DATA AND TECHNICAL SYNERGIES

Building partnerships for an integrative SZ4D

The study of subduction zone seismic, volcanic, and mass-movement geohazards can greatly benefit from a research strategy that includes building upon existing international partnerships and leveraging instrumentation and facilities, cyberinfrastructure and data management, and capacity-building activities that are common to all geohazards research. By pursuing a common regional focus, SZ4D can develop partnerships with international scientists and organizations, strategically deploy shared physical infrastructure, and collect contextual information, such as geologic mapping and geochronology, that enables multidisciplinary interpretation of geohazards. Shared mechanical processes, geography, and modes of interacting with societies to promote hazard mitigation all require partnerships to create the potential to significantly advance geohazards research.

PARTNERSHIPS

The geographic focus of SZ4D requires the fostering of new, and expanding of existing, partnerships. International collaborations are complex and require significant investment to establish diplomatic, cultural, and physical connections. Thus, SZ4D will take advantage of active scientific ties where possible. This is particularly true when a capacity-building effort is involved, as described in the **Chapter 4.1 Building Equity and Capacity with Geoscience** of this report and summarized below.

COMMON INSTRUMENTATION AND FACILITIES

The science pursued by individual working groups share many common physical infrastructure needs, including a network of in situ observational technologies, a capability to support focused field experiments and/or campaigns, access to and support for laboratory facilities for geochemical and geochronological analyses as well as mechanical experiments, a modeling collaboratory to lead integration of data with cross-scale, and process models for improved understanding of the entire system dynamics (as described in the **Chapter 4.2 Modeling Collaboratory for Subduction**).

During the first part of the twenty-first century, rapid technological advances have enabled us to observe subduction zone phenomena in four dimensions with unprecedented temporal and spatial resolution. From trenches to volcanoes, we envision future research to include a suite of field-deployed, quasi-permanent sensing systems to collect time-series data on active processes. The suite may include seafloor geodetic (acoustic-GPS and pressure) and seismometry elements in a network, ideally with real-time (or at least minima-latency) data transmission capability and potentially including borehole-based observatories, to be used to detect elastic strain accumulation and its release on a wide range of spatial and temporal scales (e.g., locking, slow slip, and tremor events). Onshore, existing geodetic and seismic networks aimed at capturing deformation related to the earthquake cycle (e.g., EarthScope Plate Boundary Observatory) could be enhanced and expanded to other countries, similar to the efforts already taking place in Chile. At the volcano scale, new synthetic aperture radar (SAR) missions such as the NASA-ISRO SAR (NISAR) mission with weekly coverage will greatly enhance deformation measurements and should be supplemented with a suite of multidisciplinary ground-based instrumentation. Access to certain facilities, even if not necessarily dedicated solely to SZ4D, will be critical to enable these envisioned observational efforts. In the marine setting, the program will need to have access to surface vessels for instrument deployment, retrieval, and seafloor observation, including deep submergence, and autonomous underwater vehicle (AUV) and/or remotely operated vehicle (ROV) access. A pool of modern broadband ocean bottom seismometer/ocean bottom pressure (OBS/OBP) instruments will need to be available to the program, along with other emerging seismic and geodetic technologies. Equally critical is a capability for high-resolution seabed (bathymetry and backscatter) and subsurface (seismic reflection and refraction, and electromagnetic) imaging. SZ4D also needs continued access to a seafloor deep drilling capability as well as vessels and tools that can flexibly and/or autonomously download data from seafloor instruments, likely including AUVs/ROVs and autonomous gliders.

The different components of MegaArray, VolcArray, and SurfArray may strongly overlap with one another in some geographic configurations. These overlapping needs are strongest in the case of onland instrumentation, which constitutes a combined instrument array that we refer to as the **Multidisciplinary Multihazard Array (Multi^{2}Array)**. The main components of the Multi^{2}Array would consist of shared multi-purpose seismic networks, surface-deformation observing systems, and high-resolution surface imaging programs. First, all three disciplinary working groups require onland seismological observations: FEC requires a set of backbone onland seismometers to detect activity of forearc faults and to resolve seismicity along portions of the subduction megathrust; MDE requires a dense distribution of seismometers in a broad area (20–100 km diameter) around targeted volcanic systems, along with sparse networks of proximal seismometers (within ~5–10 km of vents) at a larger number of volcanoes; L&S requires instrumentation throughout the forearc and volcanic arc to detect and potentially locate large mass failures such as landslides and debris flows. Second, onland GNSS-derived surface deformation measurements are a cornerstone of answering each group's priority research questions: FEC requires densification along potentially active, slipping structures throughout the forearc region; MDE requires dense geodetic networks around targeted volcanic edifices; and L&S requires a broad distribution of GNSS measurements. Third, all groups require high-resolution topographic and optical imaging of Earth's surface: FEC to detect and characterize active faults and folds of the forearc; MDE to detect changes in volcanic craters and other portions of the edifice that accompany unrest; and L&S to identify areas where mass-transport events may be generated and the changes these events may produce downstream of these features. Institutional data collection campaigns and drone-based imaging missions are needed by all three groups to resolve changes in Earth's surface resulting from subduction-zone geohazards. Together, these joint needs encapsulated in the Multi^{2}Array provide several advantages over isolated, individual disciplinary networks - they are more cost efficient due to the repurposing of observations for the characterization of different hazards, which allows strategic densification of measurements in areas where studied phenomena may be best resolved, and they provide a common set of observations to further multidisciplinary investigations of how these sets of processes may interact with one another to produce cascading hazards across the subduction-zone system.

Finally, all working groups outlined work that will result in the collection of geologic samples. These physical samples will need to be stored and distributed to the community for analyses. Community reference materials and standards will also require storage and distribution upon request. Shared facilities will ensure uniformity in how samples and their metadata are stored and handled.

Allied with the field campaigns, a similar concerted laboratory effort will be required to address many of the essential processes that drive subduction phenomena. For example, drilling projects, including the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE), JFAST, and San Andreas Fault Observatory at Depth (SAFOD) have provided samples and a framework for laboratory mechanical friction experiments (along with many other physical properties) that have led to breakthroughs in understanding the physics of locking, seismic slip, transients, and conditional behavior. At deeper levels on the plate interface, laboratory experiments are needed to elucidate the pressure and temperature of dehydration reactions, and relationships between deformation, pore fluids, and chemical reactions. A gap in experimental capabilities exists across much of the seismogenic zone, including the very region where slip transitions from seismic to aseismic, requiring new equipment and approaches to access these critical conditions. An outstanding challenge in experimental petrology is the development of accurate geobarometers, sorely lacking for volcanic/plutonic systems, that would constrain the depths of magma stalling and storage.

As a program that focuses on 4D observations, time series, and temporal evolution, SZ4D requires geochronology. A rich variety of approaches are needed to access the 4D evolution of the subduction system, from the minutes to years of magma ascent recorded in the chemical zonation of volcanic crystals, to multidecadal geodetic signals across earthquake cycles from coral stratigraphy, to thousands of years of tectonic denudation recorded in cosmogenic isotopes from the land surface, to arc crust construction over millions of years from radiogenic isotopes in crystals. Real-time observations must be integrated with long time series to fully capture the dynamics of tectonic and volcanic systems. Geochronological labs are distributed widely and require coordinated partnerships with SZ4D observationalists, modelers, and theorists.

COMMON CYBERINFRASTRUCTURE AND DATA MANAGEMENT

Data management and data discovery tools are crucial parts of a community infrastructure. Interdisciplinary science can only thrive when the entire geoscience community can access and utilize data from all disciplines, which in turn requires suitably packaged data streams and a data infrastructure to ensure the availability, accessibility, and open distribution of the products of the entire effort. This level of interoperability requires dedicated, professional data managers along with carefully designed and maintained software. Searchable datasets need to be created that include fully descriptive metadata about uncertainties and limitations. Linkages between existing data archive capabilities such as those at the IRIS Data Management Center (DMC), the Seismic Data Center, and the International Ocean Discovery Program (IODP) should be seamless with SZ4D data management systems. Communication about the datasets needs to be built into the organizational structure so that potential users are aware of, understand, and can access data from multiple disciplines. For some disciplines, these data tools are mature (e.g., the IRIS DMC for seismic data), while for other disciplines, these tools require further development.

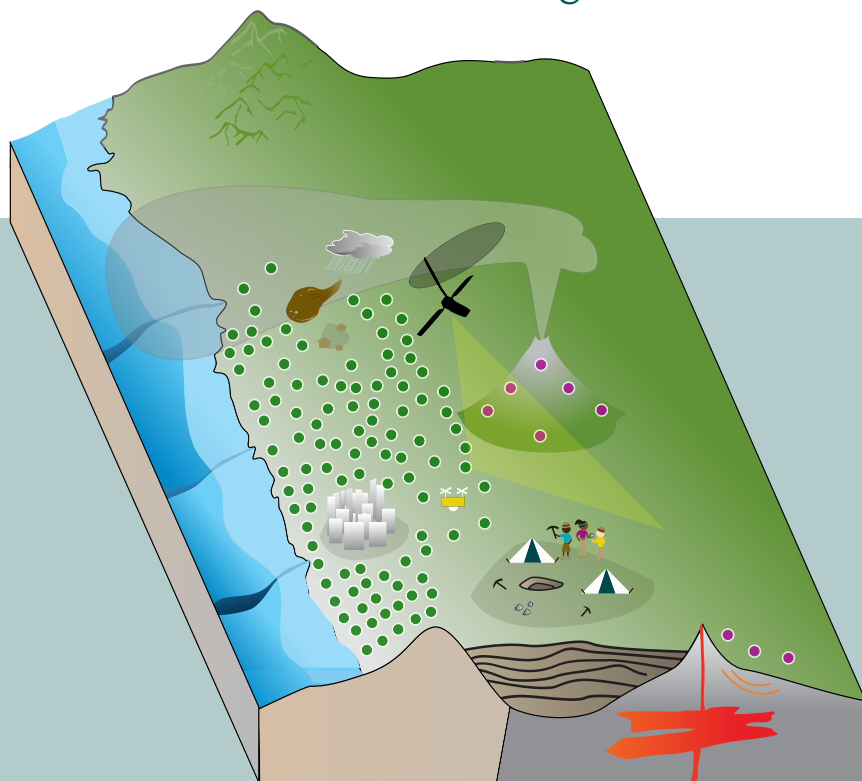
CAPACITY BUILDING ACTIVITIES

Capacity building encourages international scientific partnerships, with the intention of transferring skills, data, technology, and expertise. A shared SZ4D capacity-building effort will align with scientific targets in both emerging and developing countries in order to sustain physical infrastructure, train scientists, understand hazards, and build resiliency. Given the global importance of the subduction zone hazards, their scientific diversity, and the need to study them in multiple locations, a capacity-building effort is both a societal imperative and a scientific necessity that can yield transformative outcomes on all fronts.

A successful SZ4D program will lead to scientific discoveries and applications that would otherwise not be possible. The combined physical and intellectual infrastructure will enable observations in 4D that would otherwise not get collected. To realize the SZ4D vision of a new understanding of subduction zone processes and hazards requires a sufficient level of science funding to analyze, integrate, and synthesize these new observations. A key to succeeding in this balance over a 10-year or more timeframe is to build in mechanisms that preserve scientific agility. The long-term goals of the SZ4D Initiative will require international partners and a framework that will outlast its construction, benefiting the science community after 10 years.

SIDEBAR 5

Multi²Array: An integrated subduction-zone geohazards observatory



We envision the MULTIhazard, MULTIdisciplinary Array (Multi²Array) as being comprised of a unified observational array designed to capture the integrated effects of seismic shaking, volcanic unrest, mass failures, and surface transport. The Multi²Array enhances the observational needs of the disciplinary groups by deploying instruments in a geometry in which core observations for some applications serve as far-field observations for others. Additionally, such an integrated network will likely save cost by situating instruments in areas where they are well configured for multiple applications and equipping these multi-purpose networks with common data processing, storage, and transfer mechanisms. The Multi²Array is designed to include instruments that can be leveraged by all three disciplinary efforts (FEC, MDE, L&S), and so consists of only on-land portions of the Mega, Volc, and SurfArrays deployed in a common geographic region.