New Technology Report
PASSCAL Standing Committee Summary

Over the past two years, the PASSCAL facility has conducted an extensive review of existing and emerging technologies to support the academic research community's seismic recording needs. This has been a significant undertaking because (1) IRIS PIs represent an incredibly broad range of science and field-recording needs, and (2) the seismic instrumentation market is currently undergoing very rapid evolution. Much of the recent technical evolution is focused on integrating and streamlining operations and reducing costs for features and data quality that the research community has come to expect.

This study attempted to address seismic recording holistically, including sensors, data recording, power systems and communications. The resultant report is *not* focused on recommendations for single-instrument packages for programs/initiatives such as Large N or RAMP. Rather, it reports on a wide range of seismic recording capabilities that has relevance across the entire scope of the PASSCAL program and all of IRIS.

The full report outlines the state of these technologies. Here, we outline a few overarching themes relevant to the PI community that ultimately drive and support the PASSCAL program.

1) Technical improvements exist today or are in active development that can improve the way we acquire data at virtually all scales.

The most obvious improvements are lower power, improved batteries, smaller instrument size and weight, larger data capacity, and improved data streaming. None of these are surprising, as they are driven by the rapidly evolving broader electronics and software markets. Modern systems have the potential to provide "dirt to desktop" solutions that streamline and improve quality of both field operations and post-field data preparation. Less obvious improvements lie in the robustness of some of these instruments under harsher conditions, such as in boreholes, wet environments, cold environments, erupting volcanoes, etc. The instruments described in the report range from incremental to significant improvements in data acquisition capability. Given that most of IRIS's existing technologies are decades old, *any* investment in new instrumentation will expand the types of experiments that can be performed using PASSCAL equipment as well as improve the user experience (fewer service runs, easier deployments, etc.).

2) Technical improvements do not increase the cost per station.

In almost all cases, costs are reduced relative to recent purchases. This is due both to improvements in manufacturing and to adopting developments from the broader electronics markets.

3) Existing and imminent technical developments can enable new science directions.

The most significant advance is the capacity to deploy a larger number of stations through a combination of reduced instrumentation costs and reduced field logistics. This advance is enabled by technical developments described in this report and exists at all scales. A second significant advance is the quality and cost of sensors in the intermediate-period band, which is currently served only by long-period instrumentation that is expensive and inefficient in the field. These two developments provide the potential for array recording of non-aliased wavefields at scales that are not possible today - the Large N philosophy. The largest potential for new science capacity is likely to be at intermediate periods, which include societally relevant topics such as earthquake hazards and nuclear verification.

4) Active technical development is occurring both at the traditional earthquake instrument manufacturers and in industry, and there is an increasing overlap between these systems.

First, industry has recently invested heavily in non-cabled nodal recording systems, which reduce field effort and environmental impact. This has been enabled by the same power, size, memory, and reliability improvements in electronics that are described above. Second, industry is becoming interested in recording at lower frequency ranges, at least to 1 Hz and perhaps to many seconds, as well as in passive, continuous recording. Both are being driven by characterization of hydrofracturing and by the need for longer wavelengths to enable full-waveform inversion at the basin-to-reservoir scale. This is a significant and recent change that may reduce costs and create improved synergies between IRIS and industry seismology.

5) The investigations detailed in this report directly inspired some of the new technologies outlined in the report.

Many of the systems described in this report did not exist two years ago. Most notably, in response to the inquiries of this investigation several traditional manufacturers have developed smaller, more efficient systems at lower cost, as was made apparent by visits to vendor booths at the 2013 AGU meeting. It can be argued with some conviction that IRIS inspired manufacturers to adopt modern technologies and solve some of our long-standing issues. Examples include borehole systems, intermediate-period sensors, and integrated all-in-one (sensor, DAS, power) systems. This rapid evolution delayed this report, but resulted in more exciting developments to report. At least within the traditional manufacturers, IRIS can (and should!) influence product development.

In addition, there are several significant technical themes in this report that we feel are important to highlight. These include:

1) All signs point toward the next generation of instrumentation being engineered specifically for vault-less deployment, either borehole or directly buried systems.

We cannot achieve a new era of science if we remain tied to vaults that are expensive and time-consuming and have a non-insignificant environmental footprint. A few vault-less systems have been tested by PASSCAL in the field and are available off-the-shelf today. While additional testing is required to prove this technology, it has the potential to significantly streamline operations.

2) Ongoing developments point towards the increased use of integrated systems, including sensor, DAS, and power, and incorporating dirt-to-desktop data streaming.

Effective use of such systems will require some standardization and perhaps fewer configuration options and more limited ability to mix and match hardware. The primary advantages are more robust systems and more efficient operations. Reduced, or at least not increased, maintenance may be achievable by purchasing fewer different systems and by lower replacement cost. A shift may be required from open-source to licensed software, but this may be an advantage by making data throughput a turnkey process. Standards set by IRIS are necessary to ensure quality and reduce maintenance.

3) No single technology exists that can meet the needs of the entire seismic community.

This is a natural consequence of the vast range of scientific scales and goals. Thus as decisions are made for future purchases, IRIS needs to carefully consider how to meet the needs of all communities, both existing applications and new applications that might be enabled by new technologies. That being said, the number of different systems supported by PASSCAL should be minimized to reduce support costs, perhaps through consideration of multi-scale embedded deployments. It goes without saying that acquisition of future instrumentation needs to be done with an eye towards ensuring continuity of existing capabilities. PASSCAL support for some of the existing systems will likely have to co-exist with support for new systems, at least for a period of time until all applications have been replaced by new technologies.

The 2014 PASSCAL Standing Committee:

Megan Anderson
Ted Clarke
Samantha Hansen
John Hole
Seth Moran (chair)
Shad O'Neel
David Okaya
Lara Wagner
Mike West