DRAFT SZ4D IMPLEMENTATION PLAN
A New Initiative to Understand Subduction Zone Geohazards

Authored by the SZ4D Research Coordination Network (RCN)

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Executive Summary

Our planet is constantly changing. Some of these changes take place over millions of years as Earth continually sheds its heat into space. Some happen over seconds to hours and days, as earthquakes jolt the land surface, volcanic eruptions send ash and rock into the atmosphere, and landslides lay waste to entire mountainsides. These abrupt geologic events have affected humankind throughout history in fundamental ways. The devastation wrought by earthquakes and tsunamis has disrupted the everyday lives of entire societies and has caused hundreds of thousands of lives to be lost in the past century alone. Large volcanic eruptions have destroyed ancient cities and have altered weather patterns in ways that have led to crop failures and population decline in both local and distant areas. Landslides have erased mountain towns and villages, disrupted agriculture, severed transportation routes, and profoundly affected urban and rural populations alike. Many of these same hazards now threaten urban centers that are considerably more populated than in the past and that have more and varied infrastructure that is vital to the health of local, regional, and global economies. Some hazards are likely to intensify as our planet continues to warm in the coming decades.

SCIENTIFIC RATIONALE

Despite the global urgency to mitigate the risk of geohazards, we still have limited understanding about the fundamental drivers behind earthquakes, tsunamis, volcanic eruptions, and landslides, which hinders our predictive ability. A new community-driven scientific initiative strives to address the need to fill in the major gaps in our understanding of geohazards by coordinating fundamental research on the underlying physical and chemical characteristics and processes specific to subduction zones. This initiative, called Subduction Zones in Four Dimensions, or SZ4D, brings together scientists who study earthquakes, volcanic eruptions, landslides, and tsunamis. It focuses on subduction zones because these geographic regions provide the opportunity to strategically investigate multiple hazards simultaneously in locations that generate some of the largest risk from geological events. In addition, the geometry of subduction zones permits unusually well-controlled natural experiments that can be used to isolate and study key factors that drive geohazards.

IMPLEMENTATION PLAN DEVELOPMENT

Representatives from U.S. research communities that study faulting and earthquakes, volcanic processes, and surface processes at subduction zones make up a Research Coordination Network (RCN). The SZ4D RCN is organized into three working groups (Landscapes and Seascapes, Faulting and Earthquake Cycles, and Magmatic Drivers of Eruption) and two integrative groups (Building Equity and Capacity in Geoscience and Modeling Collaboratory for Subduction) with a total of 74 members. Through a combination of meetings, workshops, webinars, and town halls, the RCN has engaged more than 1600 participants who have collaboratively identified community priorities and key observations and measurements that will enable the scientific advances necessary to better understand geohazards to mitigate their risks to society. This draft *SZ4D Implementation Plan* is the initial result of these discussions.

The working groups and integrative groups have synthesized community input and identified several key questions that the SZ4D initiative must address:

- When and where do large damaging earthquakes happen?
- How do trans-crustal processes initiate eruptions at arc volcanoes?
- How do events within Earth's atmosphere, hydrosphere, and solid Earth generate and transport sediment across subduction zone landscapes and seascapes?
- What fraction of a subduction zone's energy budget goes into building and shaping subduction zone land- and seascapes?
- How can we transform the mindset of our geoscience community to embrace education, outreach, accessibility, capacity building, diversity, equity, inclusion, and social justice as critical components for the success of the SZ4D and future scientific endeavors by the geosciences community?

From these questions, several cross-cutting themes emerge. The most critical one revolves around forecasting and prediction. All studies of geohazards are striving to establish the circumstances under which catastrophic events can be forecast. It is already clear that some volcanic eruptions can be anticipated if sufficient instrumental observations are available. Would deployments of additional instrumentation result in better predictions, or are there fundamental limits to what the data can tell us? The discovery of slow slip events prior to some, but not all, magnitude 8 and larger earthquakes raises a similar question. Is the problem with our ability to predict earthquakes due to the fundamental complexity of the system, or is it due to the lack of instrumentation in the critical region close to the fault? And, can we anticipate the timing and scale of mass failure based on the paucity of environmental and topographic data or is the process intrinsically stochastic? Even if the forecasting of these catastrophic failures is improved enough to be useful operationally, questions remain about the efficacy of communicating the information from these forecasts. For example, can local hazards agencies successfully use forecasts to motivate appropriate public action while delineating the limits of predictions? How can we help ensure equity in mitigating the hazards?

In addition to the scientific synergies, there are practical overlaps that make a coordinated effort to study several geohazards at a limited number of subduction zones more likely to bear fruit than several separate studies. Leveraging mutually beneficial partnerships, instrumentation, data management, and capacity building activities can accelerate scientific advances, some of which cannot be anticipated. In particular, a common regional focus allows development of more integrated partnerships, strategic deployment of physical infrastructure, and an accumulation of contextual information that enables multidisciplinary interpretation.

INFRASTRUCTURE REQUIREMENTS

Answering the questions posed by the RCN will require new observations both on land and under the sea. Fortunately, new technology has now made the required large-scale data collection possible. Three key components of in situ SZ4D infrastructure include (**Figure ES-1**): (1) a large-scale, long-term backbone array of **amphibious geodetic and seismic instruments (MegaArray)**, with densification in key areas of interest; (2) multi-component, standardized **volcanic arrays (VolcArray)**; and (3) a set of **surface and environmental change detection arrays (SurfArray)** that images changes in Earth's surface and rainfall. All three arrays leverage existing investments, such as the NASA-ISRO Synthetic Aperture Radar (NISAR) mission, which is identified as a critical component that spans the entire SZ4D effort, and there are many other examples. These observational pieces can only be made meaningful if the new observations are accompanied by concerted geophysical imaging, geological studies, laboratory experiments, numerical modeling, and human development programs to provide context, all of which also require support.

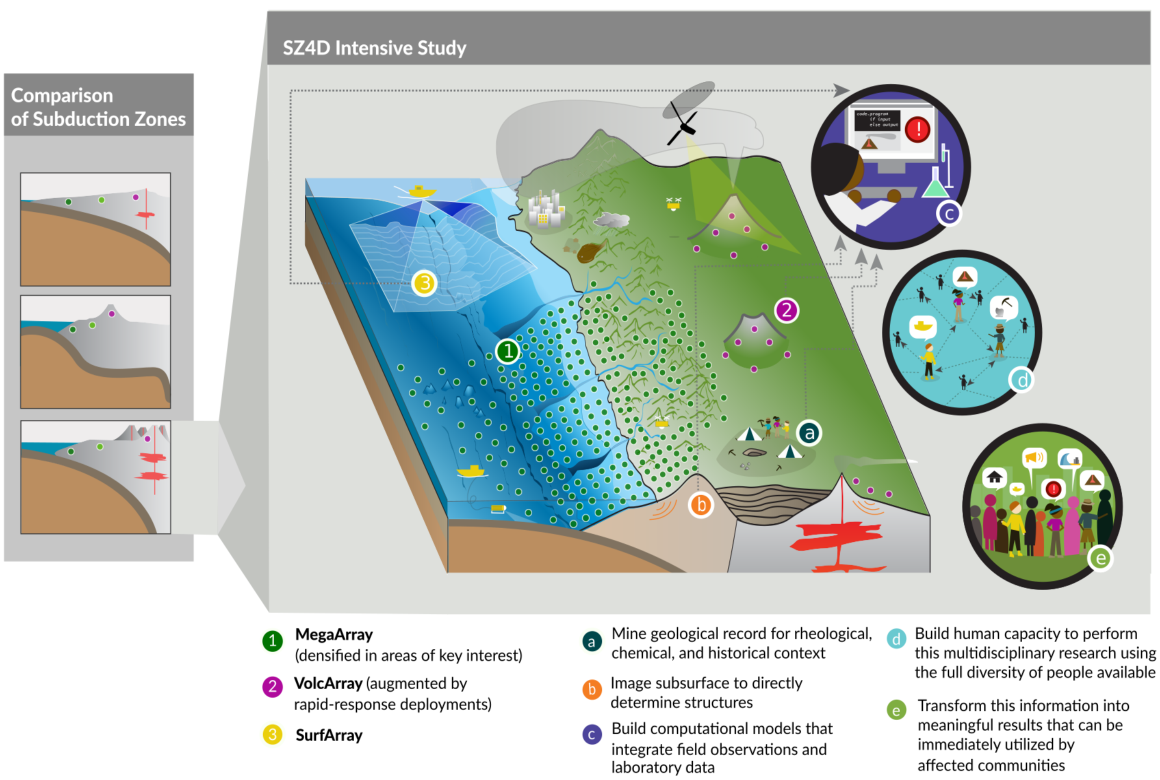


Figure ES-1. *Schematic of major instrumental arrays and activities of SZ4D.*

Strategic effort and substantial resources are required to develop ways to transfer knowledge and understanding to affected communities and for them to utilize the knowledge for hazard mitigation. In this document, the Building Equity and Capacity in Geosciences integrative group presents a plan that includes specific activities that will foster international capacity building, equity in addressing hazards, social justice, education and training, distributed outreach, and interdisciplinary collaboration, and that will increase diversity, equity, and inclusion. The plan features a collective impact model that is intended to foster a real culture change in research endeavors and ensure results that are relevant to all communities.

PHASED IMPLEMENTATION AND ENVISIONED TIMELINE

The proposed phasing of each working and integrative group's activities has a different timeline (**Figure ES-2**). The MegaArray and associated researchers will begin at a large scale and then proceed after five years to identify gradients in properties suitable for densification. The VolcArray will first develop and test instrumental networks on a few volcanoes and then expand to a portfolio of approximately 30 restless systems for long-term observations and six key systems for dense study. The landscapes and seascapes researchers will take a similar approach with SurfArray but build towards a paired system of experiments in two sites with systematic measurements. However, activities carried out by individual components depend, to varying degrees, on data that will primarily be collected by other SZ4D components. Thus, the timing of different data collection campaigns must be phased in a way that allows the different, interdependent components to be executed smoothly over the lifetime of the SZ4D (this interdependent staging is spelled out in **Figure ES-2**).

GEOGRAPHIC SITES

The RCN working groups identified a set of sites that could both satisfy the observational needs for the driving scientific questions and be used to understand how processes at subduction zones interact to yield hazards. The working group members recommended that the SZ4D effort should include one site in the United States and one international site, whose characteristics are mutually complementary. Additionally, working group members agreed that the development of an international network that leverages parallel research efforts by other countries is essential to the success of the SZ4D efforts. After considering the needs of all of the communities represented by the working groups as a whole, the SZ4D RCN concluded that the Chilean subduction zone is an optimal international target site for SZ4D efforts. While no single site provides every desired attribute for all geohazards-related disciplines, this area was identified as coming very close to meeting this condition. Nonetheless, working group members also agreed that some research efforts located in a variety of subduction zones should be viewed as a key component of the SZ4D efforts, as these smaller-scale projects would provide the diversity of involvement and scientific conditions required to build a generalized view of subduction-zone geohazards.

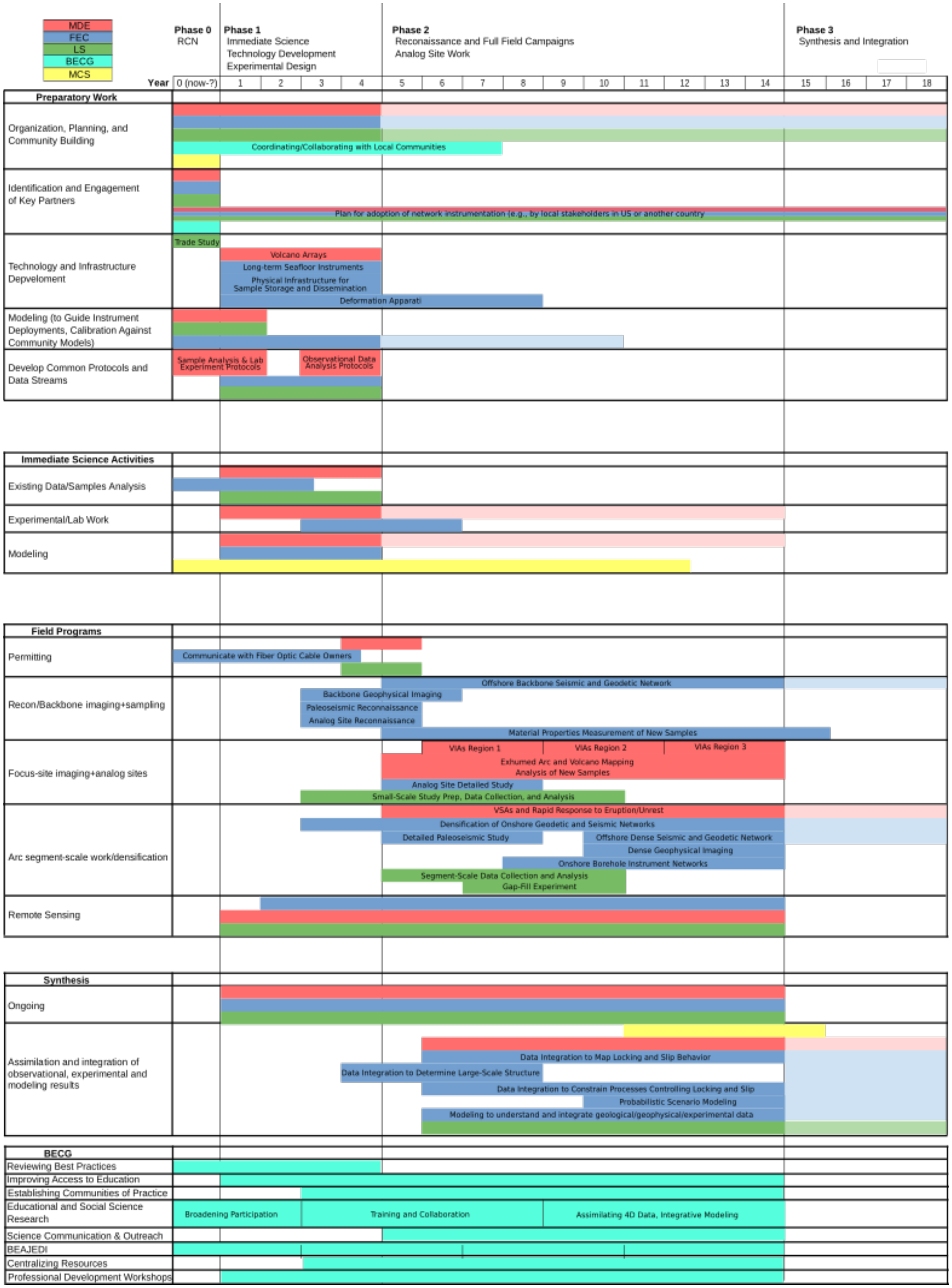


Figure ES-2. *Proposed phases of SZ4D implementation. (Link to high resolution version)*

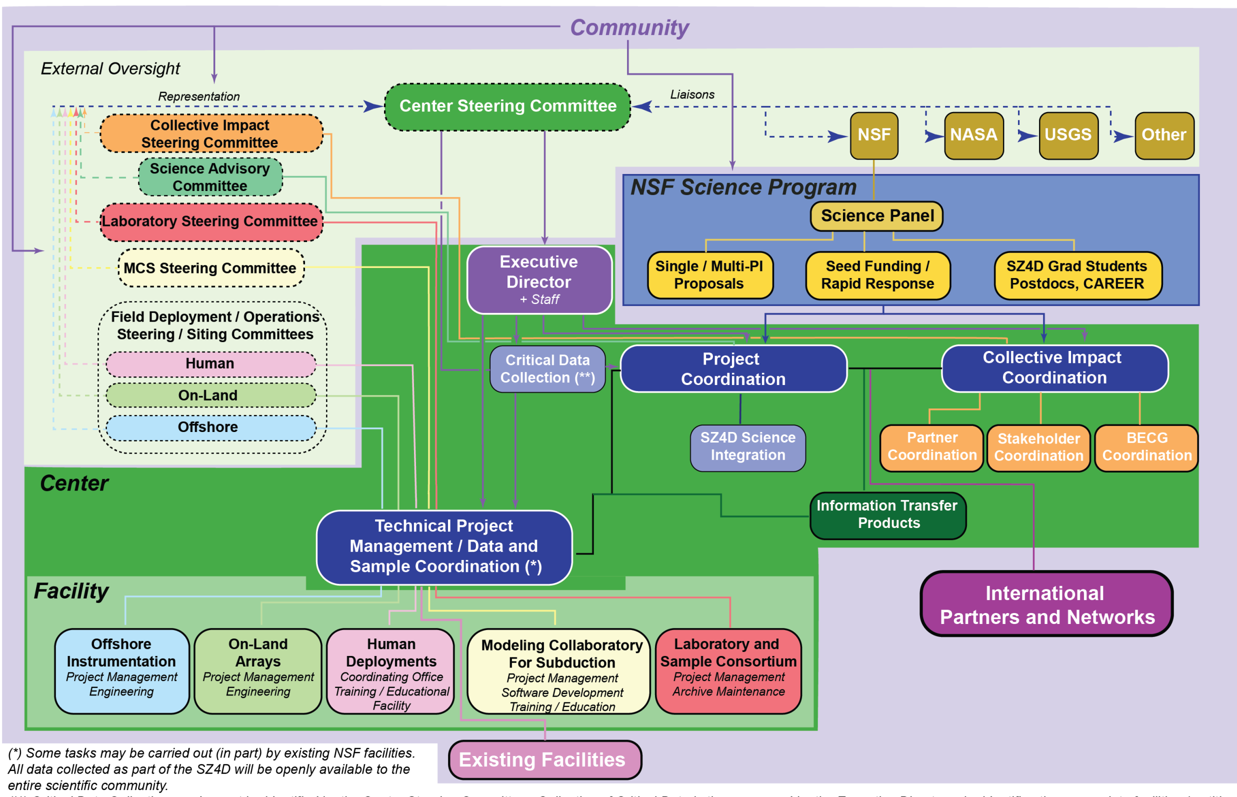
SZ4D ORGANIZATION AND GOVERNANCE

Enabling SZ4D will require investment in several key areas. First, an integrated SZ4D effort will be most successful if a Center, Facilities (new and existing), and Science Program are able to coordinate data collection, scientific studies, and collective impact activities (**Figure ES-3**). The central management structure in the envisioned effort would be the **SZ4D Center**, which would be overseen by a Center Steering Committee. The Center's responsibilities would be to oversee coordination of the different existing and new facilities responsible for the vast majority of data collection, facilitate SZ4D science integration, and coordinate these elements with partners, stakeholders, and efforts geared at equity and inclusion to maximize the collective impact of SZ4D efforts.

Five new facilities will be required, including ones for: (1) **Offshore Instrumentation,** including the MegaArray and SurfArray. This substantial effort and new facility in terms of scope includes dedicated support for seismic and geodetic instrument pools, collection of high-resolution bathymetry, operational engineering teams, and marine vessels (crewed and autonomous) for deployment, service, and rapid response near the site(s) of dense deployment. (2) **On-land Instrument Arrays**, including volcano arrays (VolcArray) with satellite telemetry for near-real-time data collection, environmental observing networks for landscape and deformation sensing (SurfArray), and deployable arrays for rapid response in regions with little prior infrastructure (MegaArray). (3) Logistics and implementation of field programs that involve **Human Deployments** as the primary observational instruments to collect systematic, standardized data (e.g., paleoseismology, framework mapping, samples for geochronology, geochemistry, and petrology). (4) A **Modeling Collaboratory** to both develop new subduction zone physical models and provide resources for their use by the whole SZ4D research community (students, postdocs, researchers). (5) A **Laboratory and Sample Consortium** for the study of material properties, rheology during deformation, and phase equilibria of molten systems. The activities of these new facilities would be coordinated with each other and with existing facilities by the SZ4D Center's Executive Director's Office, whose management activities would be defined by, and accountable to, the Center Steering Committee. We also anticipate that data needs may emerge that are not defined at the outset of the new SZ4D facilities, so we have designed a Critical Data Collection mechanism to direct resources to the appropriate facilities and entities in the event that novel data must be collected rapidly.

Additionally, to ensure that each facility has ready access to scientific expertise and whose granular priorities can be aligned with scientific objectives, a series of oversight committees will be established to provide governance for the new facilities. A slate of candidates for these committees will be developed using an inclusive self-nomination process to ensure the broadest possible representation. Candidates will then be selected by the members of the Center Steering Committee for a fixed term. Coordination of these oversight committees with the Center Steering committee will be enabled through direct representation on the Center Steering Committee, as well as through members selected from a self-nomination process for fixed terms.

The final envisioned component of the SZ4D Initiative is a **Science Program** at NSF that serves to identify and enable the most important emerging SZ4D-related scientific research using a merit-based panel review mechanism. Regular communication between the science program and SZ4D Center Steering Committee would help coordinate data collection and identify science priorities throughout the duration of the program. The three-pronged approach advocated here will maximize the scientific and societal impact of the SZ4D Initiative and help train the next generation of multi-hazard geoscientific researchers.



(*) Some tasks may be carried out (in part) by existing NSF facilities. All data collected as part of the SZ4D will be openly available to the entire scientific community.
(**) Critical Data Collection needs must be identified by the Center Steering Committee. Collection of Critical Data is then managed by the Executive Director, who identifies the appropriate facilities / entities that are the best means of collecting these data.

Figure ES-3. *Overview of SZ4D program and governance. Dashed outlines denote governance structure and are color-coded to match corresponding facilities or programmatic elements where appropriate.*