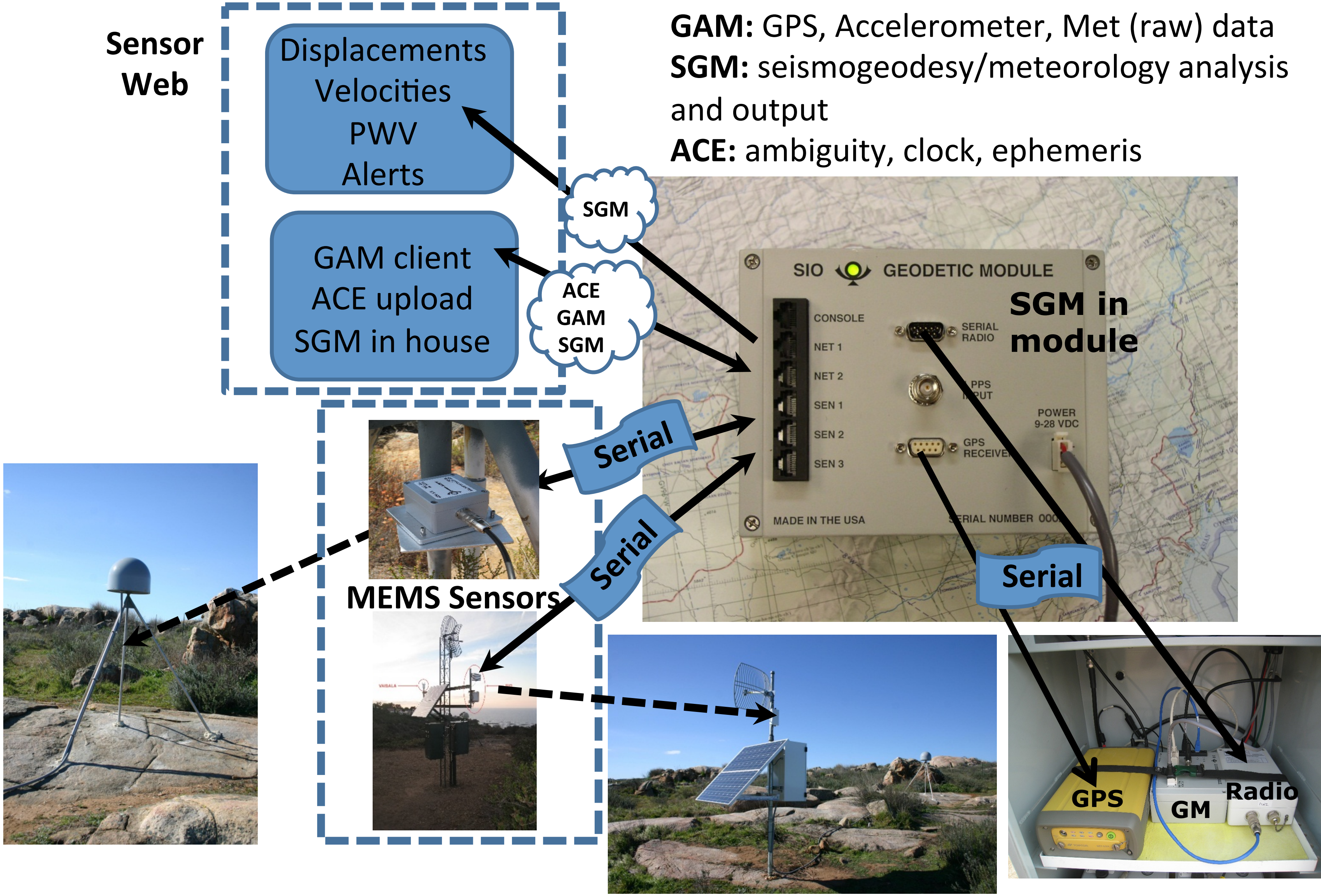
22% probability of an earthquake with M >6.5 in 30 years on the Coachella Segment of the San Andreas Fault (UCERF V3, 2014)

SIO Geodetic Modules and Accelerometer Packages have now been deployed and are operating at 17 stations (green dots along the southern San Andreas fault system in southern California).

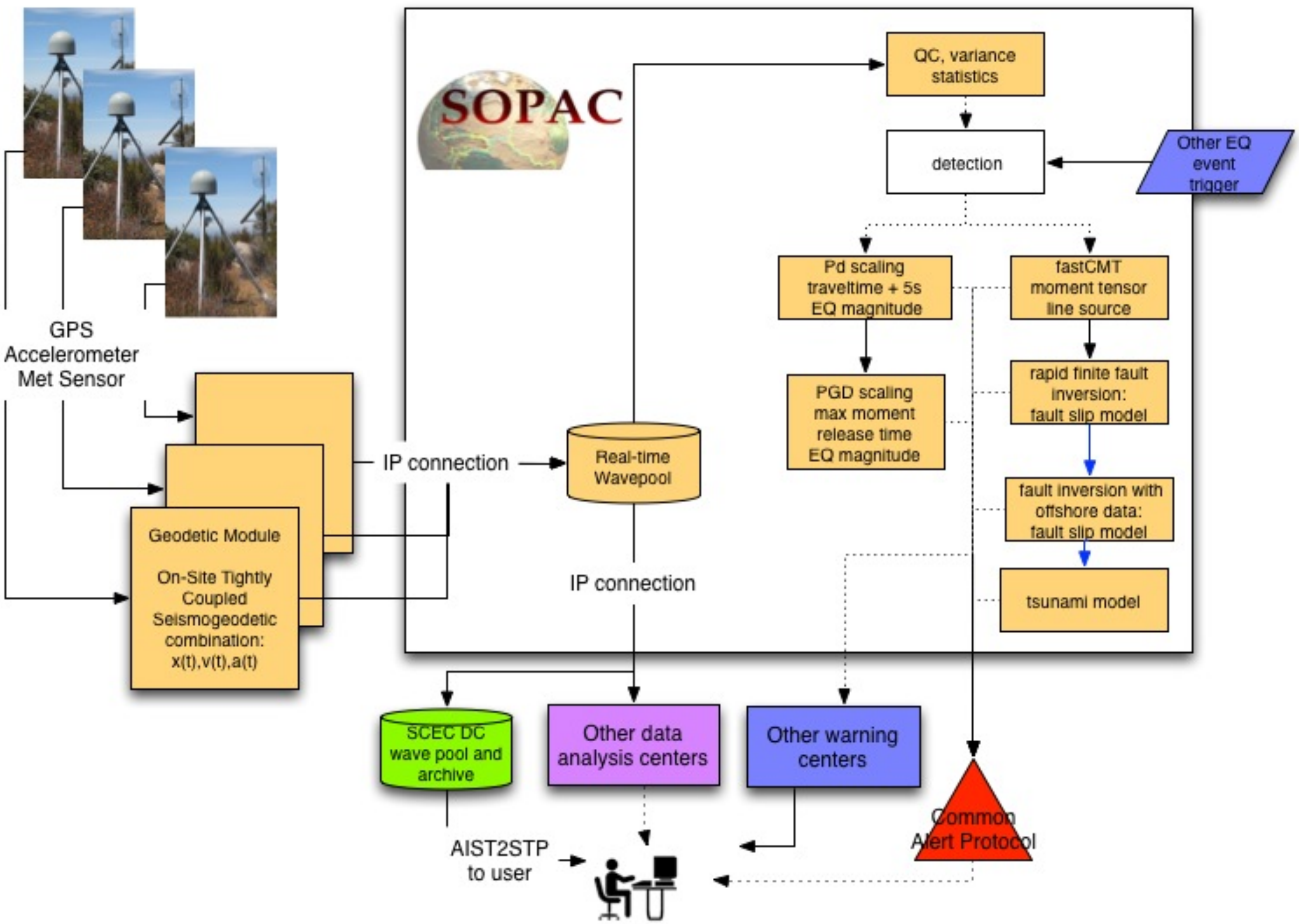
ESTO Earth Science Technology Office

Real Time Autonomous Sensor Web

GAM: GPS, Accelerometer, Met (raw) data
SGM: seismogeodesy/meteorology analysis and output
ACE: ambiguity, clock, ephemeris



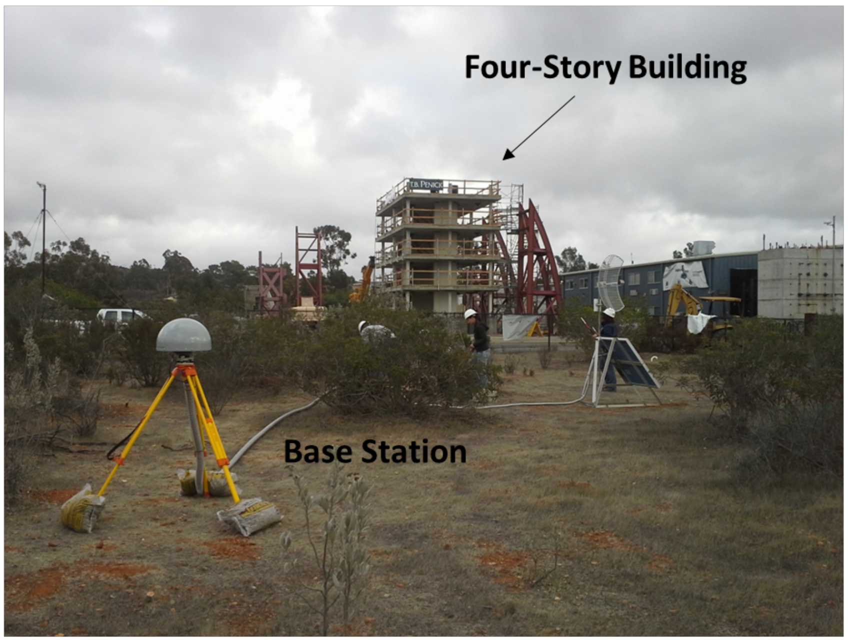
Complete AIST Technology Fusion and Export to Users



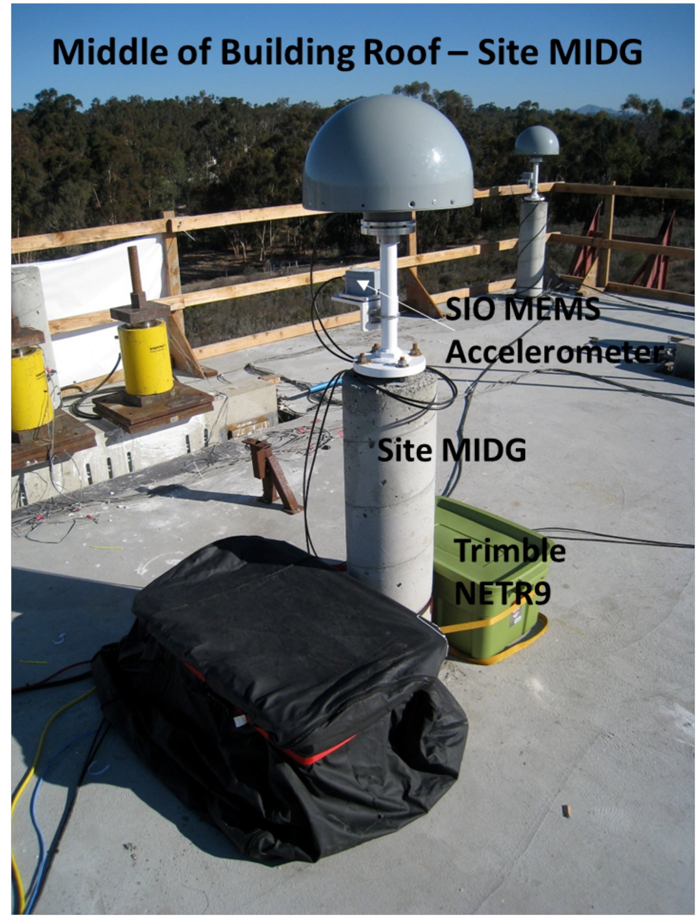
Develop a real-time Sensor Web to allow autonomous sensors to transmit and receive information with the geodetic module via regional nodes and central facilities to allow for control functions, data, data product, model exchanges and alarming

Real-time Earthquake Exercise Shake Table Experiment

NEES/UCSD LHPOST
Inertial Force Limiting Anchorage System Experiments
(December 2013 – January 2014)

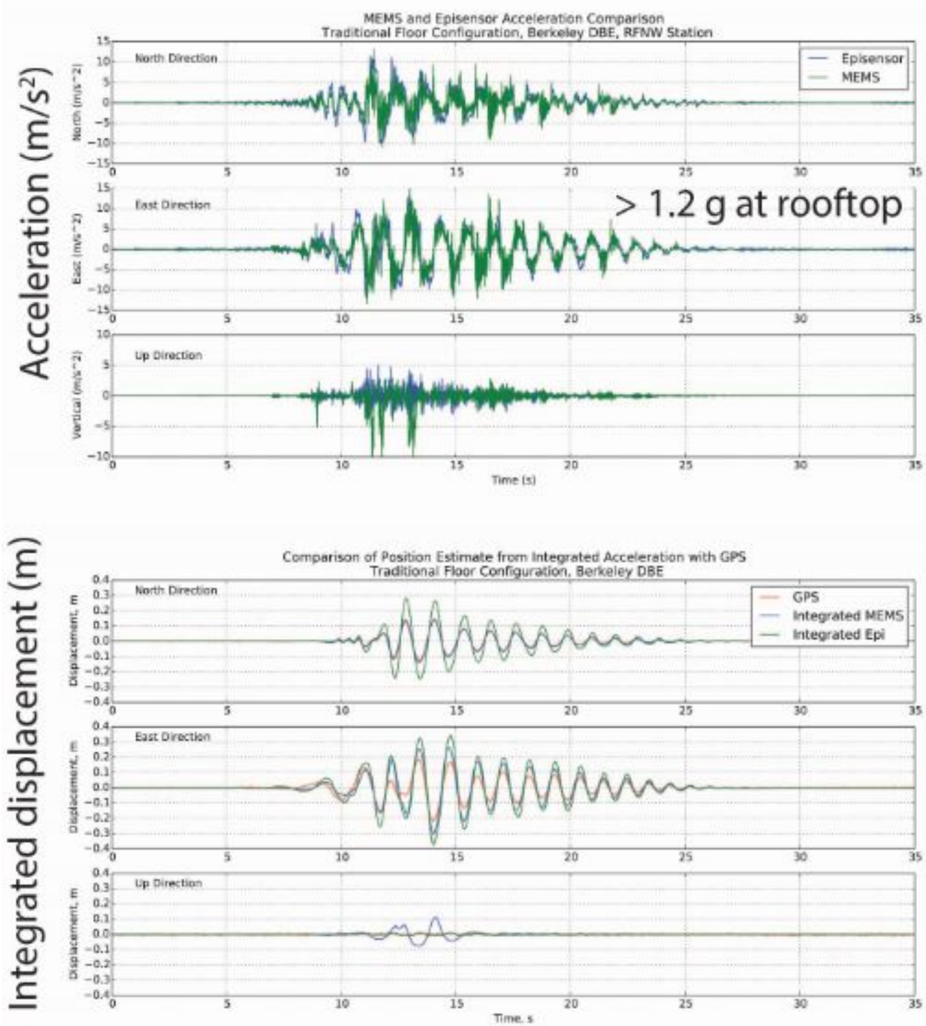


LHPOST: Large High Performance Outdoor Shake Table



Source: SOPAC

2013-14 Shake Table Tests: Comparison of SIO MEMS and High-End Accelerometers

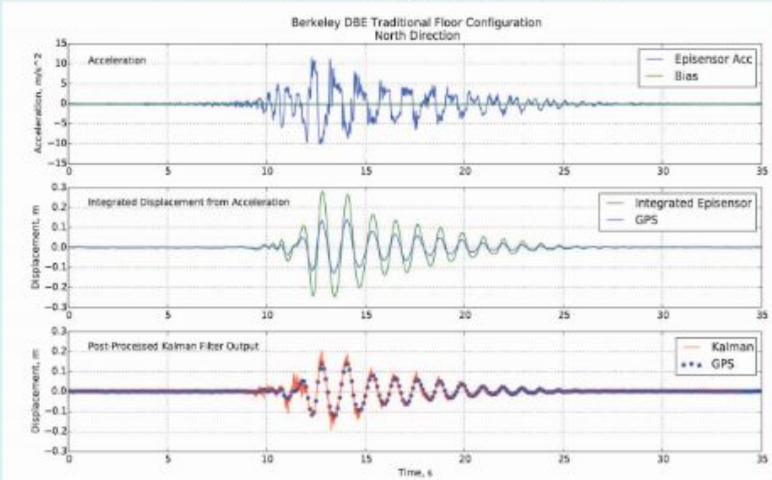


Overall performance of MEMS is good

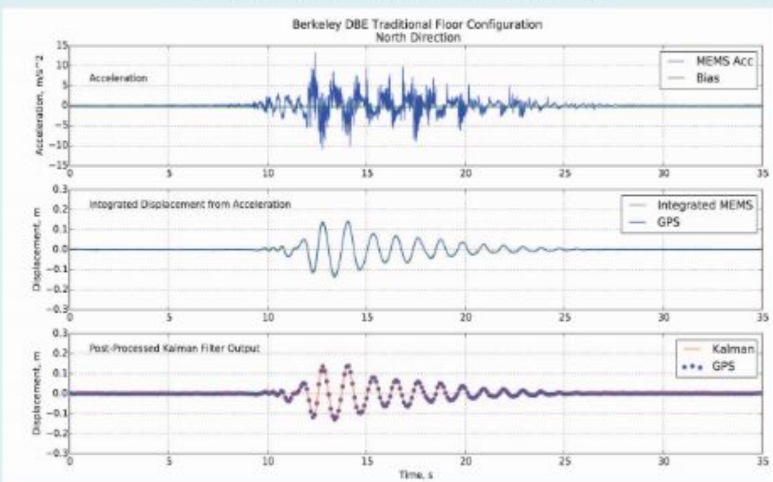
- Reliable in the range ~4.0 to .1 s period
- Comparable to Episensor
- Isolated negative spikes in vertical
- Some possible 30Hz noise
- Instances of interference (one day)

2013-14 Shake Table Tests:
Input of SIO MEMS and High-End Accelerometers to Kalman Filter

EPISENSOR NORTH COMPONENT



MEMS NORTH COMPONENT



Real-time Process Active During Tests:

- GPS phase data and MEMS acceleration were streamed in real-time to SOPAC
- GPS RTD network solution calculated and streamed for real time network adjustment
- GPS PPP-AR solution calculated in real-time
- Positions streamed in real-time to loosely coupled Kalman filter combination with MEMS data
- Seismogeodetic solution streamed in real-time to archive

Areas for improvement:

- Kalman filter variance adjustment
- Automated QC for MEMS noise

Post-analysis:

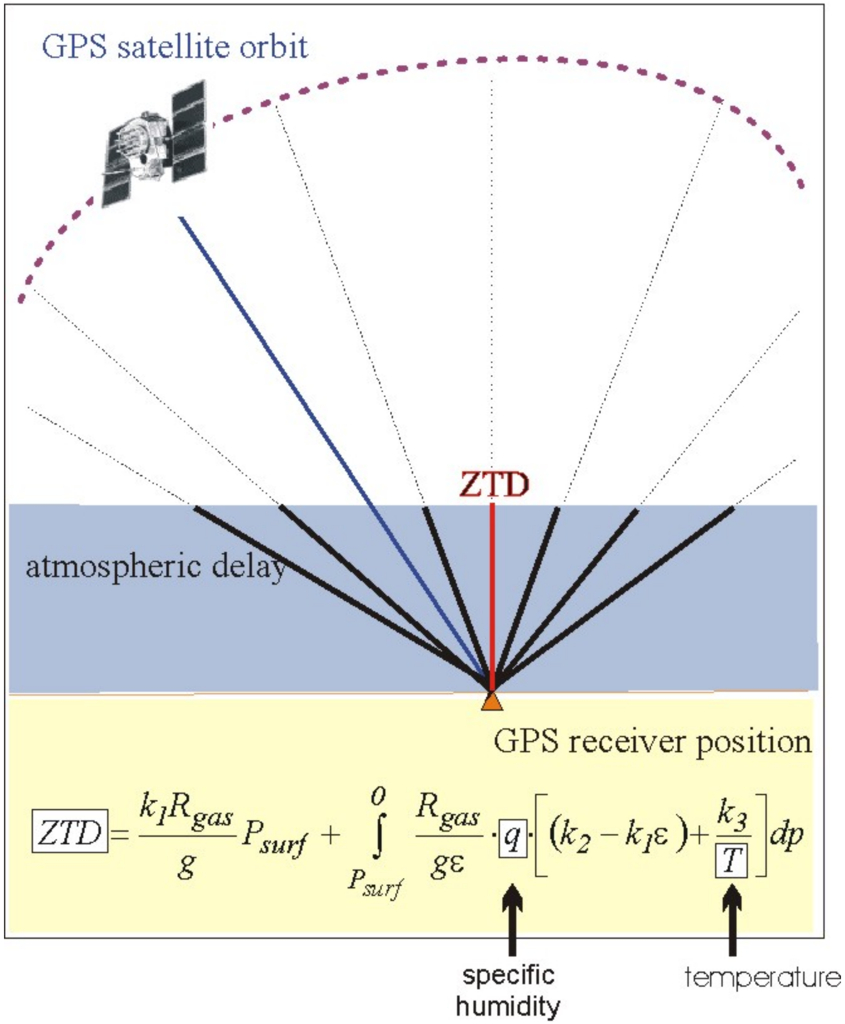
- Higher amplitude Episensor may be due to
  - uncertainty in instrument response
  - rotation of roof

  =>impacts combination negatively
- MEMS 30Hz noise may be due to
  - electronic contamination

  =>little visible impact on seismogeodetic solution for long period rooftop motions

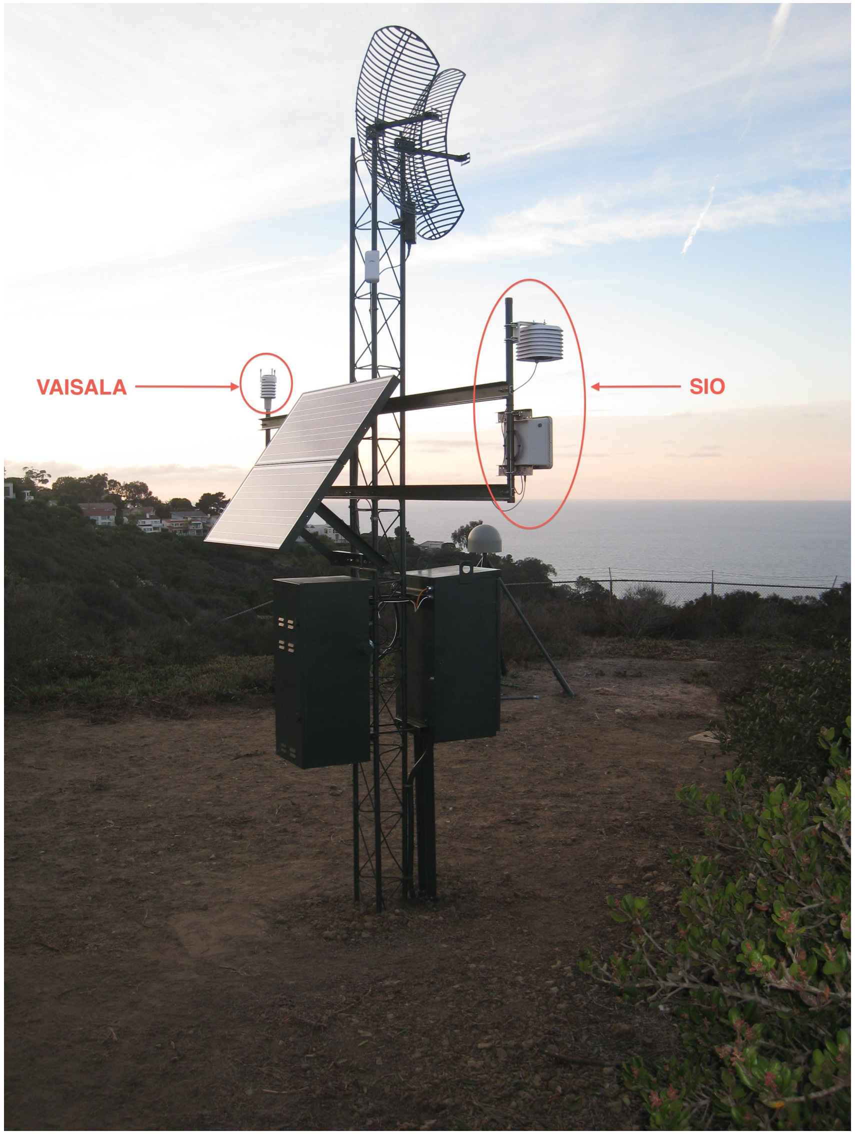
ESTO Earth Science Technology Office

Technology Demonstration – Extreme Weather Hazards



Because signals from the GPS satellites are affected by moist air, when we measure the position of a GPS station, we automatically also measure the total amount of atmospheric water vapor above.

Technology Demonstration – Extreme Weather Hazards

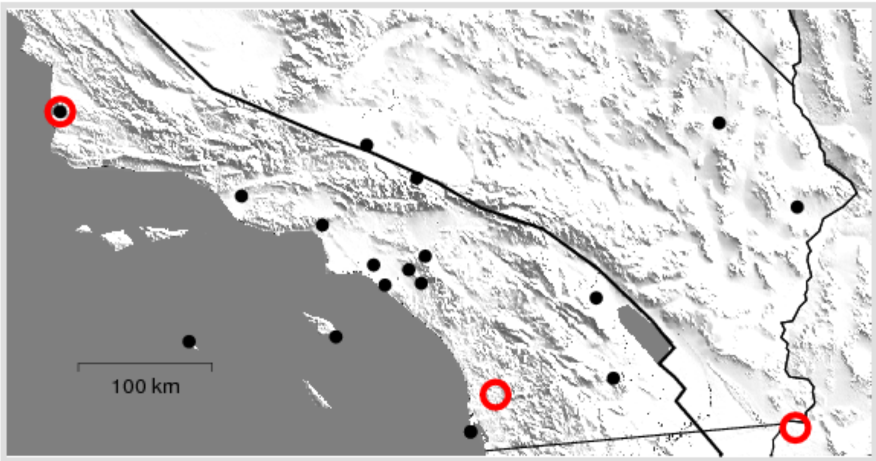


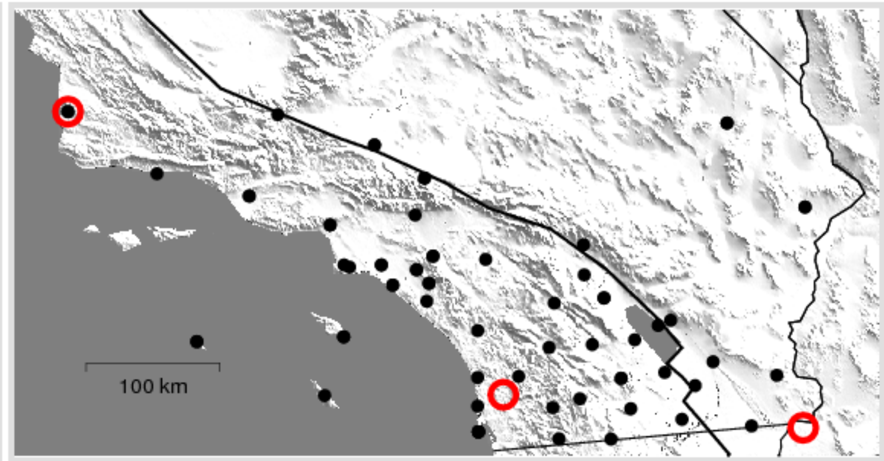
Station SIO5 on Mount Soledad, La Jolla has been upgraded with SIO GAM (Geodetic Module, MEMS Accelerometer Package and MEMS Meteorological Package). A high-end Vaisala WXT-510 Multi-Weather Sensor has been deployed to serve as a comparison with the less expensive prototype SIO met package.

Time-tagged 1 Hz GPS, 100 Hz accelerometer data, and 5 s pressure and temperature data are being continuously streamed to SIO. The GPS and met data provide estimates of precipitable water above that location.

ESTO
Earth Science Technology Office

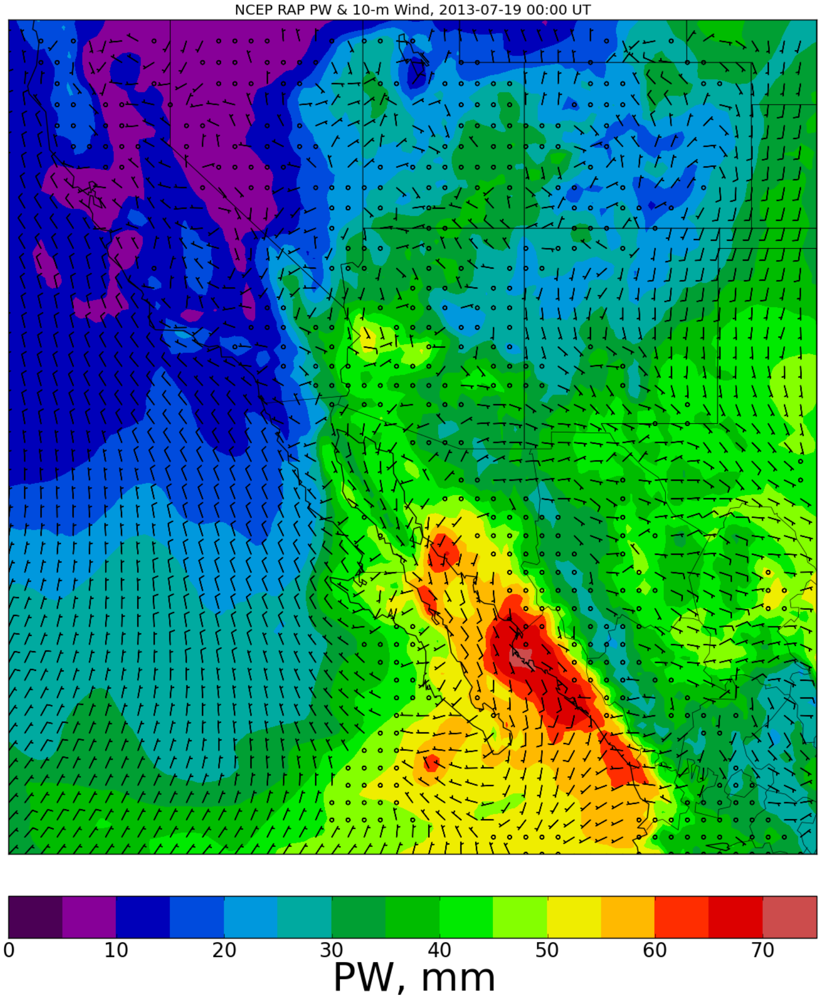
Technology Implementation – Augmentation of NOAA monitoring sites





- Southern California stations analyzed by the NOAA GPS-Met project prior to the start of this AIST project.
- The station set including 37 additional stations following the implementation of AIST. Red circles indicate radiosonde sites

North American Monsoon Event



- NCEP Rapid Refresh model precipitable water with 10m winds on 19 July 2013 illustrating monsoonal moisture surge from the Gulf of California

NCEP – NOAA National Center for Environmental Prediction

North American Monsoon Season 2013

Forecasters noted the use of GPS PW in their Area Forecast Discussions:

“SUBTROPICAL MOISTURE MOVING INTO THE DESERTS OF SOUTHEAST CALIFORNIA THIS MORNING. GPS PRECIPITABLE WATER VALUES HAVE ALREADY CLIMBED TO AROUND 1.7 INCHES FOR AREAS AROUND THE SALTON SEA. “

"ITS POSSIBLE THAT THIS INVERSION IS HELPING TO SQUELCH SIGNIFICANT CONVECTIVE ACTIVITY THIS AFTERNOON...BECAUSE A GPS-MET INTEGRATED PRECIPITABLE WATER STATION IN LA QUINTA WITH A VALUE NEAR 1.8 INCHES AND DEW POINTS IN THE 70S IN THE COACHELLA VALLEY WOULD INDICATE THAT THERE IS MORE THAN ENOUGH MOISTURE FOR CONVECTION.”

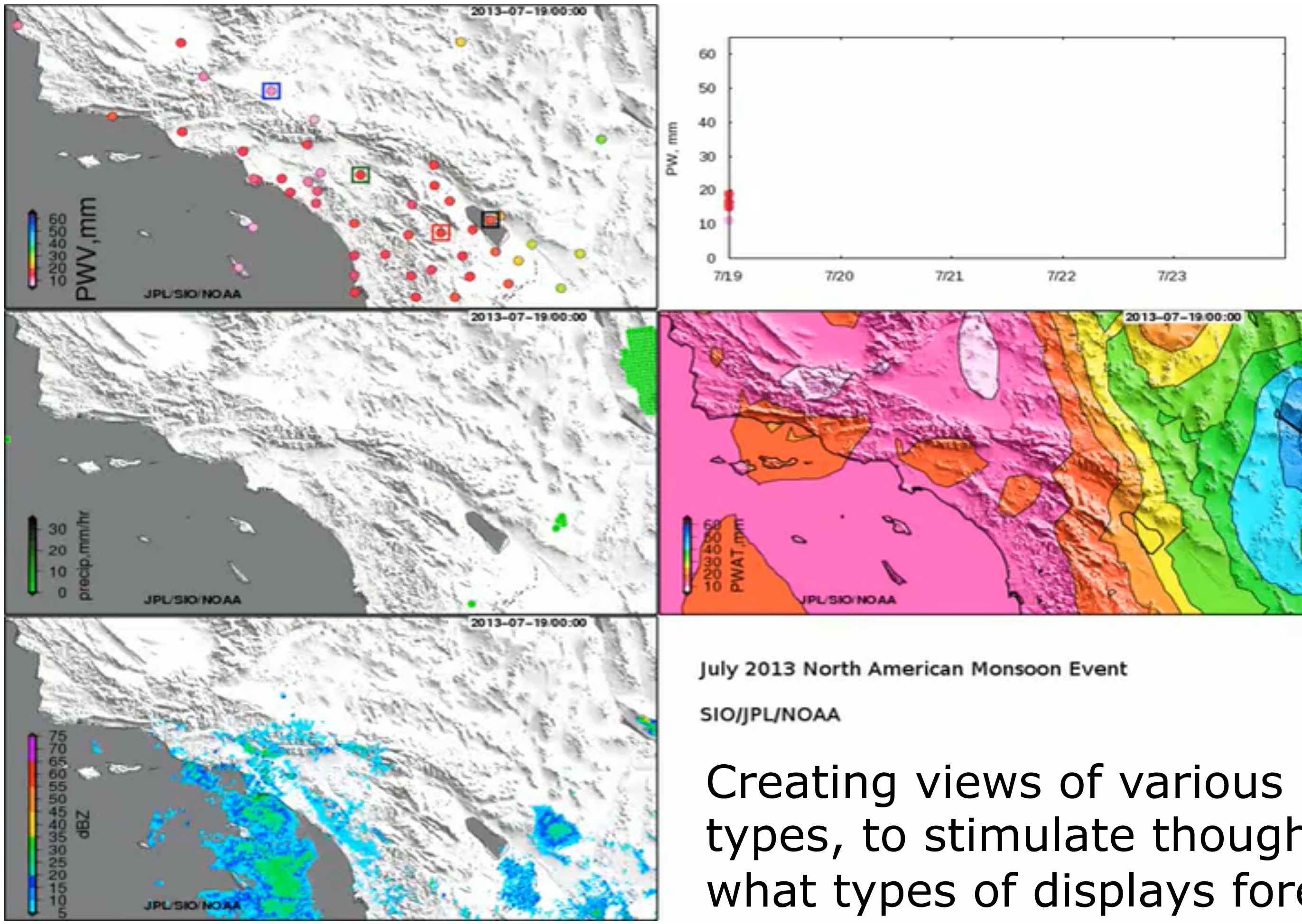
San Diego SFO Science & Operations Officer Ivory Small wrote a white paper on the use of GPS IPW in the July event, in the absence of a Yuma sounding, to issue a flash flood warning prior to verified flooding.

July 2013 North American Monsoon Event

GPS-based Precipitable Water (mm)

Radar Estimated Rainfall (mm/hr)

Radar Reflectivity (dBZ)

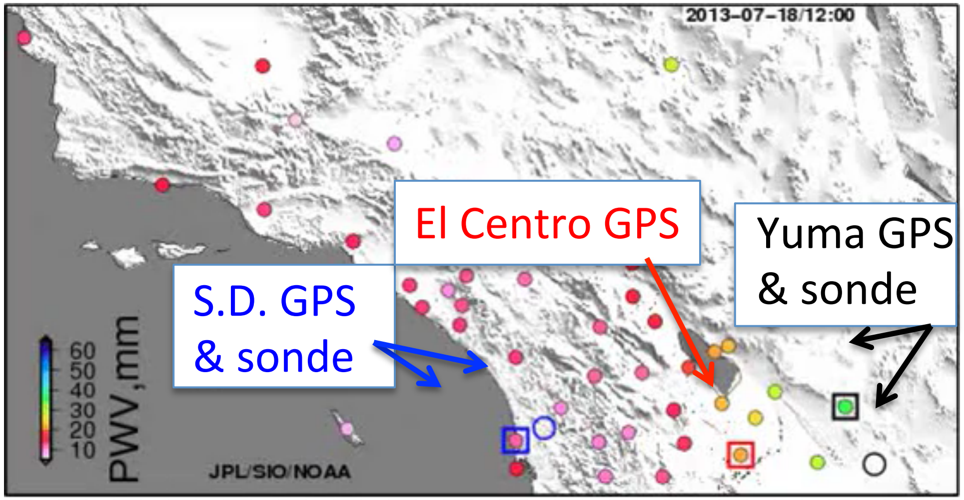


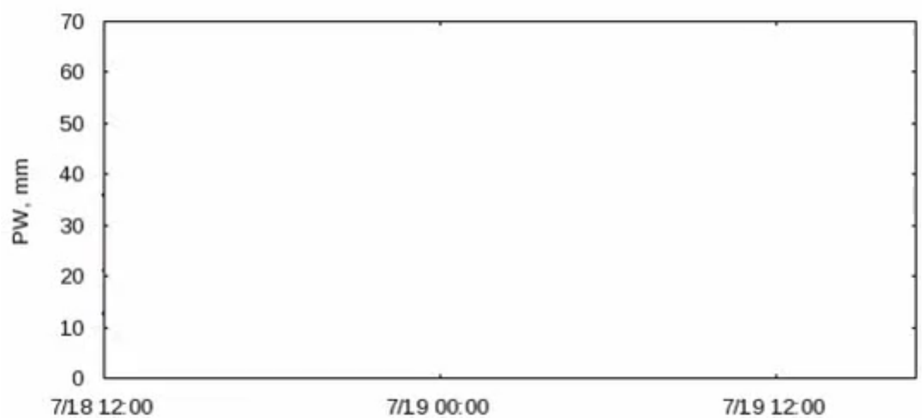
GPS-based Precipitable Water (mm)

Model Precipitable Water (mm)

Creating views of various data types, to stimulate thought on what types of displays forecasters would prefer to see in AWIPS II used for interactive viewing by NOAA forecasters

July 2013 Monsoon Event: Successful Flash Flood Warning





Forecaster remarks from NWS Weather Forecast Office in San Diego

"Realtime GPS precipitable water estimates were trending higher over eastern portions of the forecast area… a flash flood watch will be needed for Saturday"

"In order to see the character of the precipitable water values between Yuma and San Diego in the absence of a morning Yuma sounding, the GPS meteorology data was utilized."

Storm reports

"Highway 78 flooded in two locations at Yacqui Pass with 30 vehicles trapped between the two flooded locations. Many large rocks in the roadway."

"Battalion Chief flagged down by the public to report debris moving across the roadway on Sunrise Highway"

ESTO Earth Science Technology Office

Primary Accomplishments and Technical Findings: GPS Sensor Fusion and Proof of Concept

1. Completed deployment of 17 Geodetic Modules and MEMS Accelerometer packages at GPS stations in southern California – 1 Hz GPS and 100 Hz accelerometer data flowing to SOPAC server from all stations. The accelerometer data are archived at California Earthquake Data Center (SCEDC).
2. Conducted extensive testing of our Geodetic Module and MEMS Accelerometer Packages on a four-story building atop the UCSD outdoor shake table. In a series of earthquake simulations we collected more than five weeks of data on the roof and foundation of the building. Initial results indicate good performance of SIO instruments compared to observatory-grade accelerometers.
3. Incorporated data from 37stations into NOAA ESRL's ongoing operations, resulting in roughly a 50% decrease in PWV uncertainty. GPS PW estimates were assimilated hourly and half-hourly into two NOAA rapid-refresh numerical weather prediction models – nRAP with 13 km horizontal resolution and 1-hr assimilation cycle and LAPS at 3 km horizontal resolution with ½-hr resolution.
4. NOAA weather forecasters in San Diego used upgraded network to forecast a summer monsoon event in July 2013 and issue an accurate and timely flood warning (press conference at Fall AGU meeting in San Francisco). Forecasters at Oxnard have been utilizing this system since 2012 via ESRL's web page operationally and found it to be an effective tool, in some cases preferring the GPS measurements over models in making forecast decisions.
5. Meteorological prototype deployed at GPS station SIO5 validated MEMS approach for PWV estimation – preparing final package design.

Peer-Reviewed Publications

Moore, A., I. Small, S. Gutman, Y. Bock, J. Dumas, J. Haase, M. Jackson, J. Laber (2014), Densified GPS Estimates of Integrated Water Vapor Improve Forecaster Situational Awareness of Variable Moisture Fields in the Southern California Summer Monsoon, *Bull. Amer. Meteorol. Soc*. (BAMS), *in revision*.

Crowell B. W., D. Melgar, Y. Bock, J. S. Haase, and J. Geng (2013), Earthquake magnitude scaling using seismogeodetic data, *Geophys. Res. Lett*., *40*, 1-6, doi:10.1022/2003GL058391.

Geng, J., D. Melgar, Y. Bock, E. Pantoli, and J. Restrepo (2013), Recovering coseismic point ground tilts from collocated high-rate GPS and accelerometers, *Geophys. Res. Lett*., *40*, doi:10.1002/grl.51001.

Melgar, D. and Y. Bock (2013), Near-Field Tsunami Models with Rapid Earthquake Source Inversions from Land and Ocean Based Observations: The Potential for Forecast and Warning, *J. Geophys. Res*., *118*, doi: 10.1102/2013JB010506.

Bock, Y., D. Melgar, B. W. Crowell (2011), Real-Time Strong-Motion Broadband Displacements from Collocated GPS and Accelerometers, *Bull. Seismol. Soc. Am*., *101*, 2904-2925, doi: 10.1785/0120110007.

Crowell, B. W., Y. Bock and D. Melgar (2012), Real-time inversion of GPS data for finite fault modeling and rapid hazard assessment, *Geophys. Res. Lett*., *39*, L09305, doi:10.1029/2012GL051318.

ESTO
Earth Science Technology Office

Social Media Coverage - Fall AGU 2013 Press Conference (SIO/JPL/NOAA):

Press release:

http://www.jpl.nasa.gov/news/news.php?release=2013-359
https://scripps.ucsd.edu/news/14104

Press conference (youtube):

http://www.youtube.com/watch?v=rcPIShxFpvQ

Print and Internet:

http://news.discovery.com/earth/rocks-fossils/california-to-test-gps-earthquake-warning-system-131213.htm
(was on Google News front page for about a day)
http://onlinelibrary.wiley.com/doi/10.1002/2013EO520003/pdf (EOS article)
http://www.spaceref.com/news/viewpr.html?pid=42106
http://www.redorbit.com/news/science/1113025581/nasa-gps-system-detects-natural-disasters-121113/
https://www.alaskadispatch.com/article/20131211/smart-phone-technology-boosts-early-warning-extreme-weather-quakes
http://www.csmonitor.com/Science/2013/1211/Smart-phone-technology-boosts-early-warning-for-extreme-weather-quakes
http://www.technologyreview.com/news/522726/how-gps-can-keep-track-of-earthquakes-and-flooding/
http://www.natureworldnews.com/articles/5504/20140102/advanced-gps-system-will-improve-natural-disaster-warnings.htm
http://gcn.com/blogs/emerging-tech/2014/01/repurposed-gps.aspx
http://www.sciencesetavenir.fr/nature-environnement/20140102.OBS1213/la-californie-teste-ses-gps-pour-prevenir-des-catastrophes.html
http://tvnmeteo.tvn24.pl/informacje-pogoda/ciekawostki,49/szybciej-wykryja-zagrozenia-wystarczyla-aktualizacja-znanej-technologii,108262,1,0.html
http://www.spyghana.com/warning-system-natural-disaster-tested-ca/
http://www.cadenaser.com/ciencia/articulo/gps-sirve-predecir-catastrofes-naturales/csrcsrpor/20140103csrcsrcie_1/Tes
http://noticias.terra.com.br/ciencia/california-testa-sistema-de-alerta-para-desastres-naturais,5e8b681c2c253410VgnCLD2000000dc6eb0aRCRD.html
http://www.rp.pl/artykul/1076417.html
http://www.jobsnhire.com/articles/7361/20131220/nasa-scientists-developed-natural-warning-hazards-video-report.htm
http://www.ibtimes.com/nasa-scripps-use-technology-used-smartphones-boost-early-warnings-natural-calamities-floods-1508046
http://www.popularmechanics.com/how-to/blog/could-enhanced-gps-sensors-forecast-the-next-fukushima-16254459
http://www.malaysiasun.com/index.php/sid/219043143/scat/89d96798a39564bd

TV:

http://www.nbcbayarea.com/video/#!/on-air/as-seen-on/NASA-Scientists-Work-on-Predicting-Natural-Disasters/235331241
http://www.10news.com/news/new-technologies-merge-for-public-safety-010914

Radio:

http://www.bbc.co.uk/news/science-environment-25467873
http://www.bbc.co.uk/programmes/b03mff43
http://www.kpbs.org/news/2013/sep/30/san-diego-researchers-lead-the-way-in-earthquake-e/