AccelNet-Implementation: SZNet - A Coordinated Global Effort to Understand Subduction Geohazards

Project Summary

Overview

The goal of SZNet is to develop an intellectual community with three missions:

1. to *compare observations of subduction zones* around the globe with a common dataset and understanding,
2. to *cooperate to consistently instrument* critical subduction zones that can provide key and transferrable insights, and
3. to *develop and nurture an international and diverse cadre of early career scientists* that is equipped to make the necessary breakthroughs.

These missions will be supported through a combination of workshops, webinars, data exchanges, field schools, pilot projects and student exchanges. We anticipate that these activities will allow a portfolio approach to observations to enable geographical coverage that will both create the necessary baseline data and maximize the chances of capturing earthquakes, volcanic eruptions and landslides. In addition, the exchange of ideas will benefit partner networks while stimulating coordinated deployment and research strategies.

Intellectual Merit

Our limited understanding of the fundamental drivers behind earthquakes, tsunamis, volcanic eruptions, and landslides hinders our ability to anticipate these globally significant hazards. Subduction zones provide the opportunity to systematically 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 driving geohazards. The study of subduction zones is intrinsically an international enterprise because: (1) Comparison across regions allows for insights about the controlling factors of the tectonic, volcanic and landscape systems. (2) Large geohazards are inherently rare events that require a balanced portfolio approach globally to guarantee the correct observations are made systematically.

Significant investments in subduction zone geohazards are now being made internationally. Active networks in Latin America, Europe, North America, Oceania and Asia are currently pursuing complementary science agendas and building large-scale deployments. Coordination between activities is needed to ensure that the maximum science is obtained from these efforts. SZNet would combine 14 networks across 5 continents with a particular emphasis on improving observations in Chile, which hosts one of the world's most geologically active and accessible subduction zones. Multiple projects on and offshore are working to establish the large-scale data collection and research effort required to study this exemplary system and coordination is needed to optimize the scientific output both here and globally.

Broader Impacts

Understanding geohazards has direct societal significance for the inhabitants of the Pacific Rim and other subduction zones around the world. The lack of understanding of the fundamental controls on when and where impactful earthquakes, eruptions and landslides can happen is a major impediment to focusing resources and mitigation efforts. Developing this understanding through an international network would connect the disparate experiences and expertise of experts in each subduction zone to provide a unified framework through missions 1 and 2. Mission 3 would broaden the geoscience community by supporting international early career scientists with a program of field schools, pilot projects and student exchanges.

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Theme, Rationale, and Goals

The most devastating geohazards on Earth occur along subduction zones, where energy is focused into coastal belts that include thousand-kilometer-long continuous faults, parallel volcanic arcs and steep, unstable terrain extending hundreds of kilometers inland. The risks posed by geohazards in subduction zones can be catastrophic for the human populations that often concentrate in them, and also have far-reaching impacts and global societal consequences as some of the most significant global ports and economies are vulnerable. Although we currently have a limited understanding of the physical processes controlling the occurrence, timing, and magnitude of subduction hazards, modern data and new techniques suggest that significant progress is possible. In the past two decades, seismic and geodetic data have revealed the rich array of slip processes during an earthquake cycle as well as novel volcanic eruption precursors, and geomorphologists now have access to seascapes to complement their onshore work. The availability of new data and techniques creates an opportunity and obligation to organize a multidisciplinary, globally-coordinated effort to collect observations, conduct laboratory experiments, and develop models that would significantly mitigate the risk of geohazards by allowing the catastrophic events to be placed in a fully four-dimensional physical context.

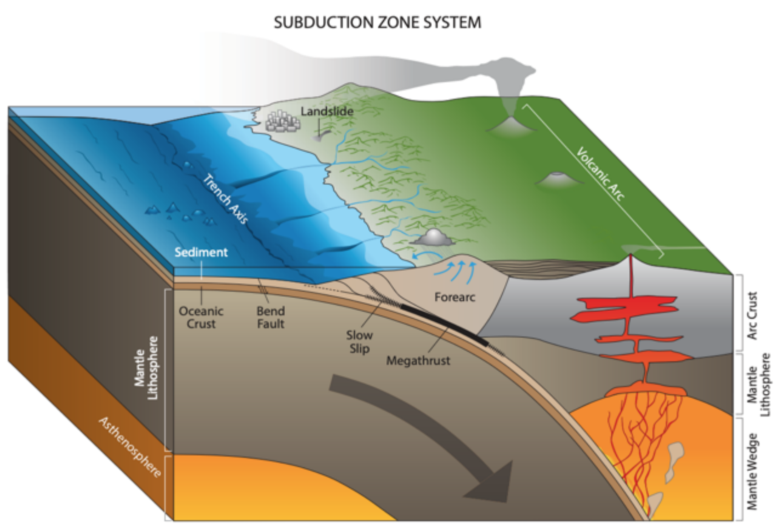


Figure 1. Schematic of a subduction zones showing the megathrust, where the largest earthquakes happen, the volcanic arc and the steep landscapes and seascapes governed by the interaction of the forearc with the coastal system (McGuire et al., 2017).

All studies of geohazards are striving to establish the circumstances under which catastrophic events can be foreseen. For instance, some volcanic eruptions already can be anticipated if sufficient instrumentation is 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, M8 earthquakes raises a similar question. Are earthquakes currently unpredictable due to the fundamental complexity of the system, or due to a lack of instrumentation close to the fault? Do challenges in predicting the timing and scale of mass failure result from a paucity of environmental and topographic data or is the process intrinsically stochastic? Answering these questions requires a significant observational and research investment globally to build and interpret a portfolio of data of the significant, rare events.

Recognizing these needs, the National Academies CORES Committee produced the Earth-in-Time report that recommended a focused effort to collect data and advance science on geohazards in subduction zones. This recommendation led to the SZ4D (Subduction Zones in Four Dimensions) initiative, which began as a Research Coordination Network (RCN) devoted to developing an implementation plan. The 74 members of the working and integrative groups met continuously throughout 2020-2022 and engaged over 3400 participants through workshops, webinars, town hall meetings, and special interest group sessions tied to specific professional conferences and meetings, all during the challenging remote work era of the pandemic. The RCN also hosted 13 webinars that disseminated insights from experts from 11 countries. A second RCN, the Modelling Collaboration for Subduction (MCS), was also funded and held two multi-day in-person workshops attended by 70-100 scientists and a months-long series of international webinars prompted by COVID that involved 740 scientists in 44 countries. These workshops, and the three resulting reports (Wada and Karlstrom, 2019; Dunham et al., 2020; Gonnerman and Anderson, 2021) articulated thematically related priority model development and training opportunities. The MCS RCN was eventually merged with the SZ4D RCN in recognition of their common goals.

The SZ4D international webinar series highlighted the rapid expansion of observational capabilities, strategies and insights in Japan, Costa Rica, Ecuador, Mexico, New Zealand, Taiwan, Southeast Asia and Chile. The talks and follow-up discussion showed that the study of subduction zones is intrinsically an international enterprise for at least two reasons: (1) Comparison across regions allows for insights about the controlling factors of the tectonic, volcanic and landscape systems. (2) Large geohazards are inherently rare events that require a portfolio approach globally to guarantee the correct observations are made systematically. Both technical and scientific exchange is necessary to maximize the new insights.

Figure 2. Geohazards Scientists met in Termas El Corazón, Chile in May 2022. The workshop report recommendations set several priorities for this proposal.

As soon as in-person international workshops became realistic in May 2022, SZ4D hosted a 70 person meeting of Chilean scientists in Termas El Corazón, Chile and a smaller workshop in Potsdam, Germany the following month (Fig. 2). These workshops and activities built the framework for SZNet as proposed here.

In fall 2022, SZ4D is publishing the implementation report that identifies the scientific drivers and strategies of the next level of research effort in subduction geohazards. With the publication of this report, SZ4D is transitioning to a separate entity funded by NSF GEO with the charge of making the implementation plan a reality. Over 200 scientists volunteered for SZ4D committees as part of the transition. SZ4D now aims to harness this energy and advance the understanding of subduction zone geohazards facing the US by building a large-scale set of instrumental arrays in the world's fastest, most active accessible subduction zone, which is in Chile. This observational work is to be interwoven with a set of modeling, geological, experimental and domestic observation efforts specifically designed to bring the insights from the rapidly converging system to the domestic subduction zones. The domestic regions include the US subduction zone with the highest risk, which is the Pacific Northwest (Cascadia), and the zone that is most active, which is the Aleutian-Alaska subduction zone. This strategy was selected because the development of an observational, useful set of knowledge prior to a catastrophic event is unlikely in the Cascadia and Aleutian-Alaska subduction zones, due to the slow plate convergence rate combined with infrequent observable major earthquakes and eruptions in the former and the extreme weather and the lack of continuous landmasses in the latter.

This comparative approach where data is collected in one region and utilized for interpretation elsewhere demands a strong international network, yet SZ4D's current funding is limited to workshops and meetings focussed on its specific technical needs with limited resources for international collaboration. The international network is required first to collate and compare the historical data and knowledge. Historical information is essential in the study of rare events, and often critical data are held at observatories or institutions without the resources to enable global access. A second barrier to data access is disciplinary and regional awareness, which can be addressed through a coordinated effort at archive exchange. Regional expertise and experience also influences scientists' understanding of the factors influencing earthquake, eruption, and landslide occurrence. As a result, **mission 1 of SZNet is to *compare observations of subduction zones* around the globe with a common dataset and understanding.**

Technical skills and solutions to the engineering challenges of subduction zones also need to be exchanged. There has been an explosion in the number of submarine geophysical observatories with a variety of technical approaches including fiber optic methods, wave gliders, and permanent cabling (e.g., Zhan, 2021; Lindsey & Martin, 2021; Iinuma et al., 2021; Nishikawa et al., 2019). Volcano observatories have been experimenting with multiparameter methods and have increased toolkits to include drones, continuous gas, dense seismic and satellite-based geodetic data in addition to more traditional approaches (e.g., Aiuppa et al., 2020; Furtney et al., 2018; Hansen & Schmadet, 2015; James et al., 2020). Similarly, topographic and bathymetric technologies have been rapidly evolving (Hill, et al. 2020; Hilley et al., 2020; Krishnan et al., 2011). These techniques need to be compared and evaluated to maximize the observational strategies around the globe. **Mission 2 of SZNet is to *cooperate to consistently instrument* critical subduction zones that provide key and transferrable insights.**

The technical and scientific exchanges rely on a network of scientists well-equipped to utilize this information. Early career scientists must grow the skills and contacts to collaborate internationally. Strategic, resourced programs are needed to bring together early career scientists across borders and disciplines, especially given the recent lack of in-person opportunities for this generation of scientists due to the global pandemic. **Mission 3 of SZNet is to *develop and nurture an international and diverse cadre of early career scientists* that is equipped to make the necessary breakthroughs.**

Participating Networks, Resources, And Synergies

The study of subduction zone hazards has thus far progressed through groups concentrating on specific zones, often within their own country or a partner country. Regional expertise is impressively developed, but international comparison is difficult. Some efforts, such as the US-based GEOPRISMS, specifically targeted comparative studies, but the focus sites were limited and the program was only resourced to instrument a subset of the necessary data for meaningful comparison. International partnerships between individual investigators and groups have been fruitful, but usually have only been resourced for pairwise comparisons of specific regions or hazards, e.g., earthquakes. A broad-based, international, formal framework for interactions that is inclusive of the earthquake, volcano and landslide communities would enable significant cross-national and cross-disciplinary fertilization in terms of knowledge, data, technical strategies and human development.

Table 1. Committed SZNet partners. See collaboration letters for more details about the composition of individual networks.

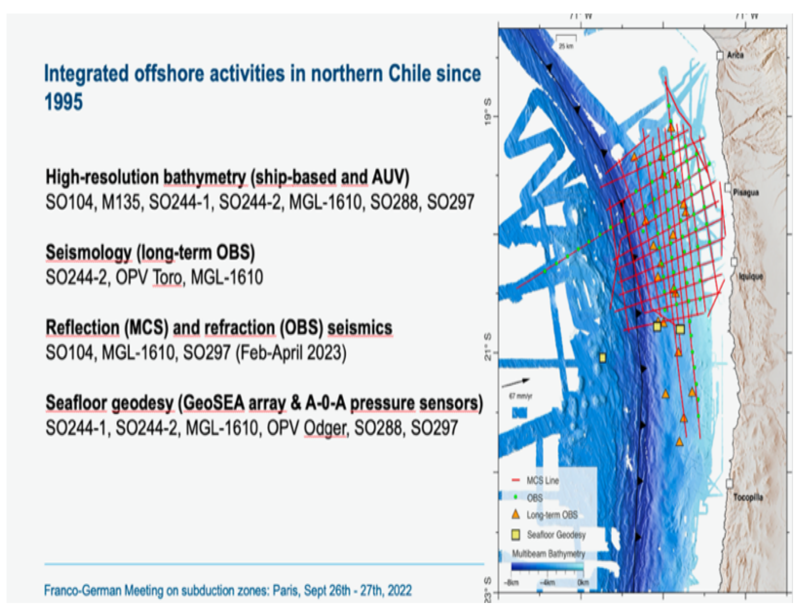
Name	**Represented Institutions and Groups**	**Key Contributions**
SZ4D	Predominantly US-based scientists studying geohazards in subduction zones, representing 55 universities as well as the US Geological Survey	Expertise in modeling, observations, field studies and geophysical data in subduction zones including significant experience in Cascadia and Alaska
AndesNet	70 scientists from academic, government and private Chilean institutions	Chilean hazards and general subduction zone processes
IPOC	EU and Chilean universities including GFZ, GEOMAR, ENS, Chilean National Seismic Network and UCN	Decades of instrumentation experience in the Chilean subduction zone onshore and offshore
FReNSZ	~200 scientists at 15 academic institutes in France including CNRS, IRD and universities	Long-term investment in the Chilean margin including major projects in offshore monitoring
ALVO	Latin American Association of Volcanology	Broad based expertise from both volcano observatories and academic volcanologists in Latin America
LACSC	Latin American and Caribbean Seismologists organized through IASPEI	Broad based expertise from both government and academic seismologists in Latin America
New Zealand Network	GNS Science & New Zealand National Seismic Hazard Model	Earthquake, volcano and landslide expertise including offshore seismic and geodetic instrumentation and hazard modeling
InVEST++	Earth Observatory of Singapore, Asian School of the Environment at Nanyang Technological University, Academia Sinica, the Institute of Technology, Bandung, and University of the Philippines	Multidisciplinary collaborations studying the subduction zones of East and Southeast Asia
Slow to Fast Earthquakes	Japanese earthquake researchers from 9 universities and research institutes	Geological and geophysical earthquake expertise including extensive, permanent offshore instrumentation in Japan
ChEESE	EU-funded academic modeling consortium	Exascale computing coupling multiple physical processes targeted at geohazards applications
Canadian Network	Combination of EARTH-CREATE, Ocean Networks Canada and NRCan including academic and government researchers	Earthquake and submarine network expertise

Name	Represented Institutions and Groups	Key Contributions
Center for Collective Impact in Earthquake Science (C-CIES)	Univ. Texas, El Paso lead with 18 collaborating institutions	Funded Track I Geohazards center focused nationally on low probability, high impact events using collective impact framework to engage diverse communities (CIELO-G)
CONVERSE	US Academic Volcanologists	Funded Track I Geohazards volcanology center focusing on scientific response to eruptions
CLaSH	US Academic landslide researchers	Funded Track I Geohazards center focusing on landslide hazards

The committed partner networks fall into several categories (See Table 1 for a complete listing and attached support letters). One set of partners is related to the Chilean subduction zone. Chile is arguably the world's most active natural laboratory across all hazards with 12 earthquakes greater than M8 since 1900 including the world's largest recorded earthquake, as well as over 90 active volcanoes with 33 discrete eruptions in the twentieth century. The rapid convergence leads to rapid uplift, which combines with a significant longitudinal climate gradient to create a nearly ideal laboratory for comparing tectonic and environmental effects on landscapes and seascape. Multiple networks have recognized the special nature of Chile and put effort into understanding and instrumenting the Chilean margin. The limited resources available have been concentrated in certain regions of the 4500-km long margin. This is much more to do to build sufficiently complete coverage on and offshore that can reasonably address the prevalence and controls on earthquakes, volcanoes and landslide. The networks efforts clearly need to be coordinated, especially if SZ4D is to provide the requisite additional pieces. Pragmatically, deployments should be coordinated to maximize the science possible given limited geographic footprints. Intellectually, insights from prior efforts need to feed into meaningful future experiments.

For these reasons, SZ4D is developing a strong partnership with AndesNet, which is a network of Chilean-based scientists who have long worked together and became formalized following the May 2022 in-person workshop discussed above. IPOC and FRENSZ are European-based networks that have worked in Chile for decades. In 2008, IPOC formed around a long-standing geophysical network led by GFZ in partnership with other European and South American universities with a concentration of efforts in deploying geophysical instrumentation onshore in Northern Chile. GEOMAR has led the offshore component of the efforts and has more than 40 projects in the region (Fig. 3). FRENSZ is a recently formalized combination of French academic institutions that have subduction zone interests which stretch back decades, especially in Chile. For instance, the

Figure 3. Examples of GEOMAR projects offshore Chile



IGPP group in Paris has measured plate motion in the region for nearly 30 years. All of these networks are represented in SZNet and will also be represented on the SZChileNet subcommittee (see discussion of structure below).

Another group of partners are the geographically more expansive networks that span Latin America, but are more tightly focused disciplinarily. ALVO and LACSC are organizations that promote regional cooperation, exchange and capacity building in Latin American Volcanology and Seismology, respectively. ALVO was formed in 2010 and celebrated its 10-year anniversary with a 200-person conference and publication spanning the geographic and disciplinary scope of the network (Agusto et al., 2022). LACSC is a commission of IASPEI (International Association of Seismology and Physics of the Earth's Interior) that was formed in 2014 and meets biennially and typically has an attendance of 250-300 researchers. The most recent meeting was Oct 5-7, 2022 in Quito, Ecuador.

SZNet proposes to further more far-reaching comparisons by incorporating another set of international partners that have networks that primarily, although not exclusively, focus on their own region's geohazards. The New Zealand network includes geophysicists, geologists, hazard/risk modelers, and social scientists, from government research agencies (GNS Science and NIWA) and several universities across New Zealand. The team has recently completed a large ($7M NZD) program to reveal the seismic and tsunami hazard posed to Zealand by the Hikurangi subduction zone which involved the acquisition of globally unique on- and offshore geophysical and geological datasets to increase our understanding of the past and present earthquake behavior of the subduction zone. The InVEST++ network includes scientists at the Earth Observatory of Singapore (EOS) and Asian School of the Environment at Nanyang Technological University (Singapore), Academia Sinica (Taiwan), the Institute of Technology, Bandung (Indonesia), and the University of the Philippines (Philippines) based on long-standing collaborations to study the subduction zones of East and Southeast Asia including the tectonics, volcanoes, cascading hazards, geodesy, paleogeodesy and geology. To strengthen collaborations in the region, the InVEST network was funded by the Singaporean government at S$19M to bring together a collection of the geohazards faculty at EOS with regional and international collaborators, and also social scientists, historians and engineers, to study the Southeast Asian Ring of Fire and its societal hazards and impacts. The Slow-to-Fast Earthquake Japanese Network is funded under a program for transformative research areas that involves 9 research institutions in Japan and builds on long-standing joint efforts between universities and government agencies, including the Japanese Agency for Marine-Earth Science and Technology (JAMSTEC), which is the world's leader in seafloor instrumentation with active cabled observatories and extensive research vessel capabilities. Canada shares subduction zones with the US and has several, overlapping networks relevant to SZNet. Natural Resources Canada (NRCan), Ocean Networks Canada and Earth-CREATE together include government expertise, subsea instrumentation and academic earthquake researchers. All of these international partners are committed to the SZNet project.

ChEESE is a unique partner that brings international numerical modeling and high-performance computing expertise. ChEESE is a consortium of 15 partners in Europe entering its second funding phase in early 2023 to continue to develop a center of excellence in Exascale computing that services society on critical aspects of geohazards. The first phase of ChEESE has been very successful and led to a rich ecosystem of successive European initiatives (e.g., the eFlows4HPC, Geo-INQUIRE and DT-GEO projects) preparing the European Solid Earth community and stakeholders such as the European Plate Observing System (EPOS) for massive data streams and extreme-scale computing. The expertise of ChEESE complements the strong modelling focus of MCS within SZ4D.

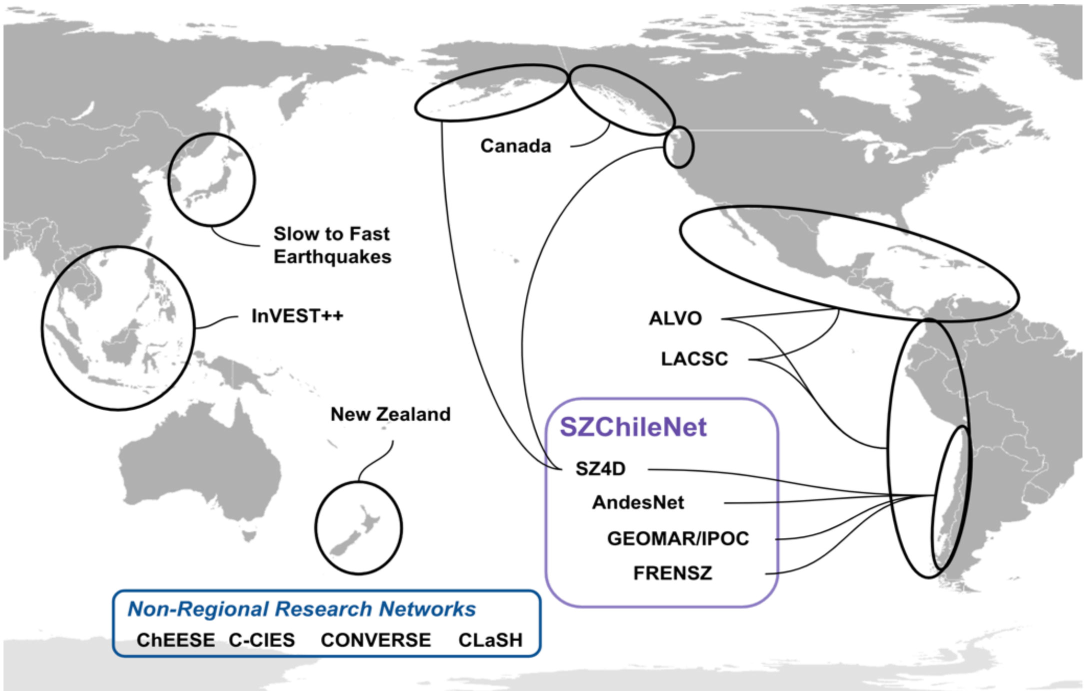


Figure 4. Geographic distribution of focus areas of partner networks. Some networks, such as ChEESE, C-CIES, CONVERSE and CLaSH, do not have a geographic focus.

An additional set of partnerships is with recently initiated domestic geohazards centers. NSF announced an opportunity in 2021 to broaden the types of scientific centers focused on geohazards beyond their traditional earthquake focus. Successful catalyst proposals were funded to start centers in landslide (CLaSH) and volcano hazards (CONVERSE), as well as a center specifically focusing on diversifying the geoscientific community through a collective impact strategy (C-CISE). These centers bring balance to SZNet by incorporating disciplinary communities that have not had as long a history of network organization.

The partners in Table 1 have all committed to SZNet as documented by the attached collaboration letters. New network members can be added to the SZNet as needed at any time through an application and approval process described in the Network Coordination and Management Plan. This flexibility is important as it is anticipated that new networks may emerge both domestically and internationally. For instance, the CRESCENT center focusing on Cascadia earthquakes is currently under consideration by the National Science Foundation and would be a natural collaborator should it be funded and interested in joining SZNet. Other networks could easily be envisioned as joining in the rapidly developing field of geohazards.

SZNet will be governed overall by a Coordinating Committee composed of a representative of each network. In recognition of the distinct nature of the partnerships focussed on Chile, the Coordinating Committee will include a subcommittee SZChileNet to work specifically on issues related to activities in the region. The Coordinating Committee will be responsible for ensuring substantive and regular communication and overseeing all activities. (See Network Coordination and Management Plan Supplement Document for full description of governance and management structure).

Network of Network Activities

The proposed activities of the network are aligned with the three missions as outlined in Table 2. The specific workshops, webinars and field topics prioritized rely heavily on the SZ4D implementation plan as well as other community documents that identify knowledge gaps as referenced below. Particular priority was placed on the workshop reports from the May 2022 and June 2022 international workshops where members of the AndesNet were able to articulate their needs.

Table 2. Planned Activities and Milestones. Mission 1 and 2 Activities are described in this section. Mission 3 activities are described under student and early career

PLANNED ACTIVITIES	YEAR 1	YEAR 2	YEAR 3	YEAR 4
Overall Coordination				
In Person Coordination Meetings	X		X	
Quarterly Virtual Coordination Meetings	X	X	X	X
Mission 1: Compare Observations of Subduction Zones				
Topical In Person Workshops	**Legacy Data**		**Geohazard Predictability and Prediction**	
International Virtual Webinars	X	X	X	X
Legacy Data Ingenstion & Data Portal	X	X	X	X
Mission 2: Cooperation to Consistently Instrument Critical Subduction Zones				
Mission 2 Topical In Person Workshops		**Ocean Floor**		**Geological Field Data**
		Lab Capabilities		
Mission 3: Develop & Nurture International & Diverse Early Career Scientists				
Chilean Field School	X			
Cascadia Field School		X		
Chillean Pilot Project			X	
Cascadia Pilot Project				X
Student Exchanges	X	X	X	X
Milestones				
	Launch of Coordinating Committee & Initiation of Activities	**Launch of Data Portal**	**Execution of Major in-person Workshop that aligns plans**	**Submission of coordinated deployment proposals**

Overall Coordination Activities

The primary goal of SZNet is to build an intellectual community. This requires continual coordination between the network representatives at the Coordinating Committee level. All participating networks have committed to quarterly virtual Coordinating Committee meetings as well as biennial in-person meetings. The agenda of the meetings will include overseeing the network activities as well as more forward-looking items such as an exchange of proposal and deployment plans. The overall coordination will be supplemented by regular e-newsletters and a maintained email list supported by the SZNet staff.

The coordination plan includes annual milestones, which were selected to be concrete accomplishments that have bearing across the entire network (See Table 2). Ultimately, the work builds towards submission of coordinated deployment and research proposals which is included as milestone 4 in year 4.

Mission 1 Subduction Zone Comparison Activities

Network Activities 1.1: Workshops

Subduction zone comparison can best be facilitated through knowledge and data exchange. To this end, SZNet plans a series of in-person workshops on topics of interest across the networks. The topics have been selected from identified needs in recent community documents as areas where an international effort is required because of either complementary datasets or technical capabilities.

The first of the mission 1 workshops will be the Legacy Data workshop in year 1. The purpose will be to bring to light historical data in subduction zones that requires archiving and data management. The topic was selected based on the need emphasized in the SZ4D Potsdam Workshop. This activity is essential to the collaborative goals of SZNet because: (1) differential access to data management services is a major hurdle to an equitable global partnership, (2) surfacing historic data allows for meaningful comparison across subduction zones by international scientists, especially for geologic processes where long-term records across decades are essential. (3) geohazards research is disproportionately affected by information from rare, extreme events. Fully representing these events in the global archive is essential. *The workshop outcome will be a plan to archive and enable global access to existing data to complement current efforts and fill in the earthquake, eruptive and sedimentary cycles.* This workshop will lead immediately into the data dissemination activities described in Network Activities 1.3.

The second workshop of mission 1 will be in year 3, which will be on prediction and predictability of geohazards. What are the key missing observational, modeling and conceptual pieces to understanding the extent of prediction in geohazards systems and how can we maximize the international portfolio to address them? Because of the cross-cutting nature of the workshop and its strategic importance in coalescing collaborations, this workshop is budgeted for more participants than any of the other in-person workshops. The need is identified from the first cross-cutting question of the SZ4D Report. *Outcomes will be: (a) to generate cooperative array design, experiments and data exchange and (2) to identify cooperative projects that combine international data.*

Network Activities 1.2: International Webinars

The in-person workshops will be complemented by international webinars. These webinars will be designed as virtual workshops that will enable broad participation across the globe in areas where the primary goal is general knowledge exchange that can be achieved through focused talks and discussion. Each webinar will span 1-2 days and have multiple talks with discussion.

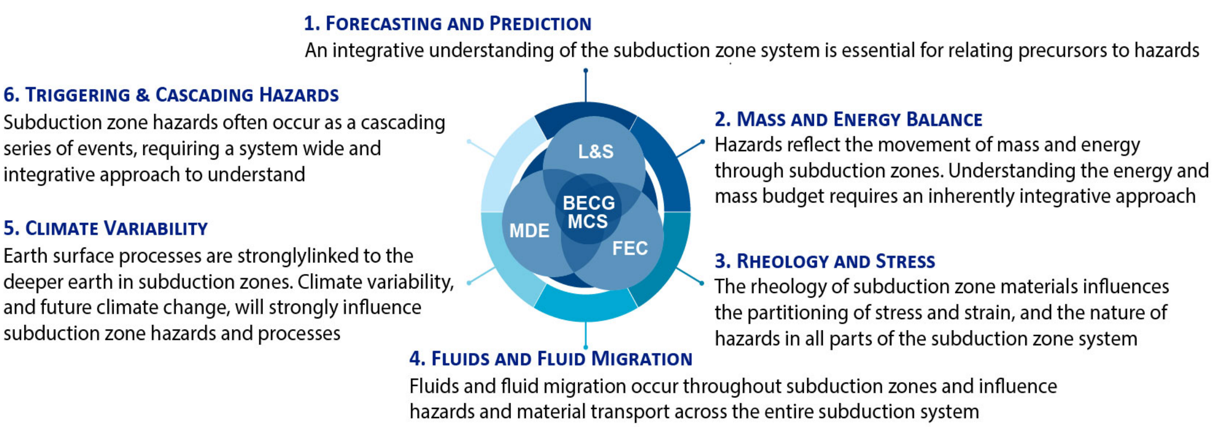


Figure 5. Cross-cutting themes from the SZ4D Report. Cross-cutting questions 2-6 are subjects of webinars. Question 1 is the subject of an in-person workshop.

The SZNet staff will support 3 webinars a year (Table 3). The preliminary schedule is drawn from community documents such as the SZ4D Implementation Report and MCS Workshop Reports. Highest priority is given to the cross-cutting themes of the SZ4D report since these subjects intrinsically require broad thinking both disciplinarily and globally (Figure 5). The cross-cutting topics are in year 1 and 2 to help engage as broad a cross-section of scientists as possible at the initiation of the network. Additional workshops and webinars that leverage existing efforts and fill in important gaps with more specialized topics are sequenced in later years once a community is built. For instance, the SZ4D Catalyst proposal will fund workshops on the technical aspects of upscaling ultra-high-resolution bathymetry, and thus SZNet focuses on the companion problem of using that information to learn about tsunamigenic processes (year 2). The Coordinating Committee will revisit the schedule each year and update it as new information and needs are brought to light.

Table 3. Preliminary Webinar Schedule. Documents motivated the webinar selection are: [1]SZ4D Implementation Report, [2]MCS Workshop Megathrust Workshop Report((Dunham et al., 2020), [3]MCS Fluids Workshop Report (Wada and Karlstrom, 2019), [4]Future Directions in Seafloor Geodesy 2021 Community Workshop Report

Year 1	**Triggering and Cascading** Hazards. How do cascading sequences of events impact subduction zone hazards? [1]	**Fluids and Fluid Migration** How does fluid migration influence hazards and material transport across the entire subduction system? [1, 2]	**Rheology and Stress** How does the rheology of subduction zone materials influence the partitioning of stress and strain, and how does this control the nature of hazards across the subduction zone system? [1]
Year 2	**The mass and energy budget** How do we track the passage of mass and energy through subduction zones and how do we relate critical transitions in mass and energy transfer to hazardous events? [1]	**Climate Variability** How will climate variability, and future climate change, influence future subduction zone hazards and processes? [1]	**Tsunamigenesis** Evaluating the relative contributions of splay faults, landslides, megathrust earthquakes and other mechanisms to tsunami generation. [1, 2]
Year 3	**Developing a common geological dataset** What standard measurements and protocols can build towards a comparable set of geological frameworks? [1] *Note: Builds discussions leading to year 4 Mission 2 in-person workshop.*	**Practical experience with hazard communication** International exchange of experiences interacting with the public and policymakers during and immediately following a crisis such as an earthquake, volcano or landslide. Special emphasis on experience with potentially precursory signals. [1]	**Model validation and verification** How do we build a model ecosystem for subduction hazards that is computationally robust, benchmarked, and validated with observations? Address landscape evolution models, landslide models, conduit flow models, crustal deformation codes, magma chamber models noting existing infrastructure for earthquakes [2,3]
Year 4	**Oceanographic signals captured by geophysical instrumentation** New collaborations with oceanography can reduce noise sources and for providing new constraints that are beneficial to both disciplines. [4]	**Data-driven computation for geohazard forecasting and prediction** How will new datastreams and multiparameter datasets be leveraged to enhance our understanding across all subduction geohazards? [1]	**Long-term influence on short-term processes** How do tectonic-scale geodynamic over geologic time influence subduction geohazard occurrence, magnitude, and style? [1, 2]

Network Activities 1.3: Data Exchange

In addition, data exchange will be facilitated by support for ingestion of legacy digital data and metadata from SZNet to public archives and the launch of a clearinghouse to provide a common platform for subduction zone data. These activities will be performed in close collaboration with geophysical facility staff.

We have budgeted data management support to ingest and distribute legacy geophysical data that is brought to light in the Legacy Data Workshop in year 1 (see Activities 1.1). The workshop will identify the types of data available (e.g., seismic, strain, tilt, GNSS, etc.), formats in which the data will be delivered, metadata format and content, the number and locations of stations, and the volume of data. The IRIS project team will attend this workshop and collaborate to establish detailed plans for data handling and archiving. As digital data are delivered, IRIS will make these data sets freely available via its Data Management System either as part of its assembled data sets repository or in its primary archives, depending on the data format and completeness of metadata.

A second data exchange need is to make discoverable the international catalog of existing archives. This problem is particularly complex because the scope of geohazards represented includes needs for diverse data types including environmental and hydrological data as well as more traditional oceanographic and solid Earth data.

SZNet data types span many different scientific disciplines, and each requires domain expertise to properly curate and serve them. IRIS will implement a web portal that binds these different data repositories under a single umbrella so that users can navigate the various data types for multidisciplinary research. The initial portal will be a list of data repository links and user-oriented descriptions of data in each repository. This relatively simple implementation is designed to fit within the SZNet budget while increasing the utility of existing archives worldwide. The design for the web portal will allow for future platform expansion to include interactive tools to query and visualize specific information (e.g., station/sampling locations and times, visual previews of data, etc.) from each of the repositories that support sharing of necessary metadata layers.

Mission 2 Subduction Zone Instrumentation Activities

The second mission of SZNet is to foster common instrumentation and observations. This effort requires building interdisciplinary fluency as well as technical benchmarking. Workshops will be the major activity under this mission. They will be supplemented by pilot projects in collaboration with SZChileNet that compare techniques and capabilities in field settings. These pilot projects serve a dual purpose of developing both the collaboration and instrumental networks. In recognition of their role in developing early career scientists, they are described under Student and Early-Career Professional Development (Mission 3).

Two Mission 2 in-person workshops will be in year 2. The first will be the ocean floor instrumentation comparison. The purpose is to develop a global knowledge base of technical capabilities and opportunities in seafloor geodesy and seismology based on the need identified in the SZ4D Implementation report. *The outcome will be technology exchange and cooperative experiments.* The second will be a workshop on laboratory capabilities. What can and cannot be achieved in currently laboratory experiments on rock deformation, magmatic processes and sediment transport? Where can we collaborate through laboratory exchanges to maximize capabilities and where do we need to invest in new technologies? This need was established by the SZ4D Implementation Report as well as the SZ4D Experimental Workshop in August 2022. *The outcomes will be to identify specific laboratory exchange opportunities to be supported by the SZNet student exchange program and identify high priority technical development.*

Another mission 2 in-person workshop will be in year 4 on geological field data. The workshop will focus on how to standardize and organize international field data and samples, which was also a need identified in the SZ4D Implementation Report. The international workshop will build on preliminary discussions fostered through the webinar schedule and coordinating committee. *The outcome will be a set of international recommendations for common data.*

Student and Early-Career Professional Development

The third mission of SZNet is to foster a cadre of early career scientists that have an ability to synthesize information from different subduction zones and create a diverse set of international contacts, all within an inclusive environment. In addition to prioritizing early-career attendance at all workshops, SZNet will have two specific activities focused on supporting early-career scientists: The Field School/Pilot Project Series and the Student Exchange Program. These foci were selected because of their prominence in discussions with the AndesNet collaborators, as documented in both the Chile and Potsdam Workshop Reports. All programs for early-career researchers will involve a strong component of structured mentorship provided by facilitators, built around the creation of mutually shared expectations and values (Waldron 2021), with the aim of reducing common barriers experienced by underrepresented groups.

Field Schools and Pilot Projects

Field schools that bring scientists together to focus on research of a particular geographic site is a well-established strategy (Mogk and Goodwin, 2012). International travel support will be essential to ensure attendance of early-career professionals from the different participating networks. SZNet will therefore sponsor field school in the first two years of the network. Both field schools will involve a two-week long experience from the volcanic arc to the shoreline, integrating the three driving themes of the SZ4D program: Magmatic Drivers of Eruptions (MDE), Landscapes and Seascapes (LS), and Faulting and Earthquake Cycles (FEC). Local scientists will lead each respective field school, running the educational discussions and field stops, with comparisons drawn with the sibling subduction zone. Early career participation will be prioritized, making sure an equitable mix of career stages, gender distribution, and research specialities are considered.

The first field school will be in Cascadia. Several multi-hazard transects in southern Washington and Central Oregon would allow for a successful introduction to the geology, hazards, communities, and landscapes that make up the region. In the second year, the school will be in Chile. The multi-hazard transect would stretch from the active volcanic zone in central Chile, paramount to the success of the MDE and LS programs, before shifting over to the metropolitan region and then continuing to the coast. This will provide the fundamental geologic background of the region and allow participants to understand the societal impact of regional hazards to the Chilean people.

In year 3 and 4, SZNet will shift to pilot studies to fulfill the same functions of developing a cross-trained, international community of scientists. Pilot studies will explore the effectiveness of planned instrumentation to resolve the questions being posed in the larger SZ4D program, through the lens of a significant educational component. Both projects will focus on hands-on instrumental experiences for all involved participants, with modest exposure to the software and models associated with data processing.

The year 3 pilot study will center on neotectonics (fault detection) in Cascadia by learning from the extensive paleoseismic record that exists for the Cascadia region while also focusing on data collection techniques. Drones will be used for a structure-for-motion project, which will be coupled with a classic technique used in fault detection: trench digging. The year 4 pilot study will be in Chile and be aligned with a component of the SZ4D project is an array of instrumentation between the active arc segment and coast region that monitors landscape evolution. This pilot study would implement a small portion of this array, allowing participants to deploy several instruments used to measure rainfall, soil porosity, pH and slope stability. Participants would be able to collect data over the course of several days, which would then be processed in subsequent portions of the field school.

SZ4D is committed to the continued implementation of collected investment, building towards scientific advancement, increasing equity and inclusion, and integrating community needs. In service of these goals, all of the field schools and pilot projects will involve a public event designed to engage the participants with the local community. These broadly advertised evening events will have field leaders lead a discussion surrounding the local geology, hazards, and instrumentation, with students encouraged to help answer questions raised by the community. These events are expected to occur over 3 hours, and will include panel discussions, listening to community needs and concerns, and open questions to the local scientists. Such an approach allows for SZNet participants to meet with local citizens, practice science communication skills and learn from a new community. SZNet includes networks with local members in both Cascadia (SZ4D) and Chile (AndesNet) who will facilitate appropriate venues. The C-CICES member network also includes expertise in collective impact that can guide the design and partnering of these events to maximize the benefit.

The field school and pilot project program provide an important opportunity to address culture change around field work. Field work has been cited as not only one of the most rewarding experiences for exciting and retaining an Earth Sciences workforce, but also as one of the limitations to increasing diversity within our field (Sharp and Kremer 2006; Huntoon and Lane 2007; Levine et al 2007; Viglione 2020). There are endless studies highlighting the marginalization of women, LGBTQIA+ and people of color within field sciences (e.g., Viglione 2020; Marin-Spiotta et al. 2020; Mattheis et al. 2022), as well as the financial barriers to entry (Giles et al. 2020; Abeyta et al. 2021), all of which limit our ability to diversify the geosciences. As such, we plan to design and implement a field safety and bystander intervention training that addresses these challenges as part of the first day of the field schools and field trips, following the Report of the Workshop to Promote Safety in Field Sciences (DOI: 10 5281/zenodo 5604956) as well as provide field gear to all participants.

Student Exchange Program

SZNet will develop an early-career exchange program that can provide funds for scientists to visit laboratories in partner countries. The exchanges will be particularly concentrated on SZChileNet to ensure a deep collaboration in the focus area. This program is based on a need articulated at the SZ4D Potsdam Workshop from Chilean scientists who noted both technical limitations of laboratories in-country and a more general need to have students develop international networks. Support is included for 5 students each year to have extended visits in order to analyze samples, utilize computational facilities, visit field sites, embed themselves in an observatory or engage in other, similar deep collaboration experiences. The application process will be managed by the Student Exchange subcommittee of the Coordinating Committee (See Network Coordination and Management Plan) with the support of the SZNet staff.

The proposed exchange involves scientists from culturally distinct localities. As such, there is a need to make sure that the expectations for behavior and success in these settings, as well as the formation of shared values of all participants, are explicitly laid out. The success of a visiting scientist is based not only on the resources present at the institution, but on the mentorship and lab environment that scientist is entering. To make sure that all exchange students are being set up for success, we will run CIMER (Center for Improvement of Mentorship Experiences in Research) training for hosts that focus on creating spaces and expectations that allow for all students to be successful in their visit.

Evaluation

Success of SZNet is measured first and foremost by the development of an intellectual network. Intellectual synergies are difficult to measure, but essential to the success of science. Quantifiable proxies such as joint publications and funded projects can be tracked, but are ultimately less important than long-term exchange of ideas. The ability of each partner to thrive and generate new scientific breakthroughs using the insights developed in the network must also be taken into account. Measures of success defined in Table 4 take into account both of these dimensions by including both individual networks projects as well as joint projects. The trajectory of the entire community will be compared to the pre-SZNet productivity to evaluate success. In addition, we will track funded, coordinated deployments to take new observations in a way that maximizes the scientific gains.

Metrics specific to each mission must also be evaluated. The outcomes for Mission 1 and 2 workshops listed in the Network Activities will be assessed. In addition, the quantifiable metrics of Table 4 include analytics to track growth and use of the data clearinghouse. Mission 3 measures of success by number of students and early career scientists impacted, feedback on the nature of these impacts (participant surveys and alumni communication tools to monitor career trajectories), demographics of scientists at all levels of the network.

All metrics will be tracked by the SZNet Program manager and reported to the Coordinating Committee on an annual basis. The regular report during the project is designed to identify the degree to which the partnerships are mutually beneficial and if adjustments are needed over time to ensure equity.

Table 4. SZNet Goal, Activities, and evaluation and metrics. Note workshop outcomes are listed under Mission 1 and 2 activities.

Mission	Activity	Evaluation & Metrics
1,2,3	Overall Coordination	Funded collaborative proposals between networks. Separately funded complementary proposals in each network. Collaborative projects across national boundaries as tracked from collaborative papers. Website hits, email list growth.
1,2	Workshops	Achievement of Mission 1 and 2 workshop outcomes (see Network Activities text). Number of early career attendees. Number of international attendees. Participant surveys.
1	Webinars	Attendee volume and diversity as measured by nationality across networks.
1	Legacy Data Ingestion	Archived data volume (Gbytes both stored and requested). Data usage as tracked by digital object identifiers (DOIs).
1	Data Portal	Number of identified web archives made available. Number of distinct users that received a data request. Diversity of disciplinary archives identified as measured by primary field of usage. Data usage as tracked by DOIs.
3	Field Schools, Pilot Projects, and early career participation in workshops	Number of student participants in schools, pilot projects, and workshops. Diversity of early career scientists attending virtual and in-person activities as measured by voluntary demographic statistics tracking. Participant surveys and alumni tracking from field schools to monitor career trajectories.
3	Student Exchanges	Number of student participants. Participant surveys. Successful degrees earned based on work during exchanges. Long-term collaborations established based on tracking surveys repeated annually post exchange.

Broader Impacts

Understanding geohazards has direct societal significance for the inhabitants of the Pacific Rim and other subduction zones around the world. The lack of understanding of the fundamental controls on when and where impactful earthquakes, eruptions and landslides can happen is a major impediment to focussing resources and mitigation efforts. Developing this understanding through the lens of an international framework allows for the connection of disparate experiences and expertise of experts worldwide. Through missions 1 and 2, the nuances and experiences of scientists from different subduction zone segments will be combined to provide insight on fundamental processes controlling subduction zone hazards, building a more unified understanding that will be disseminated widely. Mission 3 of this program will serve to broaden and connect the international geoscience community, focusing this support on early-career scientists, through the participation in field schools, and pilot projects and student exchanges. Where the field schools and pilot projects will be integral for expanding global research perspectives for early career researchers, the student exchanges will focus on professional development opportunities and enhancing participants skills through exposure to lab settings and resources that may be unavailable at their home institution.

Summary and Outlook

The international scientific community is poised to make major new advances in understanding earthquakes, volcanoes and landslides in subduction zones by capitalizing on recent progress in understanding, the availability of new instrumentation and advances in computational capabilities. Individual countries and networks are making significant investments in new observations and modeling. These investments could yield greater insight if coordinated at a global level. The coordination needs to address intellectual issues, such as the degree of predictability of hazards as well as pragmatic issues, such as data distribution and instrument placement. SZNet proposes a set of workshops, coordination meetings, webinars, field schools, pilot projects and student exchanges that together will address these coordination needs while simultaneously nurturing an international community of scientists equipped to work across disciplinary and geographic boundaries. If successful, SZNet will position us to maximize the scientific gain from existing data and research efforts as well as coordinate the new, more ambitious instrumentation that is required to capture the long-term processes and the rare, catastrophic events that affect millions of lives.

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