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From: Raymond Willemann [mailto:ray@iris.edu]
Sent: Tuesday, March 08, 2011 10:15 AM
To: info@nehrp.gov
Cc: David Simpson; James Gridley; Robert Woodward; David Applegate; Hayes, John(Jack) R.
Subject: FlexiRAMP

This material is submitted for consideration by the Advisory Committee on Earthquake Hazard Reduction during its meeting on March 10-11, and while it prepares its Annual Report for 2011.

With best regards,

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Aftershock recording systems can make several important contributions to reducing risk from earthquakes by contributing to fault rupture models that are used in evaluating predictions of ground shaking, collecting data for research to develop a comprehensive physics-based understanding of earthquake phenomena, and providing an aftershock early-warning capability. One important new development in the past year is planning for a new pool of flexible instruments that can be rapidly mobilized to deploy a dense array of seismic stations. If NSF or USGS funds development of a new Flexible Rapid Array Mobilization Pool (FlexiRAMP) a much larger number of instruments will be available so that future aftershock recording deployments can meet the station density and data quality requirements of modern seismology.

One approach to maintaining a much larger pool of aftershock instruments than has existed in the past would be to deploy FlexiRAMP instruments for other research projects, but in ways that facilitate rapid retrieval and re-deployment. By securing a high scientific return from regular use, FlexiRAMP would justify long-term operation of a large pool of instruments. A white paper on FlexiRAMP is submitted for ACEHR's consideration. Further discussion of the FlexiRAMP concept is anticipated at IRIS's 2011 Instrumentation Technology Symposium on June 16-17 in Albuquerque, NM.

In addition to aftershock recording, FlexiRAMP would be suitable for use in other circumstances where a quickly developing situation creates an unplanned need for measuring seismic activity. Examples include earthquake swarms near volcanoes and near deep injection sites for enhanced gas recovery or carbon sequestration. FlexiRAMP instruments might also be used in realistic deployment exercises that are part of multi-hazard response demonstrations.

Attachment: FlexiRAMP White Paper

Draft White Paper
FlexiRAMP

A Flexible Array for Rapid Array Mobilization Program

1 Objective

As the recent earthquakes in Haiti and Chile demonstrated, a large earthquake is often followed by aftershocks with the largest being one or two unit magnitudes smaller than the main shock. If a large network of seismic stations can be installed rapidly in the mainshock region we could capture large events at much greater resolution than has been possible previously with permanent networks. For example fifty EarthScope broadband stations were shipped to Chile one month after the 2010 M=8.8 earthquake. The largest aftershock, so far, has been an M6.9 event, which occurred one week after the mainshock. The earthquake ruptured 750 km of the plate margin, which means station spacing, if linear, will be about 15 km. Seismic waves lose spatial coherence after a station separation of a wavelength. Therefore to capture correlated high frequency radiation requires much smaller spacing of less than a km.

The goal of FlexiRamp is to install an order of magnitude more stations (500-1000) in an aftershock zone for high-resolution measurements. The stations are required to be of sufficiently simple design that they can be installed rapidly, and capture the largest aftershocks, the probability of which decays rapidly (1/t) after the event. In between major earthquake aftershock sequences, a fraction (e.g. 75%) the equipment will be used in flexible array mode, thereby ensuring expensive equipment is being used for scientific discovery and that a pool of qualified operators are ready and trained for major deployments after a large event.

2 Science Goals

2.1 The Earthquake Source

As currently used, the majority of PASSCAL equipment is used for seismic path experiments. By introducing a FlexiRAMP component we would involve those that model the source. For example Jean Paul Ampuero, Caltech has presented scientific goals that a FlexiRAMP network comprised of high resolution sub-arrays would address. At present source tomography is limited by station spacing and insufficient knowledge of the medium. With typical station spacings of over 10 km, the highest frequencies that can be back-projected onto the fault are less than 0.5 Hz giving resolution of 5 to 10 km on the fault plane. Owing to this coarse resolution, a kinematic rupture model is often assumed, e.g., an expanding or traveling rupture patch, with the source tomography giving moment rate. Source modelers have found that kinematic and dynamical sources have very different ruptures (TeraShake simulations) with the dynamic ruptures having a much rougher distribution of moment release, with both forward and backward propagating rupture, super shears, and directivity that decreases at higher frequencies. A high resolution array in the nea-field of an earthquake can be beam formed to track the source as was done using the HiNet Japanese array to track the Sumatra Andaman earthquake, and which gave rise to the first accurate estimates of its size and moment release.

2.2 Path studies

The difficulty of measuring properties of the source is that the high frequency coda are a combination of source effects and scattering effects along the path. High-resolution networks offer the only possibility for making this separation. For example small events can be used as empirical Greens functions to estimate scattering coda. Beam forming can be used to discriminate back scattering from source generated signals. In addition local earthquake tomography can be used to determine fine details of structure.

2.3 Seismicity

The evolution of seismicity in an aftershock zone is of considerable theoretical interest. Are aftershocks triggered dynamically as Emily Brodsky thinks, or by static stress change as Ross Stein has advocated? Is the distribution of aftershocks a representation of the heterogeneity of the main shocks with multiple branches of rupture, that set up a volume of stress concentrations? High-resolution FlexiRAMP measurements offer a test of the ETAS model (Epidemic Type Aftershock Sequence, Ogata, 2001). The ETAS model describes earthquakes as a stochastic branching sequence of triggered events. It was used successfully last year, after the April 6, 2009, Friuli earthquake in Italy, to predict where damaging aftershocks would occur, but stations were too few and too widely spaced, to make detailed measurements. Given this new paradigm, after a large earthquake, for example in the western US, Mexico, or Peru one could install the FlexiRAMP to record the thousands of aftershocks that occur. If the largest aftershock in a sequence is 1 magnitude smaller than the main shock, e.g., a magnitude 8 is followed by a magnitude 7 one can use the network to detect how the shocks leading up to the M=7, are distributed in space and time, with the objective of developing ETAS prediction algorithms based on seismicity.

2.4 Structural Engineering and Damage

As well as installing free field networks, a portion of the equipment will also be installed in buildings and infrastructure such as on bridges and dams. This will provide engineering data on design factors, necessary for buildings to remain operational after earthquakes, that are critical for saving lives and minimizing economic impact. Structural damage is often heterogeneous during a mainshock. As well as caused by amplitude of acceleration other factors such as site effects, focusing defocusing, liquefaction, basin resonances come into play. A FlexRAMP deployment can help to understand the origin of heterogeneous damage.

3 Description of FlexiRAMP

3.1 History

The idea of assembling an array of easily deployable instruments for aftershock studies has been developed at two workshops, one at the EarthScope meeting in 2008 and a second sponsored by IRIS at the SSA meeting in 2009. Representatives of the science community that study both the seismic source and path met with instrument manufacturers to discuss suitable instrumentation for aftershock monitoring. One of difficulties of RAMP deployments has been the idea of having expensive equipment sitting on a shelf unused. Another aspect is that the time to install a broadband station is on average 1 day and so installing 500-1000 stations in a timely manner would be very difficult. Also it was felt that as many stations as possible be wirelessly linked to a central computing system so that the region can be monitored in near real time and in some deployments capable of real time warning.

3.2 Flexible Arrays as part of FlexiRAMP

To get around the cost issue it was proposed that some large fraction of the equipment pool be used by researchers as Flexible arrays is the same manner that the Flexible Arrays of EarthScope have covered the country, albeit for FlexiRAMP at higher resolution and smaller scale. Users could investigate local targets such as magma chambers, structural geology, trapping, scattering and focusing of seismic waves, harmonic tremor. However the loan of the equipment would be contingent on an agreement to demobilize at the time of a large event and contribute to the RAMP pool that would be installed. For example, of 1000 units 750 might be on loan, with 250 at PASSCAL which would go immediately to the aftershock zone. The remainder would be pulled from the field and would follow. Given human nature, not all will make it, but with easily deployable and therefore easily demobilized instruments, a good percentage might be expected – and some loans canceled if a good faith response was not evident. The advantage of this scheme is that there will be a constantly trained pool of operators, software development, and science done with an expensive resource. When all the instruments are brought together, otherwise unobtainable science can be achieved.

3.3 FlexiRAMP Specifications

From the above we have proposed a hierarchical array with stations that complement but not duplicate the present broadband pool. One might envisage some of the broadband pool will be installed, as in Chile. But for rapid installation simpler systems are needed. We have suggested that seismometers such as the L4C or L22 would be a good choice for high resolution work where long periods are not so necessary. Their chief advantages are ruggedness and their not requiring power. These are weak motion instruments should be paired with strong motion seismometers. MEMS seismometers may be attractive to complete the dynamic range from 10^{-10} g to 2 g. The unit should be able to survive on batteries for 1 week and on small solar panels indefinitely. It should have wireless and/or cell communication.

The unit specifications may be summarized as:

Seismometers:	3 channels weak motion short period, passive seismometers – or low noise MEMS 3 channels Strong motion, very low power, active, MEMS
DAS	6 channels A/D less 0.5 Watts, Wireless, GPRS capability, GPS, 200 sps up to 1000 sps, On board storage full experiment (GBytes)
Battery	Lead acid or Lithium 20 Amp Hr
Software	Event detect, duty cycle RF, Meshed networking, Array event detect, Real time warning capability
Design	Single unit with MEMS/WIRELESS/GPS on board and seismometer, solar panel, antenna attached. Simplicity in installation and networking essential (e.g., throw out of the back of a truck)

4.1 Proposal FlexiRAMP Shootout

The nodes described above will cost about $10k apiece. One thousand would be close to ten million. Before this level of investment could be justified it would be prudent to have demonstrations of proof of concept. If funds can be raised (e.g., 0.5M) in the IRIS proposal an RFP could be submitted to instrument manufacturers and designers (Quanterra, Refrek, Trillium, Guralp, Strekeisen, Quakecatchers …) to submit small networks of instruments that cover the FlexiRAMP specifications above. Then IRIS personnel and non-conflicted PIs would coordinate a shootout in an active aftershock region, as well as some flexible array studies before settling on a final design.

4.1 FlexiRAMP Operations

The PASSCAL Instrument Center would be the home for the instrumentation, but for the Flexi instruments it may be practical to have as their second homes the existing instrument sub-centers, e,g, SCEC, Berkeley, U Washington, and Midwest and east coast, say 150 at each. These details need to be ironed out, but NEES has a similar approach and these sub-centers should be coordinated.

5. Conclusions

We cannot predict earthquakes in a narrow volume of space (kms) and time (days) other than a general forecasting of when (years) and where (hundreds of km) they are likely to occur. We have, however, achieved great success in engineering structures or retrofitting them to withstand shaking, but even there, as recent events have shown, there can be surprises. The **objective** is to understand the basic physics of earthquakes and their effects. With the information we seek, we propose to understand and possibly predict aftershocks and use that information to eventually predict main shocks. Because main shocks at a given location happen about every 200 years, it has been impossible to build up statistics on possible precursors. Modern understanding of the earthquake source is that an aftershock sequence is a time-compressed version of long term seismicity. If there are repeatable predictive behaviors before an event, an aftershock zone is where we are most likely to measure them. By knowing the time and location of a large aftershock, as well as giving warning, we can instrument buildings and infrastructure to measure structural failure during strong shaking.

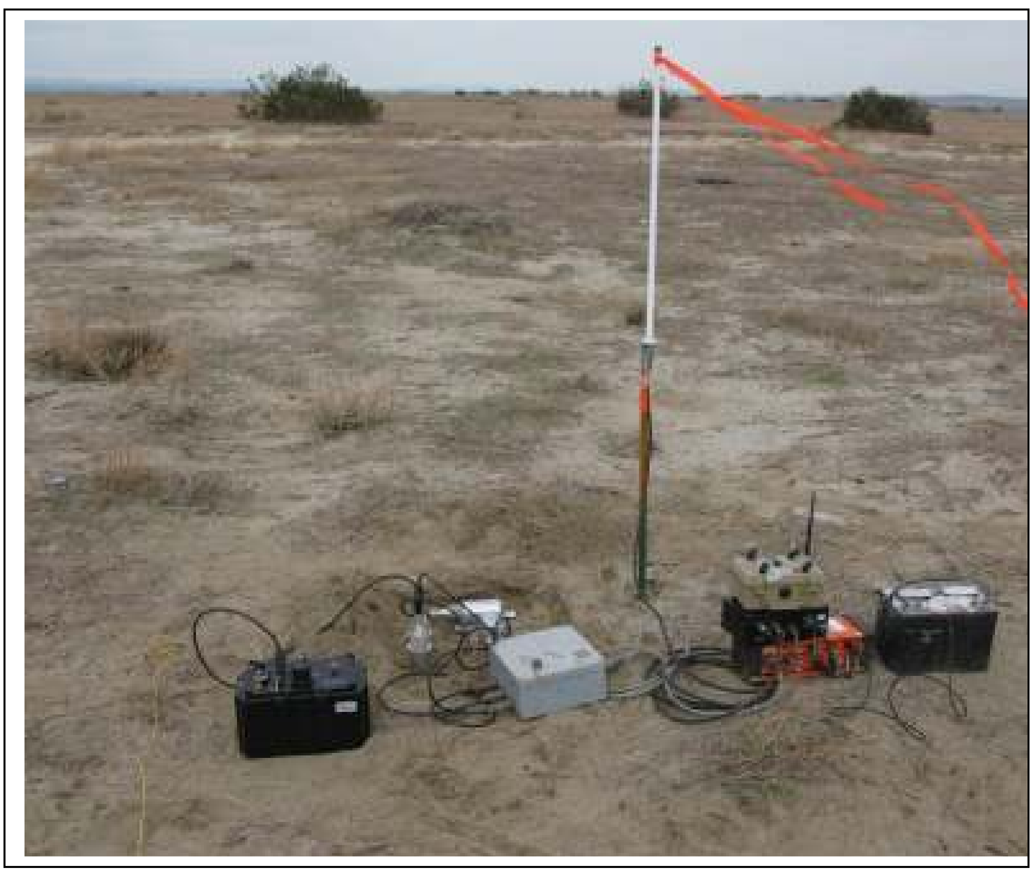
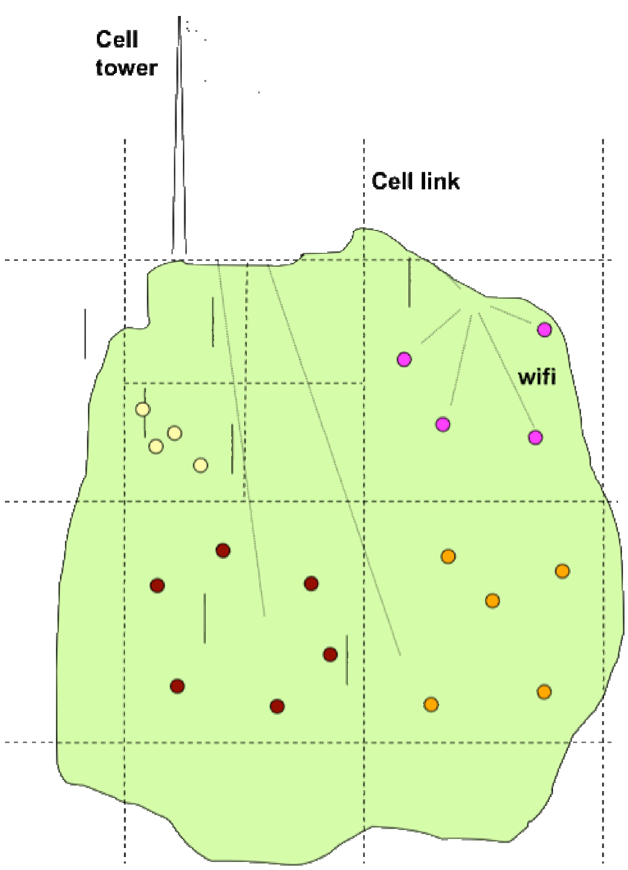


Figure 1. LHS GeoNet station. RHS Quanterra, Data Communications Controller, L4C seismometer, Wireless network with 1 km range.

Figure 2. Schematic Network of hierarchical network of a range of nodes



Network ideas:

1. Self-organizing clusters.
All sites have **WiFi and GPRS** (cell) onsite.

2. All sites have GPSs.
Can self-organize into the squares based on the **topography, line-of-site and cell link throughput capability**. Flat areas can be larger.

3. WiFi (WiMax, 802.11) inside squares with data flowing to a sink. Higher bandwidth.

4. Local sink – Internet connected node via a cell link. Events delivery or all data delivery.

Benefits:

Dense, smaller networks are easier to install. Fewer communication problems and smaller, lighter infrastructure like antennas.

Clustered models are easier to program and manage.

Cost benefits based on fewer cell enabled connections. Reduced overloading of cell towers.