Item VII

State of California
Seismic Safety Commission

Memo

To: Commissioners

From: Richard McCarthy
Seismic Safety Commission
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Date: 5/2/16

Subject: Final Draft Report: "Select Technologies and Capabilities to Improve Earthquake Resiliency in California", Jet Propulsion Laboratory

Background

The Commission and the Jet Propulsion Laboratory/National Aeronautic and Space Administration have been looking at several technologies and capabilities to try to help improve detection and the assessment of damage caused by earthquakes. Several technologies and a software program have been presented to the Commission several times over the last 6 months.

The attached final draft report has incorporated all the commissioners written and oral comments. An updated Executive Summary includes a brief discussion of the findings and recommendations. The findings and recommendations focus on airborne and satellite radars, infrared imagers and gas detectors, land based microwave transceivers to look for victims in debris, and a software system to develop information for use in loss estimate modeling.

Recommendation:

Staff recommends the Commission review the final draft report and approve the project as completed. Discussion by the Commission is necessary to give the staff guidance on a Phase II Project with the Jet Propulsion Laboratory.

Item VII

Select Technologies and Capabilities to Improve Earthquake Resiliency in California
(DRAFT)

Report Prepared by the Jet Propulsion Laboratory, California Institute of Technology
National Aeronautics and Space Administration

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Executive Summary

In June 2015, the Jet Propulsion Laboratory (JPL) began a collaboration with the California Alfred E. Alquist Seismic Safety Commission (CSSC) on a pilot project (Phase-I) to identify JPL technological capabilities that could help California communities and businesses mitigate loss and speed recovery in the event of natural disasters, including but not limited to earthquakes. JPL has identified several space-borne, airborne, and *in-situ* technologies that could be brought to bear in the areas of Earthquake Damage & Hazard Assessment and Search & Rescue. JPL has presented its findings to the CSSC, and will continue to collaborate with the CSSC to prioritize the technologies according to the State's needs. A proposal for a Phase-II of the collaboration will follow to tailor these technologies to the specific State's requirements. The following report summarizes JPL's findings, and is the deliverable to the SSC that marks the end of Phase-I of the collaboration.

Findings

JPL Technology	How technology would be applied by the State
Damage & Hazard Assessment	
Space-borne radar – fault detection and damage assessment	1. Assist the State in assessing the earthquake impact on critical infrastructure such as bridges, airports, hospitals and other locations pre-identified by federal, state and local partners. Space-borne radar maps would provide regional scale maps of potential damage that would assist state in locating areas in need of further reconnaissance or assistance. 2. Detailed, high spatial resolution maps of the surface ruptures caused by the earthquake would be used by state geologists and others evaluating damage to roads and other structures caused by ground fracture.
Airborne radar fault mapping and damage assessment	1. Airborne fault mapping and damage assessment would provide targeted damage assessment of critical infrastructure (e.g., Sacramento levees) at higher resolution than can be provided by space-borne radar. 2. Airborne radar surveys would provide an accurate and efficient method for assessing damage over a large area, allowing targeting of 'boots on the ground' assessment.
Airborne spectroscopy gas leak detection	Assist state in identifying and assessing gas leaks triggered by an earthquake in the days and weeks following the event.
Search & Rescue	
Locating survivors with *in-situ* radar	Assist Search & Rescue teams in locating survivors trapped in collapsed buildings following a major earthquake, helping to save more lives in the first few days following the event.

Recommendations

1. Work with LA County Search & Rescue Team to test FINDER prototype, identify required improvements based on USAR's needs, and begin implementation of improvements.
2. Develop tasking protocols for radar-based damage assessment, including data products flow and training materials to federal, state and local emergency management.
3. Develop requirements and an implementation plan for airborne gas leak detection following an earthquake.

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1. Introduction

As part of its Earth Science research activity over the years JPL has developed several remote sensing and in-situ technologies to study natural processes that shape our world and influence our environment. Although these technologies have originally emerged to address scientific research need, they proved time and again to be useful in an array of natural and man-made disaster. JPL is collaborating with the CSSC to chart a development path for application of these technologies to the specific needs of the State of California in earthquake hazard and damage assessment, and in post disaster Search & Rescue operations. In addition to the remote sensing technologies (such as radar and spectroscopy) that are used to detect subtle indicators of earthquake damage or survivors, JPL and its sponsors have also made substantial investments in the often overlooked Information Technology (IT) capabilities required in order to provide actionable data products. This IT infrastructure is critical for the low-latency generation of reliable and repeatable data products that will ultimately be used by emergency resource managers and Search & Rescue personnel. Finally, in collaboration with Federal and state organizations, JPL has recently begun developing disaster-response protocols where the above technologies can be brought to bear. These protocols are necessary to move from providing interesting science products to providing key stakeholders the information they need for disaster response in a timely, efficient, and reliable manner.

The following report is a summary of the candidate JPL technologies that were identified in the first phase (Phase I) of the collaboration, and is the deliverable to the SSC that marks the end of Phase I of the collaboration. Analysis of the technologies' performance in a series of local and global disasters is used to both highlight current capabilities, and identify future technological developments and improvements that address the State's needs as identified by the SSC. Specific suggestions on how to further advance these technologies for the benefit of the State is outlined at the end of the report. Based on the report and through following discussions with the SSC, a Phase II proposal will be submitted to the SSC with the objective of tailoring specific JPL capabilities to the State needs.

2. Findings:

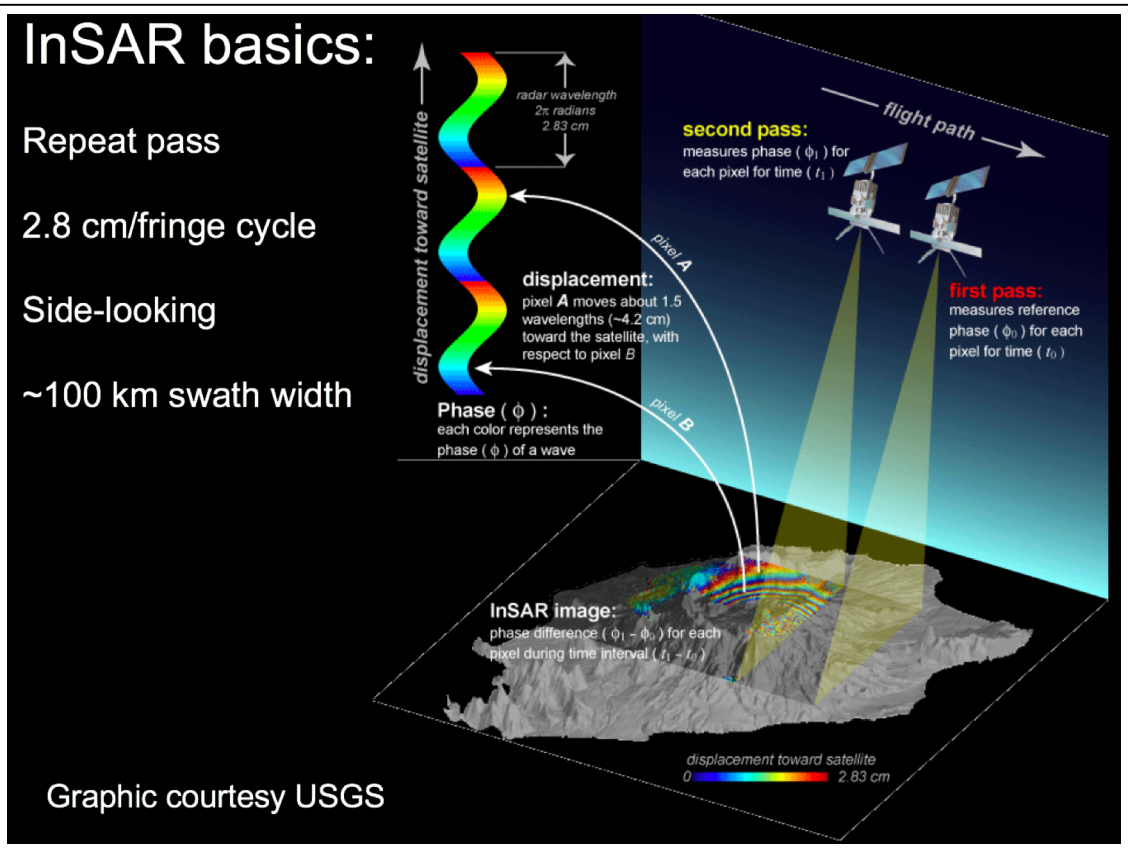
2.1. Damage and Hazard Assessment

JPL has developed several remote sensing (space-borne and airborne) technologies that are used to identify and track changes on the ground caused by earthquakes and other natural or man-made disasters. In an event of a large-scale natural disaster, these technologies offer the unique capability of making physical measurements over a large area that can be used to manage limited resources for relief and search & rescue operations. Radar techniques rely on the comparison of "before-and-after" imaging of the earthquake area, from which information such as a maps of the deformation field and the extent of the damage are produced. Airborne spectrometers are used to detect trace amounts of gas – a critical information for rapid response to post-quake toxic and fire hazards. The following is a description of the JPL technologies and data products used in the area of Earthquake Damage and Hazard assessment, including real-world examples of their use and a description of their potential use in the State of California in an event of a large earthquake.

2.1.1. Space-borne radar – fault detection and damage assessment

2.1.1.1. Technology Description

When an earthquake occurs, seismic data provides an initial estimate of magnitude and location. However, for large earthquakes, improve situational awareness can be improved by knowing the full extent of the rupture - large earthquakes result from 100's of kilometers of fault breaking, not just a point on the map corresponding to the epicenter. Rapid GPS, InSAR, and



Information Box: Interferometric Synthetic Aperture Radar. Satellite or airborne based ground observing radar measures subtle ground deformation that occurs between consecutive paths of the observing platform.

pixel tracking measurements from impacted regions combined with modeling can tell us where and how much a fault ruptured, constraining these values more reliably than is possible using seismic data alone.
Satellite-borne radar provides precise distance measurement from the flying instrument to any given point on the ground within the swath of the radar. Using knowledge of the radar satellite platform and repeating orbits, changes on the ground can be inferred. For deformation measurement a technique called interferometry is used (see information box below) to identify ground movement caused by a quake or volcanic inflation.
A key to the success of the technique is the ability to identify the same patch of ground (or pixel) between two satellite paths. This capability, referred to as 'coherence' depends on a careful data analysis that takes into account the satellite orbit, the viewing angle, the topography, and more. Whereas good coherence is required to isolate the desired ground deformation measurement from non-deformation variations that might take place between orbital paths (such as vegetation growth or atmospheric changes), in some instances it has been shown that in areas of violent shaking, localized poor coherence caused by rubble from the quake can be used as a proxy for damage (See description of application to the Nepal quake below).

Data products generation and dissemination:
The Advanced Rapid Imaging and Analysis (ARIA) Center for Natural Hazards project for Natural Hazards is focused on rapidly generating higher level geodetic imaging products and placing them in the hands of the local, national, and international natural hazard communities by providing capabilities at an operational level. Space-based geodetic measurement techniques such as Interferometric Synthetic Aperture Radar (InSAR), Differential Global Positioning System (DGPS), SAR-based change detection, and image pixel tracking have recently become critical additions to our toolset for understanding and mapping the damage caused by earthquakes, volcanic eruptions, landslides, and floods. Analyses of these data sets are still largely handcrafted following each event and are not generated rapidly and reliably enough for response to natural disasters or for timely analysis of large data sets. The ARIA project, a joint venture co-sponsored by California Institute of Technology (Caltech) and by NASA through the Jet Propulsion Laboratory (JPL), has been capturing the knowledge applied to these responses and building it into an automated infrastructure to generate imaging products in near real-time that can improve situational awareness for disaster response.

E-DECIDER, Emergency Data Enhanced Cyber-Infrastructure for Disaster Evaluation and Response, is a decision support system that combines geophysical simulations and remote sensing observations into data products for emergency preparedness and response. End users access the information through the XchangeCore[1] (product gateway), where they can browse and access the following critical products: 1) Deformation Change Detection, 2) HAZUS[2] Loss estimation and critical infrastructure information and 3) Earthquake & aftershock forecasts.
The project began in 2010 and has worked in partnership with the California Earthquake Clearinghouse and State of California partners since 2011 as part of their technology development program to bring NASA products into the state decision making framework through

[1] XchangeCore is a set of web services that: (a) translate among different web services data formats back-and-forth for a two-way exchange, (b) transform non-web service data formats into web services, (c) orchestrate Common Operational Data into content packages that assure highest relevance of the data for consumers, (d) secure agreements among providers and consumers to assure delivery of content only to authorized applications, and (e) synchronize data in real-time by notifying applications of updates to assure currency and consistency across the exchange community. (http://www.xchangecore.org)
[2] Hazus is a nationally applicable standardized methodology that contains models for estimating potential losses from natural disasters, using Geographic Information Systems (GIS) technology to estimate physical, economic and social impacts of disasters.

a number of planned exercises (coinciding with the fall Shakeout and spring Golden Guardian/Capstone exercises). E-DECIDER has also worked with FEMA and USGS in two National Level Exercises (2011 and 2014) and with the Clearinghouse in the 2015 May California Capstone/So Cal NLE/Ardent Sentry Exercises. E-DECIDER also delivered products during the Clearinghouse activation for the 24 August 2014 M 6.0 South Napa earthquake. The platform and tools leverage unique capabilities in simulation modeling, crowdsourcing, loss estimation, machine learning, image processing and geospatial intelligence for enhanced emergency response after large natural disasters and serves as a gateway for delivering actionable products to decision makers and responders. The technologies are driven by the need for rapid and accurate post-event information enabling end-users to optimally deploy limited resources during the early stages of a disaster.

2.1.1.1. Application of Technology

Response to Napa:

In response to the recent Napa earthquake (August 27, 2014) the ARIA group provided satellite-based observations that aided in situational awareness and understanding the event. Three days after the earthquake, the Italian Space Agency's (ASI) COSMO-SkyMed® (CSK®) satellite acquired their first post-event data. On the same day, the JPL/Caltech ARIA team, in collaboration with ASI and University of Basilicata, produced and released a coseismic interferogram that revealed ground deformation and surface rupture (Figure 1). The depiction of the surface rupture – discontinuities of color fringes in the CSK® interferogram – helped guide field geologists from the US Geological Survey and the California Geological Survey (CGS) to features that may have otherwise gone undetected. Small-scale cracks were found on a runway of the Napa County Airport, as well as bridge damage and damaged roads. ARIA's response to this event highlighted the importance of timeliness for mapping surface deformation features.

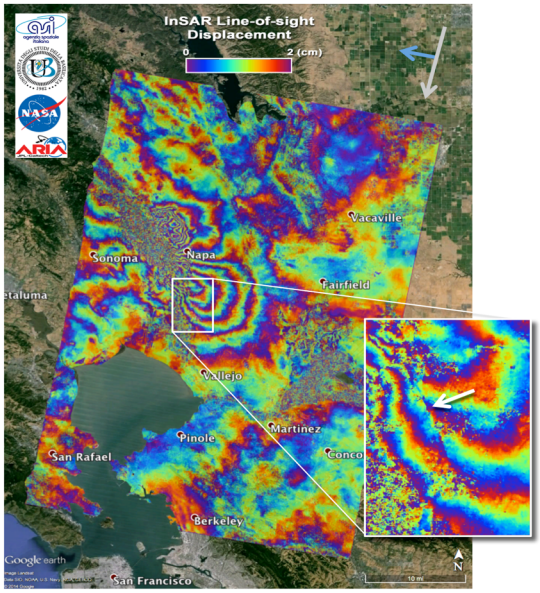


Figure 1: Interferogram of South Napa Earthquake using COSMO-SkyMed X-band data produced by ARIA. Inset image shows offset in the measured deformation that corresponded to faint surface cracks in the Napa airport runway. (Source: Yun et al., 2014.)

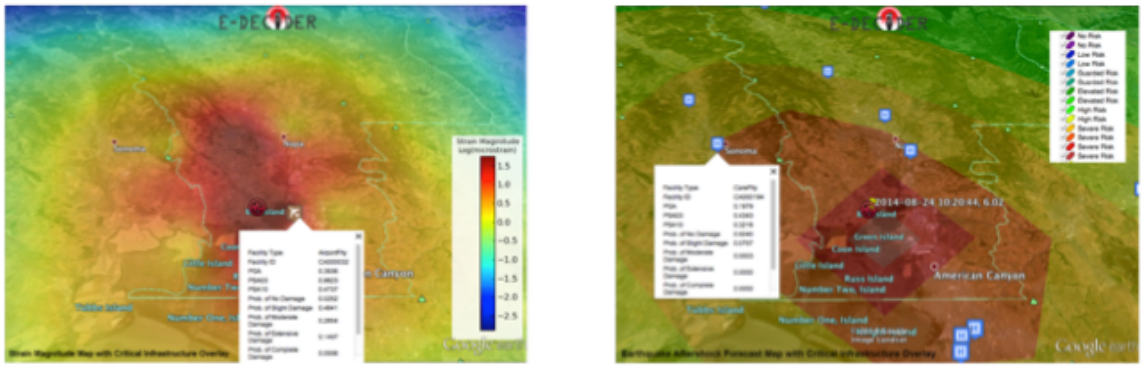


Figure 2: During the South Napa earthquake response in August 2014, E-DECIDER coordinated data sharing with Clearinghouse partners at CGS and EERI to ensure NASA data products reached post-event assessment teams.

ARIA's rapid response products were shared through the Southern California Earthquake Center's response website and the California Earthquake Clearinghouse. Finite fault slip models constrained from CSK® interferograms and continuous GPS observations reveal a north-propagating rupture with well-resolved slip from 0-10.5 km depth (Barnhart et al., 2015).

Response to Nepal:
The 25 April 2015 Mw 7.8 Gorkha earthquake caused more than 8000 fatalities and widespread building damage in central Nepal. The Italian Space Agency's COSMO–SkyMed Synthetic Aperture Radar (SAR) satellite acquired data over Kathmandu area four days after the earthquake and the Japan Aerospace Exploration Agency's Advanced Land Observing Satellite-2 SAR satellite for larger area nine days after the main- shock. We used these radar observations and rapidly produced damage proxy maps (DPMs) derived from temporal changes in Interferometric SAR coherence (Figure 3). Our DPMs were qualitatively validated through comparison with independent damage analyses by the National Geospatial-Intelligence Agency and the United Nations Institute for Training and Research's United Nations Operational Satellite Applications Programme, and based on our own visual inspection of DigitalGlobe's World-View optical pre- versus post event imagery. Our maps were quickly released to responding agencies and the public, and used for damage assessment, determining inspection/imaging priorities, and reconnaissance fieldwork (Yun et al., 2015). Through our response to Nepal, we developed a deeper understanding of the need to have discussions with groups that will be using data for damage assessment and response coordination before the event. For California, this means talking to people who work at the local, state and federal levels.

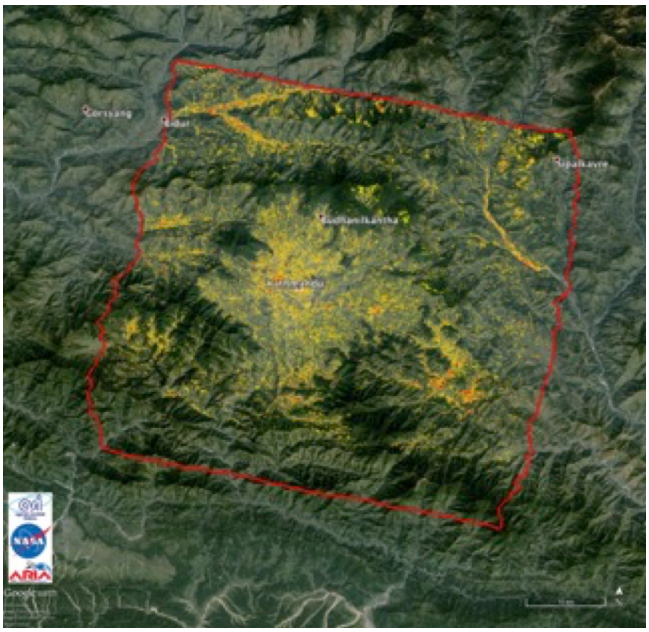


Figure 3. Damage proxy map (DPM) derived from X-band COSMO–SkyMed (CSK) SAR data and draped on Google Earth. The red bounding box is the boundary of analysis (radar footprint). Yellow to red pixels indicate increasingly more significant potential damage (Source Yun et al, 2015).

2.1.1.2. How Technology would be applied by the state

The technology will be applied by the State in two specific ways:

- It will assist the State in assessing the earthquake impact on critical infrastructure such as bridges, airports, hospitals and other locations pre-identified by federal, state and local partners. Space-borne radar maps would provide regional scale maps of potential damage that would assist state in locating areas in need of further reconnaissance or assistance.
- It will provide detailed, high spatial resolution maps of the surface ruptures caused by the earthquake, and would be used by state geologists and others evaluating damage to roads and other structures caused by ground fracture.

2.1.1.3. Future developments

JPL's partnership with the CSSC enabled the participation of JPL personnel in the May Capstone exercise that included both FEMA and CalOES players, and increased JPL's understanding of how the federal, state, and local agencies interact in response to a large earthquake. This was followed by conversations with FEMA, CalOES, and LA OEM about the damage assessment capabilities with satellite based radar. FEMALab has proposed a project that would leverage the efforts to produce the Southern California Earthquake Plan. JPL would coordinate with Los Angeles County Emergency Management, California Office of Emergency Services and FEMA Region IX to make satellite-based SAR damage assessment products useful, in appropriate post-earthquake time frame. The objectives of this project would be to:

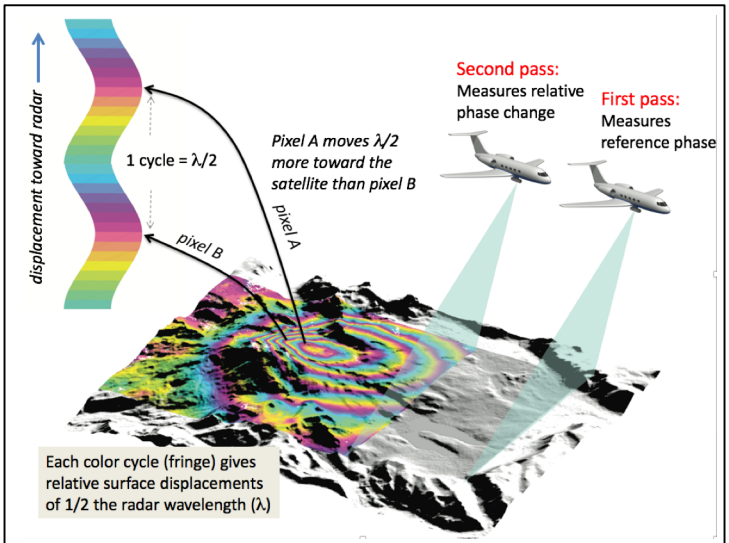
- Identify baseline infrastructure data with LA County OEM and CalOES.
- Coordinate product and process with FEMA, USGS, DHS and NASA.
  - Develop, test, train (socialize product) and exercise.
- Develop multiple agency Plan and Standard Operating Procedures.
  - Incorporate into So Cal Earthquake Plan
- Develop tasking agreements (space agencies) to be triggered by events.

FEMALab, with its experience in bringing data products into operational response scenarios, would work with JPL to design specifics tasks and milestones needed to achieve these objectives.

2.1.2. Airborne radar fault mapping and damage assessment

2.1.2.1. Technology Description

The JPL managed Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) offers the flexibility of targeted response and higher resolution than satellite based radar, which makes it particularly suited for disaster response. An airborne platform, UAVSAR can be used for rapid deployment following a disaster, without waiting for the next satellite overpass that may be days away, and can perform frequent imaging to track development of surface conditions on the timescale of hours to days, which is impossible using a satellite-borne SAR. This is important for both detecting change and determining the causal agent, for example differentiating events related to the initial rupture vs. creep or aftershocks, or due to subsequent failure of protective infrastructure.



Information Box: Airborne Interferometric Synthetic Aperture Rader SAR) Airborne based ground observing radar works on the same principle as satellite Based SAR, but offers the flexibility of more frequent paths, higher resolution, and optimal viewing angles.

2.1.2.2. Application of Technology

Earthquake deformation: JPL has applied UAVSAR to understanding crustal deformation associated with recent earthquakes in California and to the detection and location of damage. UAVSAR was used to observe the 2010 M7.2 El Mayor – Cucapah, 2014 M5.1 La Habra, and 2014 M6.0 South Napa earthquakes (Figure 4). For each earthquake geodetic imaging detected considerable slip on structures beyond the mainshock rupture zone. UAVSAR was used to detect the pattern of post-seismic motions following the El Mayor – Cucapah and South Napa earthquakes, highlighting areas of potential future fault slip. Deformation has propagated northward from the El Mayor – Cucapah rupture towards the Elsinor fault and is consistent with the location and mechanism of a M5.8 aftershock of that event. For the South Napa earthquake postseismic motion is concentrated on the primary mainshock rupture, but not on the ancillary faults that showed slip during the event.

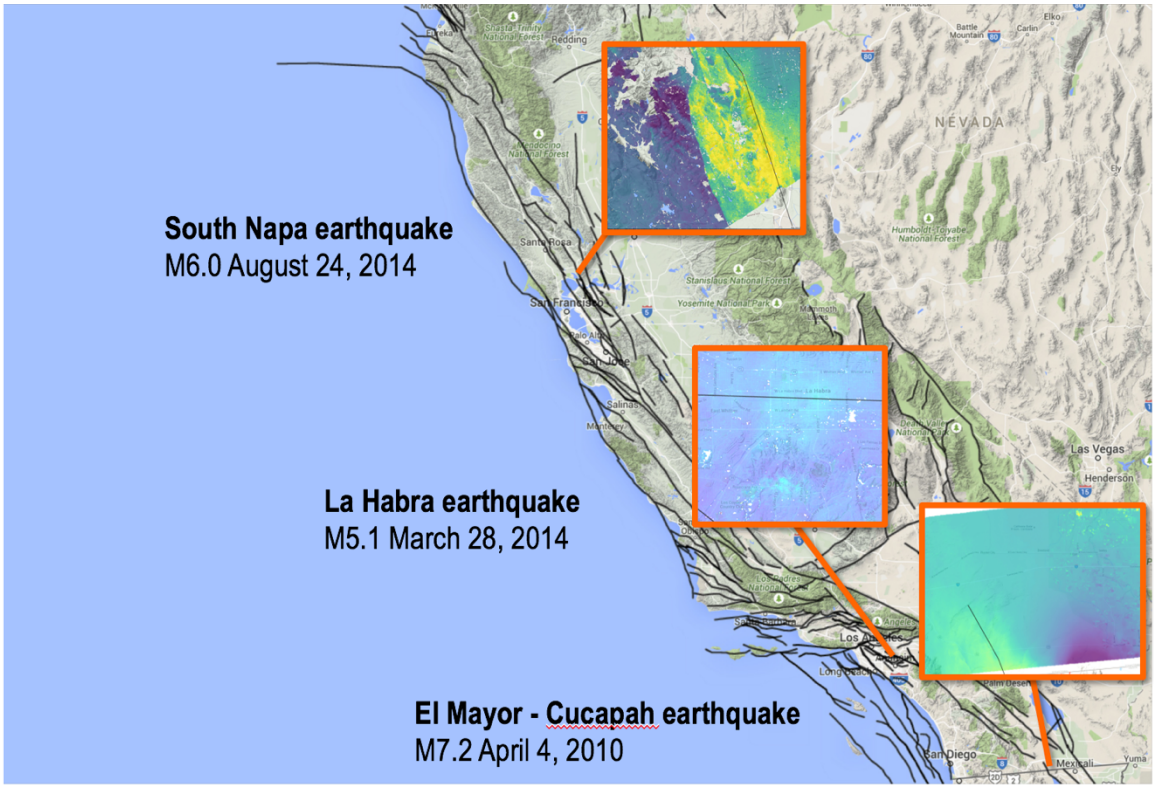


Figure 4: Recent California earthquakes observed with UAVSAR and representative interferograms from each event. The color contrast in the interferograms (boxes) reflect co-seismic and post-seismic deformation measured by UAVSAR.
In recent years, the use of synthetic aperture radar has become prevalent in observing damage to structures and infrastructure for several earthquakes in California. The kinds of damage range from minor structural damage to buildings and streets, gas and water lines in the La Habra earthquake, to detection and location of heavily damaged houses and buildings in the Napa earthquake as well as damaged roads and tilled farm lands during the El Mayor - Cucapah earthquake in 2010.

Monitoring levees in the Sacramento Delta: UAVSAR has been also successfully used to detect and monitor subsidence directly impacting the levees in the Sacramento Delta [*Jones et al., 2015*] and the California Aqueduct [*Farr et al., 2015*]. An example of levee movement is shown in Figure 5, where subsidence of the landside slope of the levee is clearly different from that of the waterside. This type of technology can be used to detect movement of the levees following earthquake and to determine whether liquefaction occurred in the islands of the Delta.

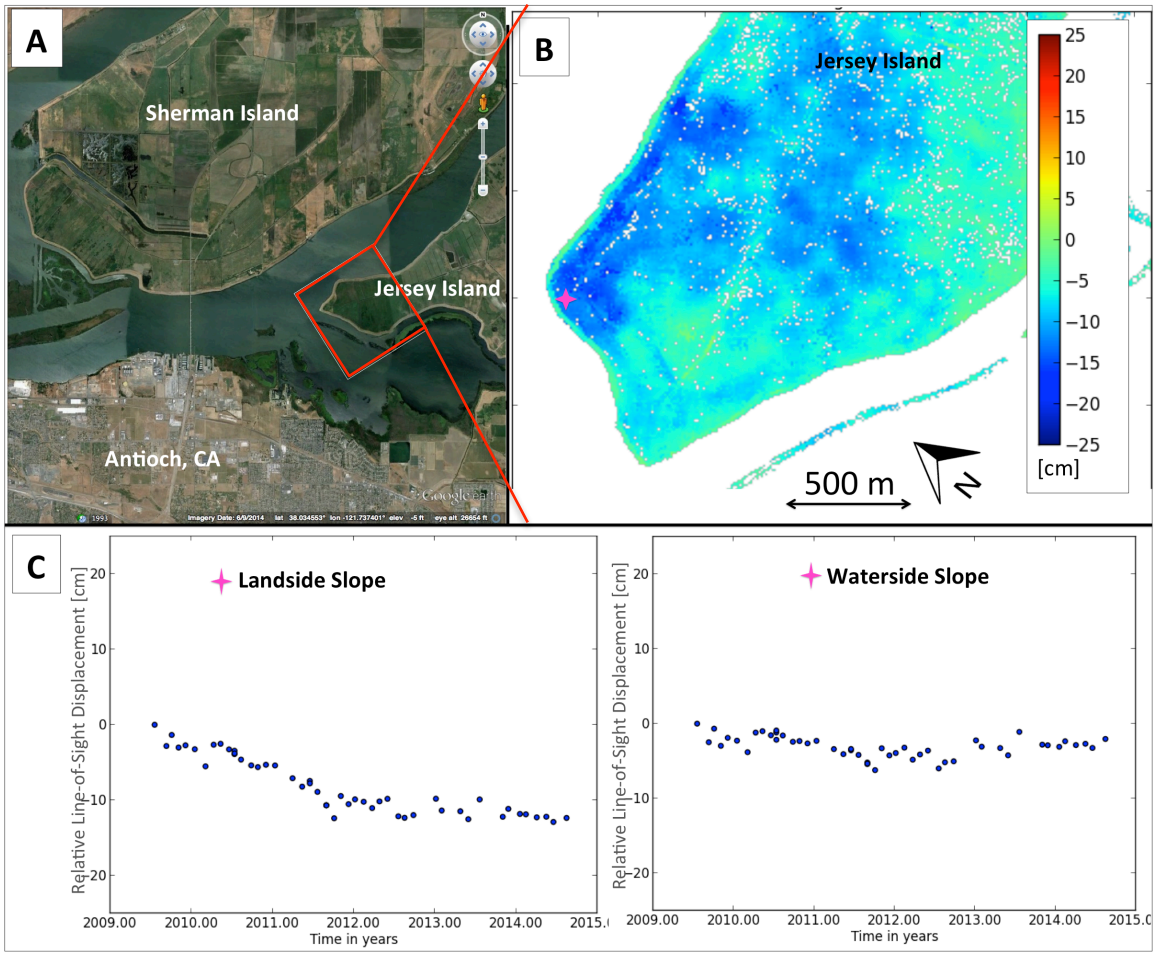


Figure 5: Example of the use of InSAR to detect differential movement between the land side and water side of a levee in the Sacramento-San Joaquin Delta. **[A]** Overview of the westernmost islands of the Delta indicating the extent of the area on Jersey Island shown in [B] **[B]** The cumulative line-of-sight displacement derived from InSAR data acquired between July 2009 and August 2014 on Blind Point Peninsula of Jersey Island. At the location indicated by the pink star, the waterside slope (light blue-green lineament outlining the island) experienced less movement than the crown and landside slope (dark blue). The increased subsidence at this location extends inland from the levee prism. White areas are masked water. **[C]** Time series analysis results for two adjacent pixels, one on the land side (left) and one on the water side (right), show that the movement trends vary significantly, with a much larger subsidence rate on the landside slope. The difference between movement on the land side and water side is not apparent along the levee to on the opposite side of Blind Point Peninsula. [UAVSAR data courtesy NASA/JPL-Caltech] [Figure from Jones et al., 2015]

An example of the type of signal expected from liquefaction is shown in Figure 6, and it is apparent that any significant liquefaction will show up clearly in InSAR.
UAVSAR can also be used to detect and monitor movement of critical infrastructure from landslides and fault rupture or creep associated with seismic hazards. Figure 6 shows movement in a landslide area just east of the Hayward Fault and adjacent to the South Bay Aqueduct. All of the examples given are measurements of slow movement, and detecting change following a major seismic event will be much easier.

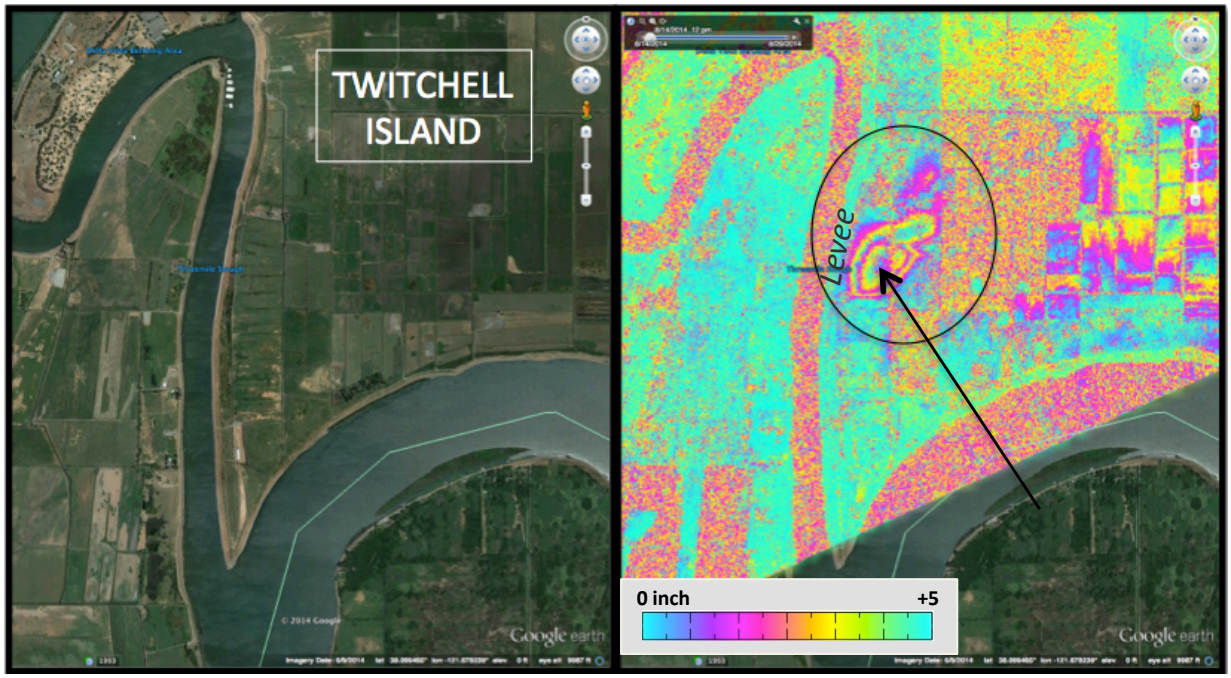


Figure 6: [left] Optical image of the Chevron Point area on Twitchell Island, California. [right] UAVSAR interferogram showing contours of surface movement experienced during the time interval in which the South Napa earthquake occurred. This is the type of signal expected from liquefaction. The surface elevation at the location indicated by the arrow decreased by >10". (Color wrap = 12 cm of movement) [UAVSAR data courtesy NASA/JPL-Caltech]

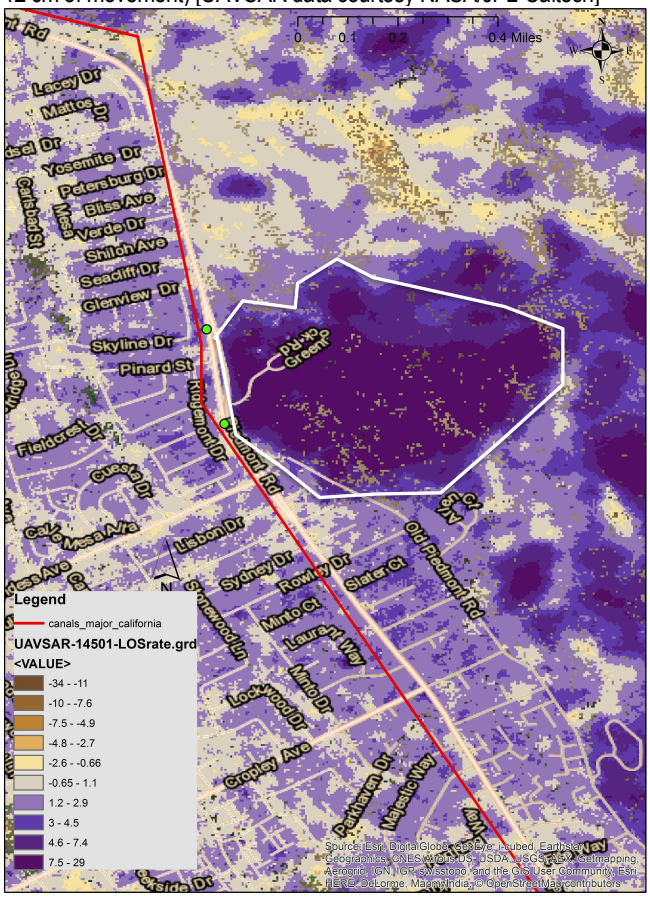


Figure 7: Rate of surface movement in mm/yr showing a slide area (outlined in white) around Greenrock Rd., Milpitas, Ca. The red line indicates the approximate location of the South Bay Aqueduct. The results show slow creep occurring between 2009 and 2015, and movement following an earthquake will be much larger magnitude. [UAVSAR data courtesy NASA/JPL-Caltech]

2.1.2.3. How Technology would be applied by the state

- Airborne fault mapping and damage assessment would provide targeted damage assessment of critical infrastructure (e.g., Sacramento levees) at higher resolution than can be provided by space-borne radar.
- Airborne radar surveys would provide an accurate and efficient method for assessing damage over a large area, allowing targeting of 'boots on the ground' assessment.

2.1.2.1. Future developments

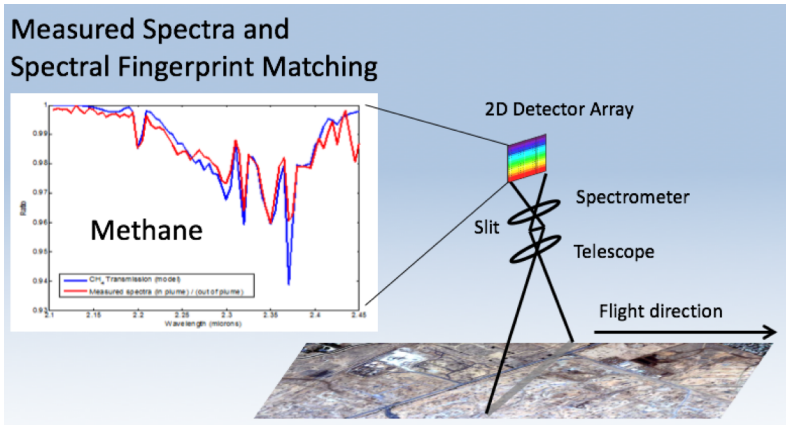
Options for Phase II project elements involving UAVSAR include:

- *Decrease actionable data-product latency:* Implementing and demonstrating a seismic disaster response on-board processing and downlink capability on the UAVSAR platform.
- *Targeted surveying (I):* Expanding the baseline imaging and measurements to coastal areas, where the locations showing landslides and fault creep have not previously been evaluated with UAVSAR.
- *Targeted surveying (II):* Collecting baseline images along critical infrastructure in California, with the selection of the areas to be made in conjunction with the Seismic Safety Commission.

2.1.3. Airborne spectroscopy gas leak detection

2.1.3.1. Technology Description

The ability to rapidly survey large areas and detect and pinpoint natural gas leaks is of critical importance immediately following an earthquake when fire hazard is extremely high. JPL has been working with the California Air Resources Board (CARB) and other agencies since 2014 to study methane leaks in the state's oil and natural gas supply chains and other sectors. JPL is currently working with CARB and the California Energy Commission (CEC) to plan a statewide survey for methane super-emitters later in summer 2016. That survey will use aircraft carrying JPL's Hyper Spectral Thermal Emission Spectrometer (HyTES) and Next Generation Airborne Visible Infrared Imaging Spectrometer (AVIRIS-NG). Multiple field campaigns with these instruments have demonstrated the ability to detect methane and other emission sources – both from controlled release tests from natural gas pipelines and previously unidentified leaks complex urban and rural environments. In the future, aircraft equipped with these instruments could provide rapid response surveys for natural gas leaks within hours to days following a large earthquake.



Information Box: Imaging Spectroscopy. A flying spectrometer is observing the electromagnetic radiation from the ground. Presence of particular gases in the atmosphere leave their unique "fingerprint" in the form of absorption bands in the radiated spectrum.

2.1.3.2. Application of Technology

Hyper-spectral Thermal Emission Spectrometer (HyTES): HyTES is an airborne instrument capable of detecting trace gas emissions from sources on the ground. These sources range from industrial, agricultural or waste management processes as well as leaks from natural gas pipelines, processing and storage facilities. HyTES can detect invisible plumes of methane (CH_4), hydrogen sulfide (H_2S), ammonia (NH_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). It typically flies at low altitude (typically around 1000m) in a Twin Otter or equivalent aircraft (Figure 8) and captures a swath nearly 1km wide. Its spatial resolution is 1-2 meters which is sharp enough to pinpoint the location of individual plumes in crowded scenes and provide context of surface infrastructure and land features (see Figure 9). As a thermal infrared instrument HyTES can operate day or night and provide surface temperature maps in addition to trace gas images.

Figure 8: HyTES on a Twin Otter aircraft.

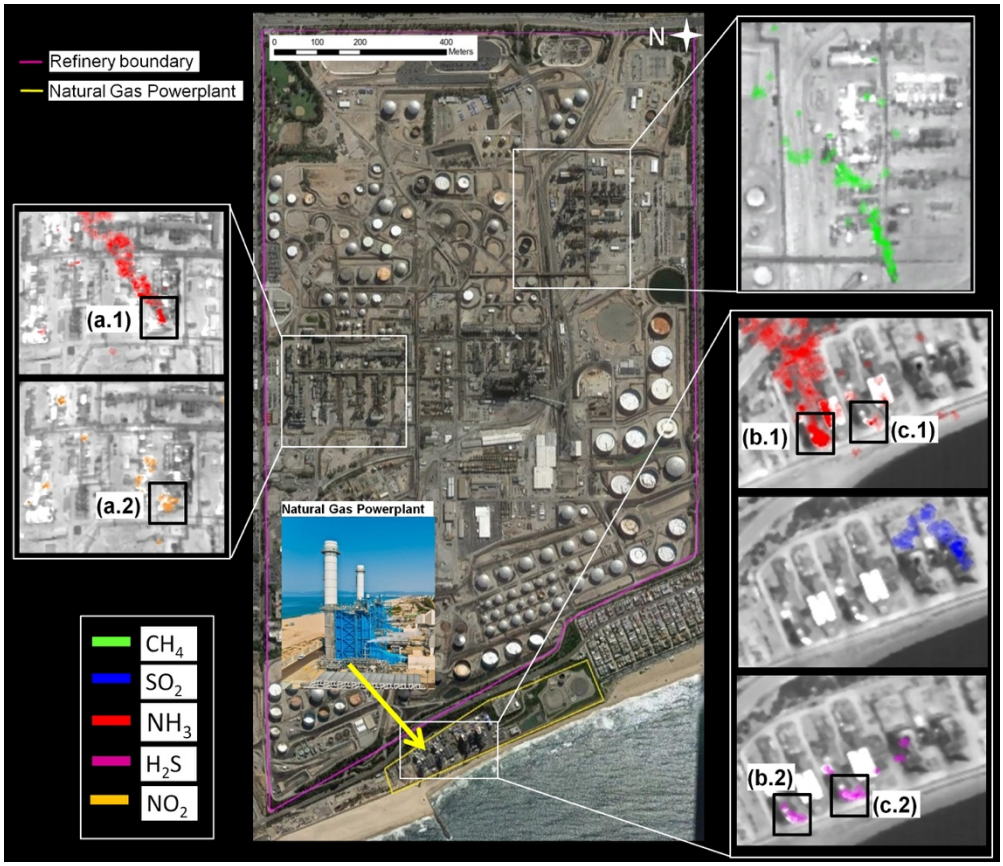


Figure 9: A HyTES multi-species gas (CH_4, NO_2, NH_3, H_2S, and SO_2) detection example from a single flight over a refinery (magenta outline) and a natural gas power plant (yellow outline)in Los Angeles. The insets show gas plumes highlighted in different colors and overlayed on surface temperature data in grayscale. NH_3 and NO_2 were detected over the refinery at the location **a.1**,/**a.2**, while at the natural gas powerplant, NH_3 and H_2S were detected at location **b.1**/**b.2**, and **c.1**/**c.2** respectively. Small plumes of SO_2 (blue) can be seen within the power plant complex. A distinctive CH_4 plume was detected in the southeastern region of the refinery. [Hulley et al 2016]

The ability of HyTES to detect methane and other trace gasses has been repeatedly demonstrated for over 200 emission sources during several weeks of aircraft field campaigns over the South Coast Air Basin and the San Joaquin Valley in 2014, 2015 and 2016 (three examples shown in figure 10).

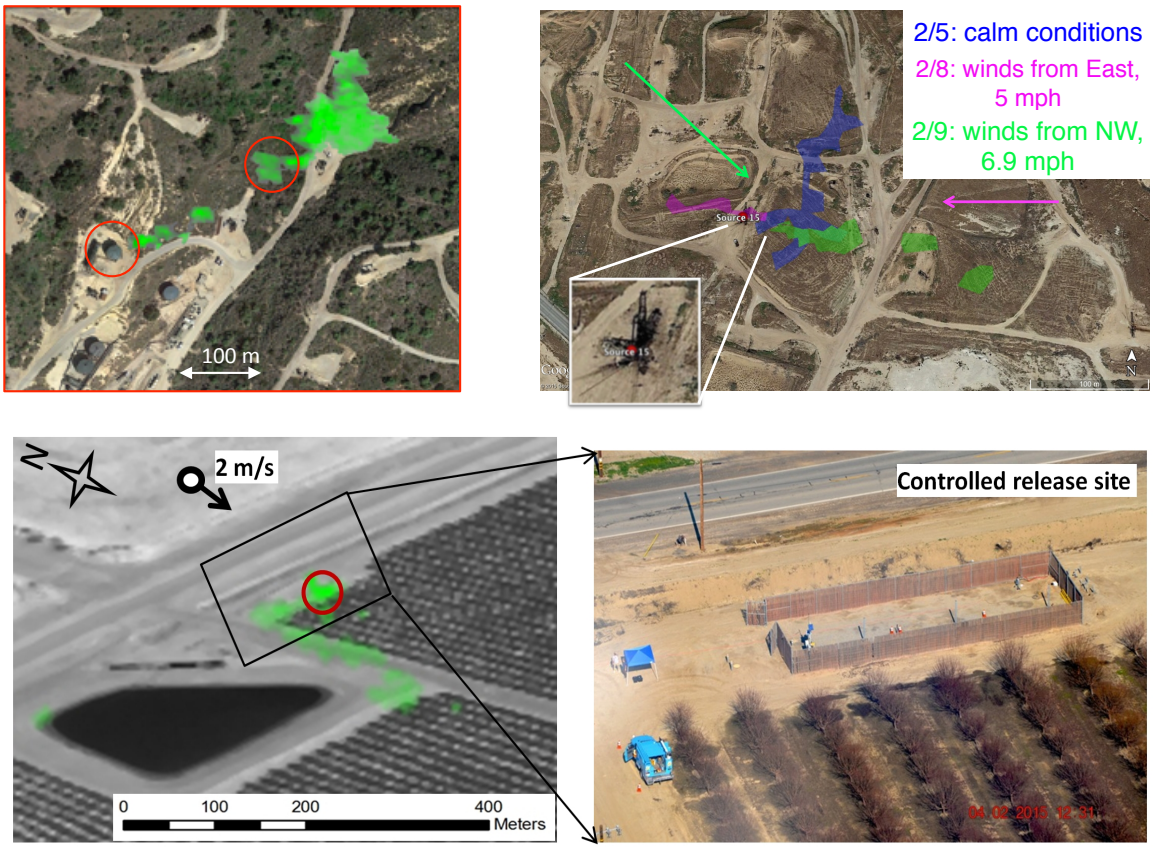


Figure 10: Examples of methane plumes detected by HyTES from leaking oil wells and storage tanks in the Los Angeles basin in 2014 (upper left), an oil well near Bakersfield for three different days and wind conditions (upper right), and a natural gas pipeline controlled release experiment in 2015 (bottom). [Hulley et al 2016]

Next Generation Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-NG):
AVIRIS-NG is a unique optical sensor that delivers calibrated images of the upwelling spectral radiance in 427 contiguous spectral channels (bands) with wavelengths from 380to 2510 nanometers. AVIRIS-NG has been flown on different aircraft platforms and a wide range of altitudes but for methane surveys it typically operates on a Twin Otter type aircraft at 1500-3000 meters, resulting in spatial resolutions of about 1.5-3 meters. It has been used to detect hundreds of methane sources in Colorado, New Mexico, and California's San Joaquin Valley in multiple campaigns in 2014 and 2015 (see examples in Figure 11).

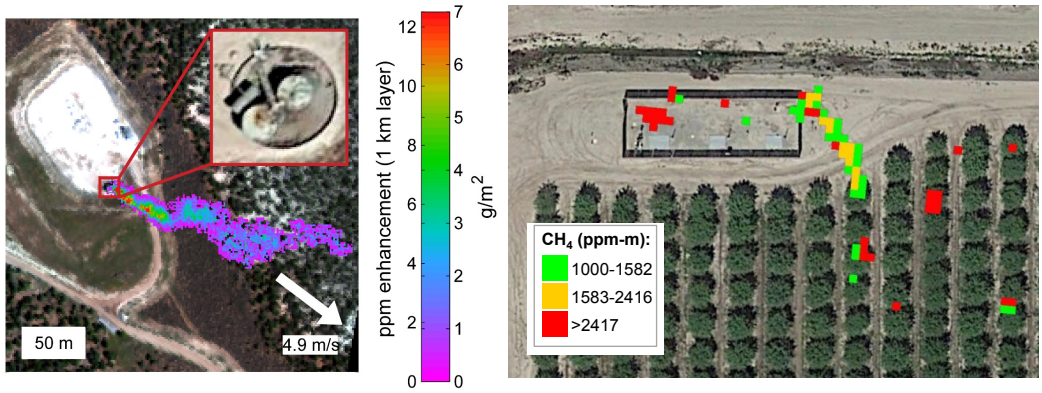


Figure 11: Examples of methane plumes detected by AVIRIS-NG from gas wells in Colorado (left) and a natural gas pipeline controlled release experiment near Bakersfield, California in April 2015 (right).

AVIRIS-NG has also demonstrated real-time methane gas detection in a case study of the NASA/ESA CO_2 and MEthane eXperiment (COMEX) campaign in California during June and August/September 2014. COMEX was a multi-platform campaign to measure CH4 plumes released from anthropogenic sources including oil and gas infrastructure. This is the first reported use of real-time trace-gas signature detection in an airborne science campaign, and presages many future applications (Figure 12). This capability was demonstrated again during another campaign in the San Joaquin Valley in April 2015.

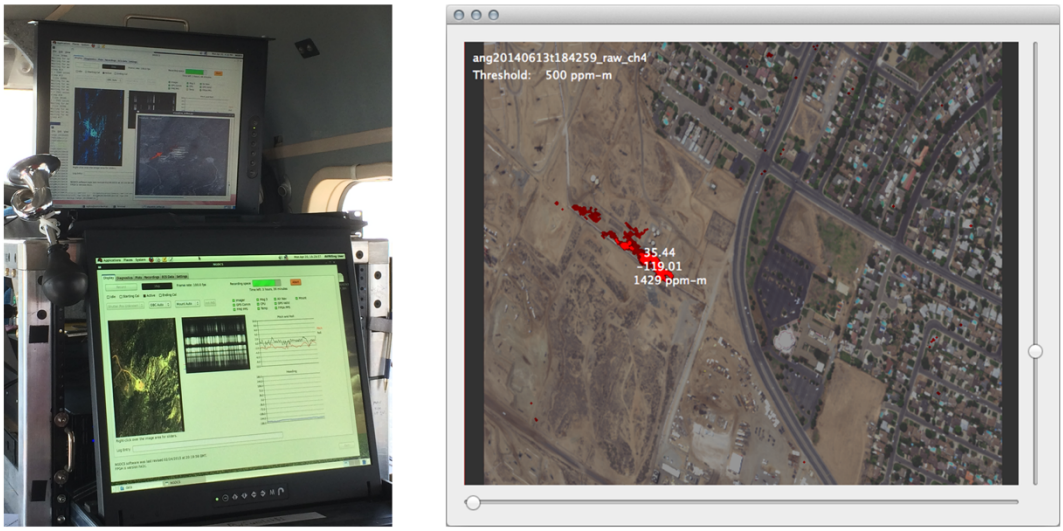


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Figure 12: AVIRIS-NG graphical user interface onboard the aircraft (left) with an example of a methane source - red plume overlaid on a visible image of an oil field – acquired in 2014 (right). The preliminary source coordinates and plume strength information were relayed to ground personnel in real-time to support rapid follow-up confirmation. [Thompson et al 2015]

2.1.3.3. How Technology would be applied by the state

JPL's airborne spectrometers would assist the State in identifying and assessing gas leaks triggered by an earthquake in the days and weeks following the event.

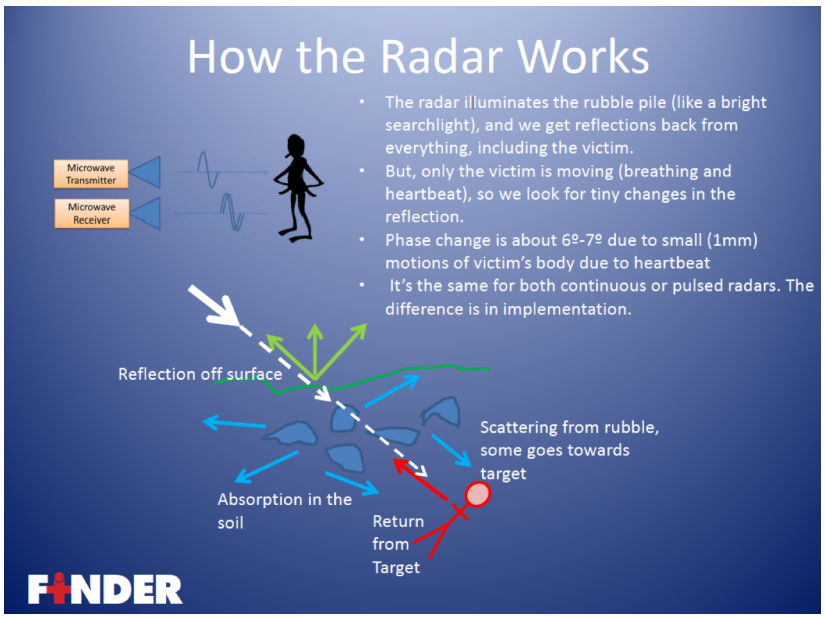
2.1.3.4. Future Developments

JPL is working with CARB and CEC to plan and conduct a systematic survey of methane super-emitters over a roughly 25,000 km^2 using the airborne imaging spectrometers described here. That survey will be conducted over roughly two months in late summer 2016 and focus on key areas in southern, central and northern California to provide a baseline assessment of major emission sources. JPL is also working on next generation versions of these instruments to optimize their methane sensitivity (towards detecting smaller emissions over larger areas more quickly) and also developing more operational, low latency data processing systems that could offer rapid communication to first-responders and other stakeholders.

2.2. Search & Rescue

2.2.1. Finding Individuals for Disaster and Emergency Response (FINDER)

2.2.1.1. Technology Description



Information Box: How FINDER WORKS?

NASA/JPL and the U.S. Department of Homeland Security are collaborating on a first-of-its-kind portable radar device to detect the heartbeats and breathing patterns of victims trapped in large piles of rubble resulting from a natural disaster such as an earthquake or tornado. The device is based on remote-sensing radar developed by JPL to monitor the location of spacecraft the Laboratory manages for NASA. In disaster scenarios, wreckage is made up of twisted and shattered materials, so radar signals reflecting back are tangled and hard to decipher. JPL's expertise in data processing helped with this challenge, as advanced algorithms isolate the tiny signals from a person's moving chest. The prototype technology, Finding Individuals for Disaster and Emergency Response (FINDER) can locate individuals buried as deep as 30 feet (about 9 meters) in crushed materials, behind 20 feet (about 6 meters) of solid concrete, and from a distance of 100 feet (about 30 meters) in open spaces.

FINDING INDIVIDUALS FOR DISASTER AND EMERGENCY RESPONSE

Jet Propulsion Laboratory
California Institute of Technology

FINDER is a prototype heartbeat detection radar designed to detect victims buried in rubble. It broadly illuminates the rubble with a low power radio signal and detects the small changes in the reflected signals due to respiration and heartbeats. The data collection requires that the FINDER unit be stationary on the ground for 30 seconds. After data is collected, the FINDER can be moved while the radar data is being processed.

Specifications

Processing time:
Power on and boot time: 60 seconds
Re-calibration time: 30-60 seconds
Search takes 30 seconds for data capture and then 30-60 seconds to process data.

Sensing angle:
90 degree included angle vertical and horizontal toward front
Bystanders detected to sides and back and removed from victim results list.

Radio Frequency Parameters:
Frequency: 3.1-3.4 GHz
Radiated Power: 1 milliWatt

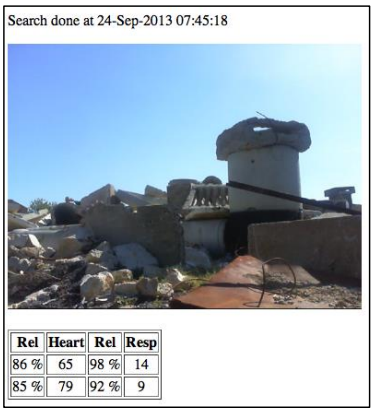
User Interface:
3 buttons on Tablet
(Power On/Off, Cal/Setup, Search)
Display analysis results with photo and GPS coordinates

Demonstrated performance:
70-80% detection (20-30% false negative) when 3-6 meters from rubble with 1-2 human victims buried 8-10 meters deep, with 2-3 operators and no other bystanders. Detection performance optimized for rubble in open pile.

Rechargeable Battery Life:
14 hours or 200 searches/calibrations whichever comes first (15 searches/hour)

FINDER unit:
- Pelican model 1510 case
- 22x14x9" (fits in overhead bin on all airlines)
- 25 lb total weight (w/batteries)

Tablet Computer used for control:
- Panasonic H2 Toughbook
- 11x11x3" , 3.5 lb
- Windows 7 Pro



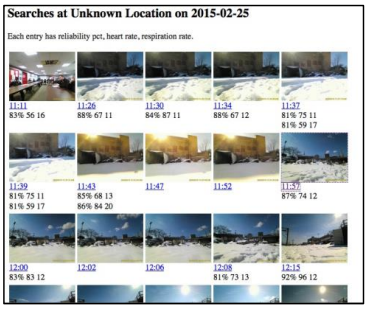


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Figure 13: FINDER Specs

2.2.1.2. Application of Technology

Response to April 1015 Nepal Earthquake: FINDER had its first successful Search & Rescue demonstration during the 2015 Nepal Quake (Figure 14), successfully rescuing four survivors trapped in rubble.

Figure 14: The Finding Individuals for Disaster and Emergency Response (FINDER) prototype technology was used to locate individuals buried under rubble in disaster scenarios. David Lewis, president of R4, Inc., took two FINDER prototypes to Nepal to assist in rescue efforts after the April 25, 2015, earthquake. This photo was taken on April 29 in Kathmandu. Credit: David Lewis, R4 Inc.

2.2.1.3. How Technology would be applied by the state

Working with Los Angeles County Urban Search & Rescue (US&R): FINDER's performance is scenario specific, and can be adapted to specific situations depending on the requirements and operation scenarios of the S&R agency. In Phase I of this project JPL has begun the preparation for a real-world field test with Los Angeles County Urban Search and Rescue team in the coming months. A sample unit, courtesy of SpecOps – a licensed commercial manufacturer of FINDER, was brought by JPL personnel to LA County US&R Task Force 2 and was discussed with the team leaders. Arrangements were made to have two FINDER units + training provided by SpecOps in advance of participation in a S&R drill in the May 2016 timeframe.

2.2.1.4. Future Developments

As described above, JPL in collaboration with SpecOps and LA County US&R Task Force 2, are preparing for a field test during a building collapse drill in the April-May 2016 time frame. JPL will assign FINDER technician to accompany the S&R personal and document their finding and specific needs for modification. Several items have already come up in discussion as possible candidates for further development: Miniaturization, Drone deployment, triangulation with multiple units, and distance to target detection.

3. Recommendations

Work with LA County Search & Rescue Team to test FINDER prototype, identify required improvements based on USAR's needs, and begin implementation of improvements.
In Phase II, JPL would work with the US&R task force to prioritize FINDER potential improvements, and begin development on the highest priority items.

Develop tasking protocols for radar-based damage assessment, including data products flow and training materials to federal, state and local emergency management.
The JPL airborne radar and spectrometers are considered NASA research instruments. Consequently, their usage is prioritized by the needs of the NASA scientific community as determined by the respective NASA Science offices and the availability of NASA flight platforms as determined by the NASA Airborne Program office. On occasion, these instruments are deployed in response to a pressing need brought on by a natural disaster. Nevertheless, no protocol exists at this time for rapid airborne deployment of NASA's radars and spectrometers. The objective of a phase II study would be to make the JPL instruments and data products available for the State of California in time of crisis. A Phase II task could see JPL working with the CSSC to develop the State-specific protocols including emergency flight paths authorization, State-NASA-JPL rapid deployment decision process, the fitting and use of State-owned aircrafts, and actionable data products flow-down.

Develop requirements and an implementation plan for airborne gas leak detection following an earthquake.
The multiple deployments for methane and toxic gas leak detection and monitoring by HyTES and AVIRIS have provided a clear path for usage of JPL airborne spectrometers in crisis management. In addition, planning was already underway, for JPL to conduct a statewide methane survey this summer with the AVIRIS and HyTES instruments for the California Air Resources Board and Energy Commission. In Phase II, we would propose to further explore the disaster-response needs of the State for gas leak monitoring, and work with the SSC to produce a requirements document for the State of California post-seismic event gas monitoring. We shall then explore with the State the optimal and affordable approaches to fulfill these requirements in the coming years.

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