GSNL Proposal for Permanent Supersite

A.1 Proposal or Supersite Title: Kamchatka/Kuriles Volcano Supersite (KKVS)

Abstract: This is to propose the Kamchatka/Kuriles volcanoes supersite - KKVS. The region has the highest concentration of active volcanoes in the world, many of the volcanoes are a source of violent explosive eruptions affecting aviation industry, local population, and wildlife. The volcanoes of the Kamchatka Peninsula are already a World Heritage site of the United Nations, and represent key sites for the investigation of volcano growth and collapse, volcanic tsunami studies, degassing, deformation, and environmental interactions. Major settlements (Yelizovo, Klyuchi, etc.) and also the peninsular’s capital town (Petropavlosk-Kamchatsky) is built atop young volcanic deposits. New hazards emerge, such as the town Severo Kurilsk currently suffers from new volcanic activity of Ebeko volcano. As tourism is an increasingly important financial sector, also improved hazard assessment and risk communication are demanded.

Ground truthing, including seismic networks and camera networks, is available for selected sites, and will be expanded by remote sensing data (radar and optical), which are highly demanded for change detection and accurate topographic modelling. Precursors of eruptions and topographical changes of the volcanoes, closely interacting with the cryosphere (glaciers, permafrost) and affecting climate change, can be investigated by multiparametric data streams, where the KKVS supersite has the potential to develop a worldwide unique key observatory for process studies.

The aim of KKVS is to facilitate data access and exchange and to stimulate scientific cooperation. KKVS is led by members of the Kamchatka Institute of Volcanology and Seismology FEB RAS (IVS) (http://www.kscnet.ru/ivs/eng/), but will provide unique opportunities for various research groups worldwide.

A.2 Supersite Coordinator

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A.3 Core Supersite Team

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A.4 Region of Interest

The region of interest is Kamchatka (Fig. 1) and northern Kurile Islands. It has the highest concentration of active volcanoes in the world, many of which are a source of violent eruptions that affect natural environment, infrastructure, and aviation industry. The volcanoes of Kamchatka are listed since 1996 and then extended in 2001 as a **World Heritage site of the United Nations**. Many of the volcanoes are not well monitored. Precursors, interactions and topography are important to understand for hazard assessment. The herein proposed strategy defines the region of interest according to the three main approaches with different priorities:

Priority 1. Annual repeat acquisition at those high priority and hazardous volcanoes subject also to geophysical monitoring. These are 10 volcanoes.

Priority 2. Dense acquisitions at erupting and/or awakening volcanoes as a fast-response action. These are currently 5 volcanoes.

Priority 3. Single satellite data acquisition at selected potentially active volcanoes in order to create a basis for future investigation. These are 77 volcanoes (selected out of 160 volcanoes).

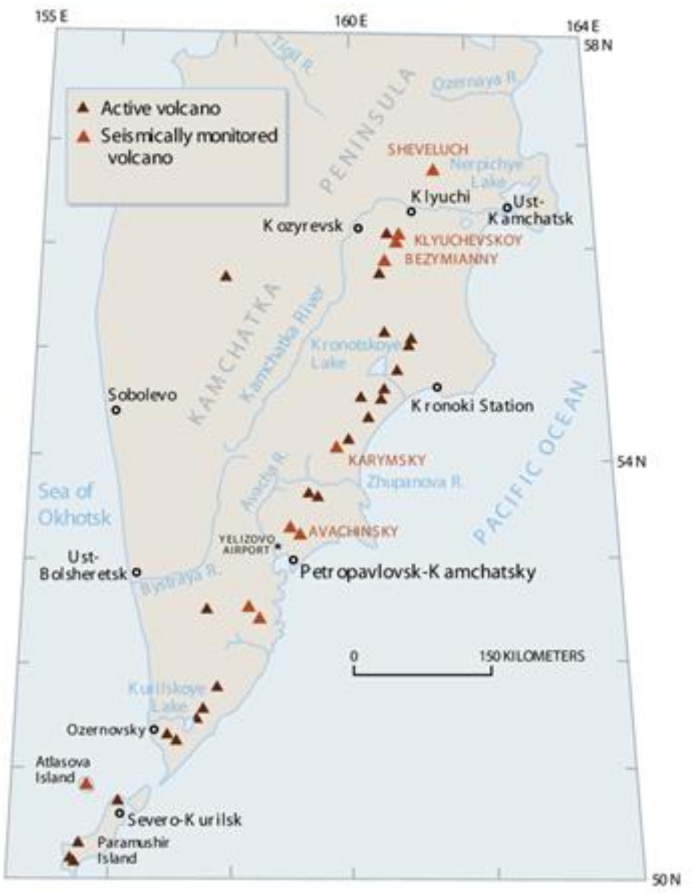

Figure 1. Kamchatka/Kuriles are the Region of Interest (RoI). By combining ground truthing (geophysical and geochemical instrumentations) with satellite remote sensing, all large Holocene volcanoes may be monitored.

The three priorities supersite project plan is:

1. Annual repeat acquisition at those highly active volcanoes subject also to geophysical monitoring.

2. Dense acquisitions at erupting volcanoes as a fast-response action (in 2019 these were Shiveluch and Bezymianny in the north, and Ebeko volcano close to Severo-Kurilsk in the south of the map).

3. Single acquisition at all potentially active volcanoes. Because there are over 160 volcanoes, we selected the scientifically and societal most interesting cases.

Edge of boundary	Latitude	Longitude
North East	56º58’07’’N	165º52’39’’E
South East	47º44’26’’N	154º03’32’’E
North West	58º42’34’’N	156º51’50’’E
South West	48º02’35’’N	152º49’09’’E

Table 1. Limits of the region of interest of the KKVS.

Prio 1: Annual acquisitions at volcanoes (10 sites): Avachinsky, Bezymianny, Karymsky, Kliuchevskoi, Mutnovsky, Gorely, Tolbachik, Shiveluch, Uzon-Geysernaia caldera, Ebeko

Link to the KML files: https://drive.google.com/file/d/1mQlm68_KO0MOEuy2RflFIKHXOzEd9l7Z/view?usp=sharing

Prio 2: Bi-Annual acquisitions at volcanoes (5 sites): Bezymianny, Karymsky, Kliuchevskoi, Shiveluch, Ebeko (note: the same 5 volcano sites are also listed as Prio 1).

Prio 3: Single acquisitions at all (selected) volcanoes: Akademii Nauk, Alney, Asacha, Avachinsky, Bakening, Bezymianny, Bolshoi Semiachik, Chasha Crater, Dikii Greben', Gamchen (Barany Cone), Gorely, Ichinsky, Iliinsky, Kambalny, Karymsky, Khangar, Khodutka, Khodutkinsky Crater, Kikhpinych, Kinenin maar, Kizimen, Kliuchevskoi, Koriaksky, Koshelev, Kozelsky, Krasheninnikov, Kronotsky, Ksudach, Kurile Lake Caldera, Maly Semiachik, Mutnovsky, North Cherpuk Cone, Novo-Bakening, Nylgimelkin (Atlasov), Opala, Ozernovsky Cone, Plosky Dalny (Ushkovsky), Plosky Tolbachik, Sedanka lava field, Shisheika dome, Shishel, Shiveluch, South Cherpuk Cone, Taunshits, Titila, Tobeltsen Cone, Tolbachik lava field, Tolmachev lava field, Udina, Uzon-Geysernaia caldera, Viliuchinsky, Vysoky, X Cone, Zheltovsky, Zhupanovsky, and on Kuriles: Chikurachki, Ebeko, Fuss Peak, Karpinsky, Lomonosov, Vernadskii Ridge, Alaid, Chirinkotan, Ekarma, Kharimkotan, Nemo Peak, Shirinki, Tao-Rusyr, Kuntomintar, Sinarka, Ketoi, Raikoke, Rasshua, Sarychev Peak, Srednii, Ushishur

A.5 Supersite motivation (2-4 pages)

A.5.1. Introduction to the Kamchatka/Kuriles Volcano Supersite (KKVS)

The Kamchatka Peninsula is located on the far eastern edge of Eurasia at the junction of collision between the North American, the Pacific and the Eurasian Plates. There are **about 160 volcanoes, 29 of them are considered to be active** (Fedotov and Masurenkov, 1991). The type of volcanic activity is mostly subduction driven eruptions of andesitic volcanoes (Shiveluch, Bezymianny, Kizimen, Karymsky, Avachinsky, and others). However, there are also basaltic volcanoes with Strombolian eruptions (Klyuchevskoy) and fissure eruptions (Tolbachik), and collapse calderas (Akademii Nauk, Gorely, Mutnovsky, etc.). A speciality of the volcanoes of Kamchatka is, that they are understood to be closely coupled to their environment, which is also why this region may serve as a **natural laboratory for process interaction studies** with worldwide applicability.

Volcanoes of Kamchatka are thought to be interacting with their surrounding, such as neighboring volcanoes may erupt simultaneously, volcanoes suddenly erupt after tectonic earthquakes, and volcano landscapes interact with glaciers and permafrost terrains, subject to climate change. There are areas with strong thermal emissions and secondary hazardous processes (Geysers Valley). Because of the large number of volcanoes, not all of them are monitored by IVS, the Kamchatka Network of Seismic Stations operated Kamchatkan Branch of Geophysical Survey RAS (EMSD, http://glob.emsd.ru/) and temporary networks by partner institutions (e.g., GEOFON, operated by the GFZ Potsdam).

Motivation of the KKVS Supersite is to allow investigating the most active volcanoes of Kamchatka/Kuriles, to exchange and merge ground based and satellite based data and therewith to stimulate the fundamental systems science, process interactions, hazard assessment and risk communication.

A.5.2. Examples of volcanoes: The type and scale of volcanoes is very variable in Kamchatka. A major hazard is posed by andesitic volcanoes with Plinian eruptions, often associated with **either dome growth or caldera forming activity**. The most striking examples of such volcanoes in Kamchatka are the volcanoes Bezymianny and Shiveluch. Objects with **post-volcanic activity** are not less dangerous, and landslides at Geysers Valley induced by thermal activity pose significant hazard as well.

The supersite coordinator and core team has years-long experience on different domains of volcano and earthquake monitoring and process studies. Seismic monitoring is achieved at localized sites only, due to a lack of funding, difficult and hazardous accessibility, and also due to the harsh climate in winter period and vandalism by local residents (Kamchatkan brown bears).

Bezymianny volcano (Fig. 2) reactivated shortly after the 1952 magnitude M9 subduction earthquake, culminating a large sector collapse of the volcano in 1956. Since that time, Bezymianny is one of the most active volcanoes of the world. It took almost thirty years until it was recognised that Bezymianny has many similarities to other unstable volcanoes. This recognition was manifested only after the 1980 Mount St. Helens collapse and lateral blast (Lipman and Millineaux, 1981) and since then many other tall volcanoes are considered structurally unstable, possibly producing destructive large scale sector collapses.

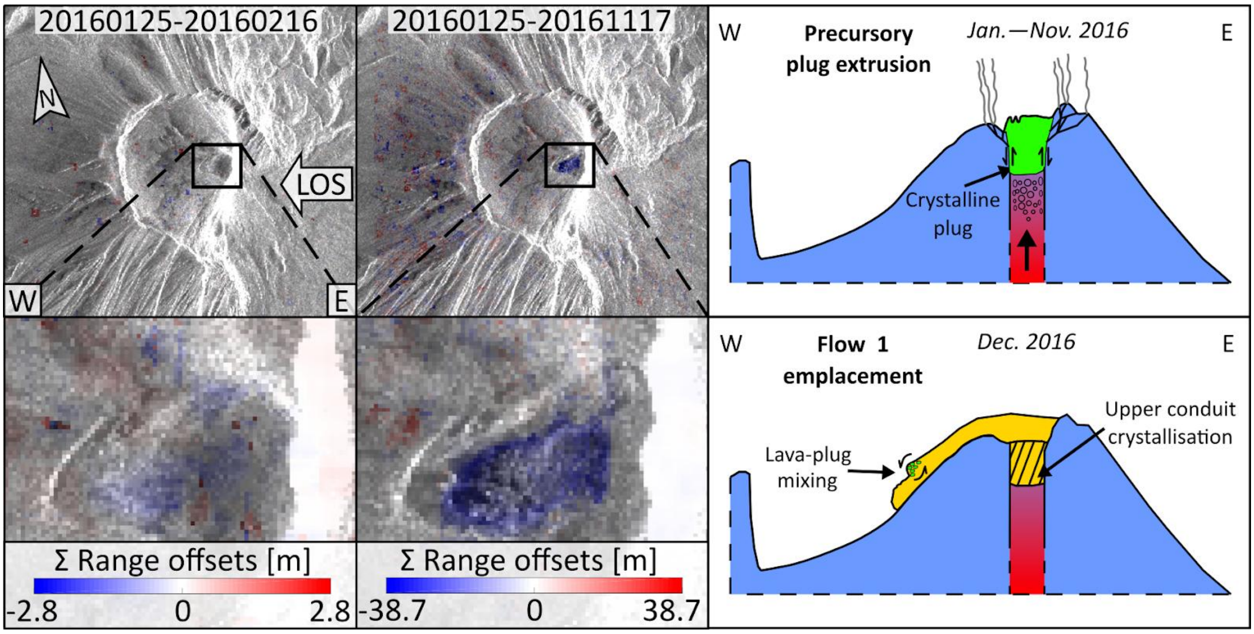

Figure 2. Bezymianny volcano monitored by high resolution SAR (TerraSAR-X spot) allows detecting pre-eruption deformation and extrusion of plug material. After Mania et al., (2019).

Shiveluch is a similar case, the volcano is located 47 km from Klyuchi town, just a few kilometers further North in the Central Kamchatka Depression at the junction of the Aleutian and Kamchatkan volcanic arc. Also Shiveluch is a dome growing volcano and produced a catastrophic eruption on November 12, 1964, that resulted in the failure of the old lava domes (Melekestsev et al., 2003) and formation of 1.8 × 3.5 km collapse amphitheater. Deposits of pyroclastic flows and debris avalanches caused by this eruption covered an area as large as 104 km^2 (Dvigalo and Shevchenko, 2015). Since 1980, a new lava dome has been growing inside the caldera. Large explosions accompany this process with ash columns up to 20 km high (Zharinov and Demyanchuk, 2013), and partial failures of the dome up to 0.28 km^3 in volume; debris avalanches from these partial collapses reach 18 km in length (Dvigalo et al., 2011) in the direction to the town. Secondary hazards such as lahars put infrastructure along rivers such as the fishing industry and roads at significant risk. In 1993, a lahar destroyed a two-kilometer section of the road at the mouth of the river Baydarnaya (19.5 km to the southwest from the active dome). Today, an even longer (5 km) section of the road passing through the alluvial fan, formed by the former lahars, is subject to potential damage. Lahars in 2018-2019 stopped only 6 km before the road and may in future even affect the intersection of the Klyuchi-Ust-Kamchatsk highway with the Behkesh riverbed (22 km to the southeast from the active dome). These lahars can occur without warning and unexpected for local people or vehicles crossing the rivers and bury roads and other infrastructure in thick sediments as a result of quick drying (Fig. 3).

Figure 3. Local transport buried under lahar deposits.

Through satellite imagery, such as Pleiades and dual-polarization Synthetic Aperture Radar (SAR) data, details of volumetric changes and paths of lahars, and the associated hazards will become accessible, and improved ground truthing can be planned. Furthermore, Shiveluch is a highly visited tourist attraction, and many people visiting the volcano are unaware about the potential hazard they are exposed to.

Researchers from the IVS-GFZ joint group processed aerial images of Shiveluch volcano acquired in 1979, 1980, 1994, 2001, 2003, 2005, 2010, and 2012; as well as 2018 Pleiades satellite images. By means of Erdas Imagine and Photomod software we built 9 high resolution DEMs (Fig. 4), traced morphological changes of the dome regrowth, and calculated volumes and extrusion rates, that let us estimate potential hazard (Shevchenko et al., 2015; Shevchenko et al., 2020 (in process). Researchers from GFZ and their partners contribute with local seismic networks (https://geofon.gfz-potsdam.de/doi/network/X9/2015). The data is freely available. Moreover, through dedicated projects, camera field installations and drone flights have been realized, allowing visual observations and photogrammetric methods to be applied.

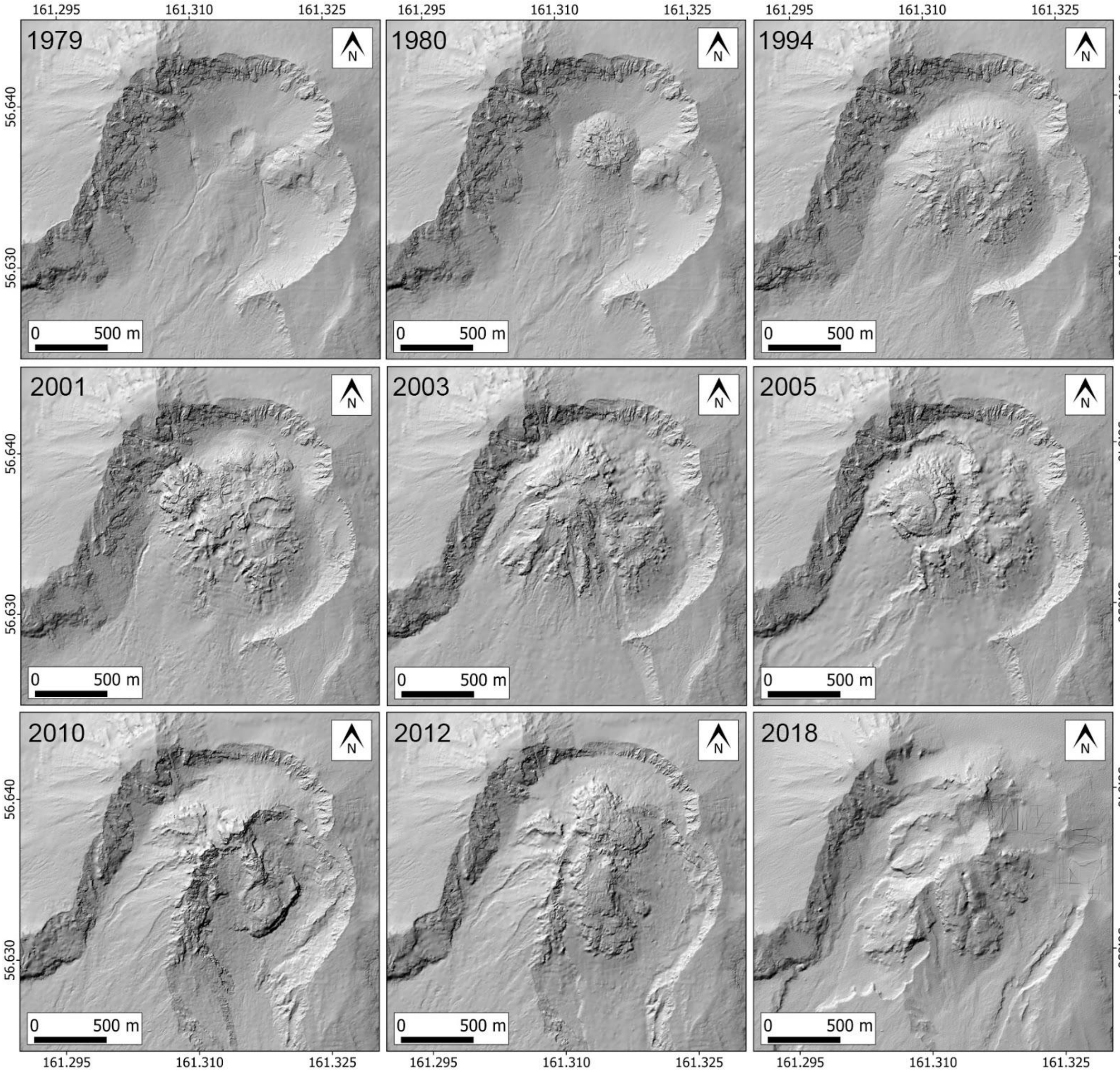

Figure 4. Morphological changes of lava dome at Shiveluch volcano over the 1980-2018 period (partially published in Shevchenko et al., 2015).

Volcanoes of Kamchatka are not only a risk for aviation industry, infrastructure, and tourists but also for populated regions. For instance, an example that poses significant potential risk in Kamchatka peninsula is **Avachinsky** volcano. It is an andesitic volcano located in southern Kamchatka, **22 km northeast of the Petropavlovsk-Kamchatsky city**, the capital town of the peninsula is actually built partly atop debris avalanches of this volcano. Over the last 250 years of observations, 14 eruptions were recorded, which were characterized by explosive and effusive activity. After almost 46 years of relative rest on January 13, 1991, a new eruption of the Avachinsky volcano began with a series of two sub-vertical explosions and lasted 5-6 days. On the second day of the eruption, the outpouring of lava began. After filling the crater to the level of the lower parts of the rim the lava excess flowed through the rim to the south-southeast slopes of the cone in the form of a blocky lava flow. Now, the solidified lava plugs the vent of the volcano occupying the entire crater. The volume of the lava plug in the crater is 8 million m^3, and it's weight amounted to 20 million tons (Melekestsev et al., 1994). The crater has the thinnest wall at the South, and it is under the load of the lava plug. So, the most weakened part of the summit is located in the direction of the Petropavlovsk-Kamchatsky city.

The photogrammetric processing of the 2001 aerial images of Avachinsky volcano revealed a system of new fractures that appeared in the southwestern part of the crater and on the adjacent sections of the slopes. The most noticeable element of the fracture zone is a fissure 315 m in length. Comparing the 1991 and 2001 DEMs of the cone, we identified horizontal displacements in the south-southwestern sector of the lava plug. We measured the distances between certain points on the lava plug's surface, which were located on both sides of the fissure. The measurements from the 2001 DEM showed, on average, a 1.4-m increase in the distances that reflects the width of the fractures on the slopes of the cone. Most likely, during the period of 1991-2001, the lava plug experienced a stretching in the south-western direction, as a result of which a fracture zone formed in the plug. Through this zone, meteoric water leaked and reached the still not cooled lava material, and it caused phreatic explosions in 2001. As a deformation of a slope is often accompanied by its collapse, the most expected hazard in case of the possible unrest of Avachinsky is the collapse of the summit. All known eruptions of the Avachinsky volcano in the Holocene and Upper Pleistocene occurred in the south-western direction, towards the Petropavlovsk-Kamchatsky city (Shevchenko et al, 2020 (in preparation)).

On the basis of these results, we performed a preliminary hazard estimation for Avachinsky volcano (Fig. 5). The red lines show the trajectories of the debris avalanches, pyroclastic flows, and lahars movement drawn from the south-western part of the crater zone. We can assume that if the collapse occurs in the winter, then the snow on the underlying surface will be a factor for a wider distribution of the material. On the map, for each of the three trajectories of the collapse-eruptive masses, the ranges of possible spread of deposits are shown at the following thicknesses of 10, 5, 2.5, and 1 m. The smallest threat to people is in the direction of the middle trajectory. The only danger may be mudflows caused by the impact of mass movement along the snow. In this case, the airport and the summer cottages located to the north of the city are under threat. A western path for volcanic material is also dangerous for the airport. But the main threat is posed by the collapse masses. It should also be taken into account that part of this trajectory passes along the surface of the glacier, which can lead to the formation of lahars at any time of the year. The eastern trajectory is highly dangerous for the suburbs of Petropavlovsk-Kamchatsky, and summer cottages located to the north-west from them. This area may be completely buried under the collapsed masses.

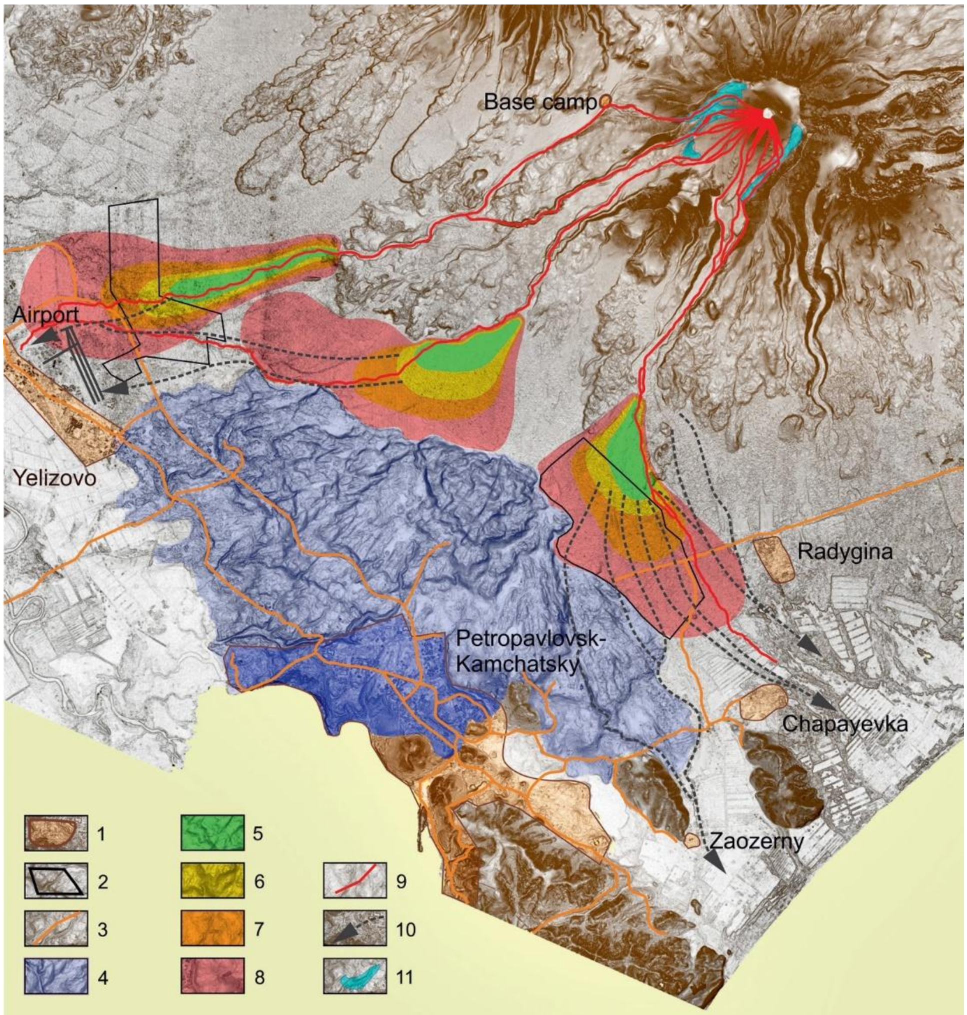

Figure 5. Preliminary hazard map of Avachinsky volcano, the capital town in the south (blue shade). Base map – Arctic DEM Geospatial Data; 1 – populated localities; 2 – summer cottages; 3 – roads; 4 – Upper Pleistocene deposits of eruptive-collapse origin, on the distal part of which Petropavlovsk-Kamchatsky is located; 5-8 – areas of possible spreading of deposits at a thickness of 10, 5, 2.5, 1 m; 9 – the trajectories of the collapses, pyroclastic flows, and lahars movement; 10 – the trajectories of secondary mud flows; 11 – glaciers that can contribute to the hazard.

Another town, which is under a threat of volcanic hazard is Severo-Kurilsk located on the Paramushir island of Kuriles just in 7 km from **Ebeko** volcano (Fig. 6). Ebeko provides four types of hazard to Severo-Kurilsk: lava flow, thephra fallout, eruptive clouds, and lahars (Melekestsev et al., 1994). Eruptive clouds and ashfalls will not pose great hazard because strong winds prevailing at Paramushir. The expected thickness of tephra from the most powerful eruption will not exceed 5 cm. The greatest hazard can be posed by lahars. The proluvial fans of local rivers had been formed by lahar deposits. A lahar can reach the city in 20-30 minutes. The volcano accumulates large amount of snow and ice during winter. Even a partial melting of which during may produce a powerful lahar of a few million m^3 (Melekestsev et al., 1994).

Figure 6. Eruption of Ebeko volcano in 2019; view from Severo-Kurilsk town. Photo by Thomas Walter.

The next example represents **post-volcanic processes and related hazards**. It is the most visited tourist attraction in Kamchatka – **Geysers Valley**. It is located in the eastern part of the Uzon-Geizernaya depression. The Geizernaya River cuts a massif composed by lacustrine-volcanic hydrothermally altered deposits. Such factors as tectonic fracturing, seismicity, steep slopes, rainfalls, and thermal activity make the valley subject to intensive slope processes. The valley was discovered in 1941 and after that there were three landslides recorded: in 1981, in 2007, and in 2014. The first among the historical landslides occurred on October 4, 1981, in the north-eastern slope of the valley, triggered by rainfall extremes during typhoon “Elsa” on October 4, 1981. The next landslide occurred on June 3, 2007 at the south-eastern slope of the valley, causing significant changes in the natural environment (Dvigalo and Melekestsev, 2009). Part of the debris material moved along the river with the formation of a mudflow. At the final stage of the landslide, a large solid block slide occurred. It was slowed down due to collision with debris deposits of the firstly collapsed masses. If it didn’t slide down as a single block and remained intact the consequence could be far more catastrophic. During this event there were people in a hut in the valley. The landslide material stopped in a few meters in front of the hut. There is evidence of fumarolic activity prior to the landslide at the future crown area (Kiryukhin et al., 2012). This suggests that erosion and landsliding is triggered by precipitation extremes (Elsa), the sliding masses block water pathways and geothermal sites, which gradually develop into new geysers and degassing sites. Details of such an interaction are not fully understood and would require interdisciplinary data and monitoring efforts. The latest landslide at the Geysers Valley occurred on January 3, 2014.

By comparing DEMs of Geysers Valley built from 2018 Pleiades images (Fig. 7) and 1993 aerial images, we revealed that the maximum thickness of the latest landslide deposits above the riverbed is 30 m; the volume of the deposits amounted to 1.9

million m^3. The rest of the deposits (the difference between depletion volume and accumulation volume is about 2 million m^3) became a source for a mudflow formation, enlarged by a thick snow cover. Having passed 4.5 km with a height difference of 200 m, the mudflow masses developed such a speed that the height of the waves reached 15 m. The mudflow disrupted the normal activity of some geysers, and completely destroyed the observation platforms located on both banks of the river. A dammed lake appeared above the newly formed dam with the water volume of 260,000 m^3. We suggest that the next landslide could occur in the area north of the 2014 landslide, as the slope there is cut by fractures. The slope angle is about 30°. The volume of the rock block that hangs above the dammed lake is four times larger than of the one collapsed in 2014. The slide of this block down into the dammed lake could lead to the formation of tsunami and powerful mudflow (Shevchenko et al., 2019). Thus, we can conclude that the next landslide could occur anytime in this area and if it happens during tourist season the consequences could be dramatic. It is necessary to perform constant monitoring using remote techniques to prevent fatalities.

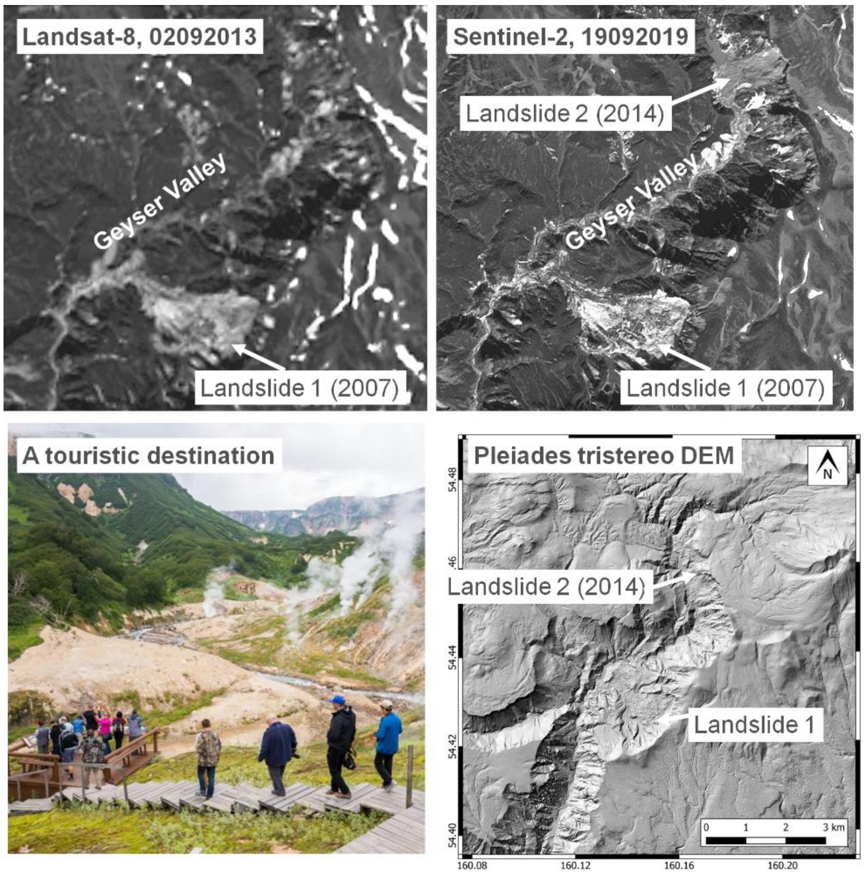

Figure 7. Geyser Valley is a main touristic destination. Upper: Landsat 8 and Sentinel 2 images show a new landslide into the valley in 2014. Lower: Landslides into the valley block the river and put tourists at risk. Hillshade visualisation of DEM built from 2018 Pleiades images of Geysers Valley.

Other researchers have investigated **deformation at Kamchatkan Volcanoes** by using interferometric synthetic aperture radar data (Fig. 8). The phase difference between two SAR scenes of the same target volcano allowed for the identification of deformation patterns characteristic for pre-eruptive inflation (Ji et al., 2013) caldera unrest at Uzon (Lundgren and Lu, 2006) and deformation associated with dike intrusion feeding the Tolbachik fissure eruption (Lundgren et al., 2015).

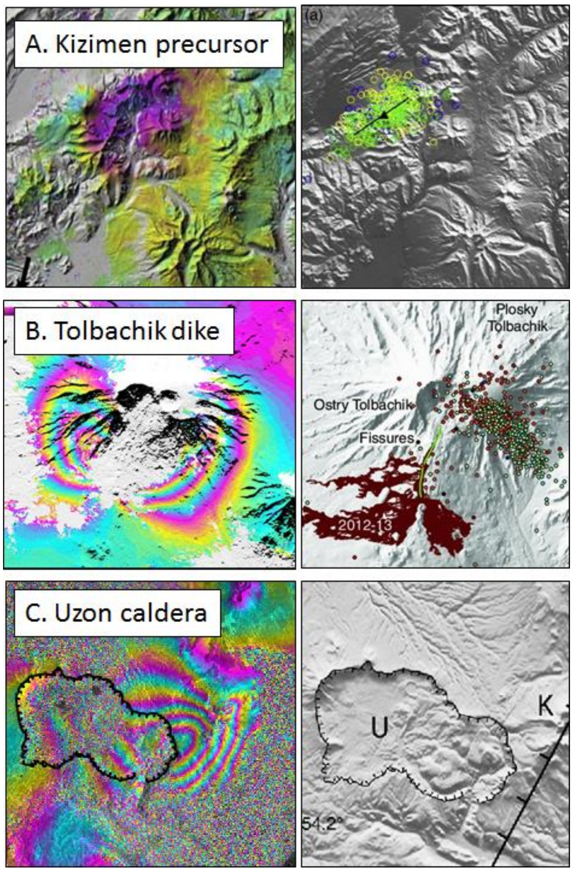

Figure 8. Satellite based InSAR examples over volcanoes of Kamchatka, showing deformation associated with eruption precursors (A.), associated with an eruption feeder dike (B.) and associated with caldera unrest (C.). Caldera deformation is showing strong gradient in vicinity of the Geysers Valley further described below.

Therefore volcano monitoring by SAR systems is also of great value for other sites. With the free availability of Sentinel data, a dense volcano monitoring program has started over Kamchatka (Fig. 9) (Valade et al., 2019).

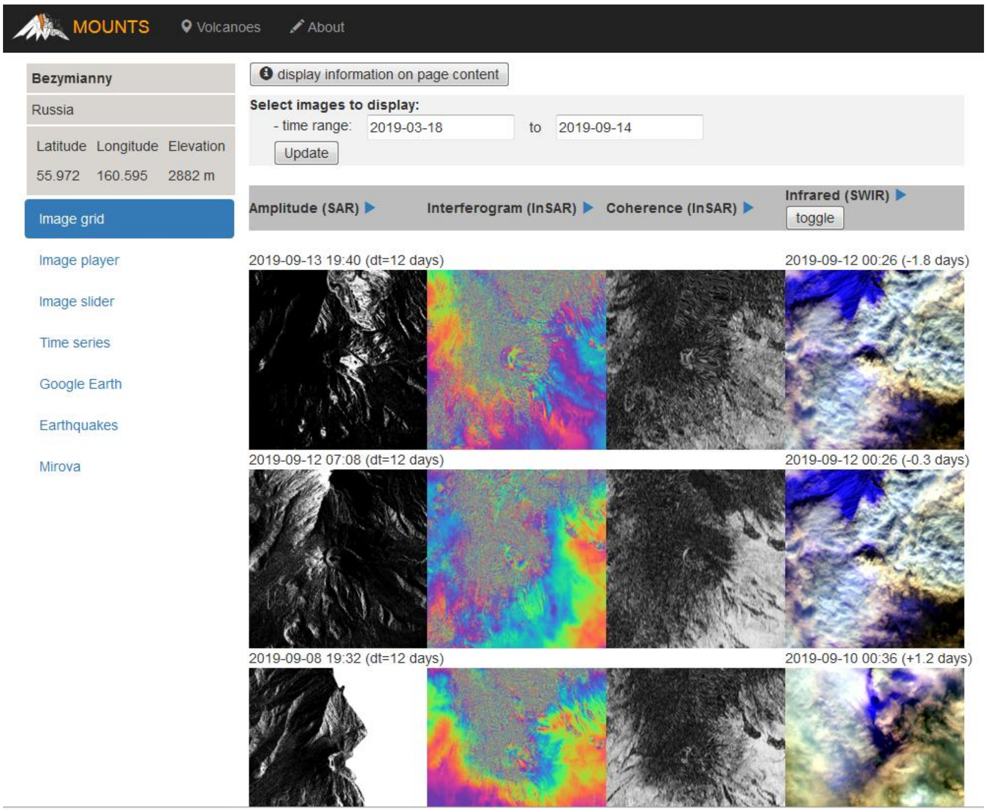

Figure 9. The real time InSAR processor MOUNTS (http://www.mounts-project.com) explores deformation and changes at Kamchatkan volcanoes. Developed at University of Berlin and the GFZ Potsdam (Valade et al., 2019).

Summarizing the volcanic risk of the region, we can conclude that currently the most hazardous volcanic objects are Shiveluch, Bezymianny, Avachinsky, and Ebeko volcanoes, and Geysers Valley in the Uzon-Geizernaya Caldera. In particular, Avachinsky and Ebeko volcanoes **pose a major hazard to the populated areas** (Petropavlovsk-Kamchatsky, Elizovo, and Severo-Kurilsk) and Shiveluch, Bezymianny, and Geysers Valley **pose hazard to Kamchatka visitors and local tourists**, which amount increases each year.

A.5.3. Volcanoes used for societal benefits: Volcanoes of Kamchatka are not only a site of complex interactions and hazards, but are used also for alternative energy production. The Mutnovsky geothermal power plant (Fig. 10) is based on up to 2,000 m deep drill holes and exceeds a 50 MW power production. The energy demand of the capital town of Petropavlosk-Kamchatsky is strongly dependent on this geothermal energy.

Figure 10. Mutnovsky geothermal power plant. Photo taken from: http://greenevolution.ru/

Concerns arose recently as the volcanic activity and thermal emission and degassing in the Mutnovsky geothermal area is increasing. Therefore denser geophysical networks are planned, and **a contribution through the supersites is of importance for scientific analysis of the changes observed**. Notably, the changes in activity occurred shortly after the drilling of additional wells, which is why man made volcano interactions as known from places elsewhere (e.g. Iceland, Juncu et al., 2016) are to be considered.

A.5.5. Duties, responsibilities, and information flow: IVS is an authorative geo-hazard monitoring institution that provides information on the volcanic hazard to the Kamchatka region administration (https://www.kamgov.ru/) and the Ministry of Emergency Situations of the Russian Federation (https://en.mchs.ru/). IVS has Forecasting Volcanic Eruptions Council led by Alexey Ozerov, which arranges regular weekly meeting with discussion on the current state of active Kamchatkan volcanoes. When a volcanic eruptions stats, IVS organizes prompt field units that conduct direct observations of an erupting volcano. **High-resolution satellite data are necessary for organizing such units and planning their's work.** The Kamchatka Volcanic Eruption Response Team (KVERT http://www.kscnet.ru/ivs/kvert/index?lang=en) is a member part of IVS that daily monitors potential volcanic hazards for aviation of the 68 active volcanoes of Kamchatka and Kuril Islands through direct and remote (the Institute's stationary webcams) observations, as well as free access satellite data analysis. The monitoring results are presented in the VolSatView information system (http://volcanoes.smislab.ru), which was created by the staff of IVS, Space research institute FEB RAS (http://www.iki.rssi.ru/eng/index.htm), Computing center FEB RAS (http://www.ccfebras.ru/), and Far-Earstern center of State research center "Planeta" (https://www.dvrcpod.ru/index.php?lan=eng). Operational hazard messages for aviation are promptly submitted under an agreement with the Main center of information technologies and meteorological service for aviation (http://aviamet-telecom.ru/) to the Elizovo Airport Meteorological Center, Pacific Airlines, Tokyo VAAC, Anchorage VAAC, Washington VAAC, Montreal VAAC, Darwin VAAC, Paris VAAC, Alaska Volcanological Observatory and other organizations. KVERT is also summarizing and assessing volcanic hazards for the general public, providing a flag (red-yellow-green) as a hazard indicator.

A.5.4. KKVS objectives: Previously, we obtained our high-resolution remote sensing data from aerial surveys and Pleiades satellite acquisitions but both of the data sources are very expensive. We can obtain them only once per several years. Availability of frequent high resolution optical and SAR acquisitions would let us carry out constant photogrammetric monitoring with the possibility to construct high-resolution DEMs, to calculate precise parameters (volumes, eruption rates etc.), and to trace morphological changes. On the basis of these results we can perform and regularly update relevant hazard estimations for the five described volcanic objects, and for other active volcanoes of Kamchatka and Kurile Islands.

Specific goals of the supersite will be:

1. To collect space-borne data for volcanoes in three priorities, first priority are highly active volcanoes with major hazards, second priority are rapid response actions at those volcanoes undergoing dramatic changes (red flagged in alert), third priority are one-time measurements at all volcanoes of the Kamchatka/Kuriles Volcano Supersite (KKVS).
2. To establish regional source models (volcanic objects), mostly based on ongoing research at Kamchatka Institute of Volcanology and Seismology.
3. To develop a strategy for deformation monitoring based on InSAR and optical (Pleiades) data processing.
4. To develop an early warning system for volcanic unrest, also involving automatic processing workflows such as from the MOUNTS system.
5. To set and integrate early-warning system coupling seismicity with deformation (Pleiades DEMs comparison, InSAR) and degassing from space-borne, and other data.
6. To improve the capability to track effusion/emission rates based on optic, radar and other aerial image products.
7. To improve the capability to generate high resolution hazards maps for lahars and other debris flows.
8. To develop new products and services based on collaboration within GSNL, for first responders, civil, and scientific communities.

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A.6 Access to in situ data

Type of data	Data source	Data access
Seismic data	The GEOFON broadband network https://doi.org/10.4401/ag-4196	https://geofon.gfz-potsdam.de/ Waveform access: https://geofon.gfz-potsdam.de/old/waveform/
Seismic data	Broadband network of radio telemetric seismic stations (RTSS) of Kamchatka http://www.emsd.ru/rtss/stations	Kamchatka Branch of the Geophysical Service RAS http://www.emsd.ru/~ssl/monitoring/main.htm The data are in open access, but to use in publication purposes please address the director of the Geophysical Service Danila Chebrov for the permission (danila@emsd.ru). http://sdis.emsd.ru/info/earthquakes/catalogue.php The data can be available only via registration

		and upon request to the director of the Geophysical Service Danila Chebrov (danila@emsd.ru). The seismic catalogues are regularly updated.
Seismic data	Temporary seismic networks - Klyuchevskoy volcanic group experiment (KISS)	Available via the GEOFON data service https://doi.org/10.14470/K47560642124 This data is currently restricted, but will soon be made available supporting the supersite initiative.
Camera monitoring networks at volcanoes	KVERT GFZ	http://geoportal.kscnet.ru/volcanoes/webcams.php?lang=en Temporary camera networks installed during the ERC project Volcapse will be made available.
Data analysis tools	SEED, MiniSEED, and many others	Tools available via GFZ and the created Spin off company at https://www.seiscomp3.org/ Scientific use of seismic data, tools now freely available at https://pyrocko.org/docs/current/apps/snuffler/ Similar as other tools: QSEIS - Synthetic seismograms for a layered flat earth EDGRN / EDCMP - Static co-seismic deformation PSGRN / PSCMP - Co- and post-seismic viscoelastic deformation POEL - Poroelastic diffusion and deformation QSSP - Complete synthetic seismograms for a spherical earth SDM - Geodetic finite-fault slip inversion PYROCKO - Tool box for seismology Triangular dislocations (TDs) - Elastic deformation modelling tool Compound dislocation models (CDMs) - Elastic deformation modelling tool
Ground deformations: high resolution DEMs.	Aerial survey with AFATE-140 and Phase One IXA180 aerial cameras	DEMs are available among IVS and GFZ scientists. After establishing the supersite will be available for all GSNL scientists.
Temperature	MODIS	http://www.mirovaweb.it/?country_id=2012

InSAR	Sentinel 1A/B Automatic processing and update of d-InSAR products.	http://www.mounts-project.com/timeseries/300250 http://www.mounts-project.com/timeseries/300260
Water geochemistry	Annual field campaigns at many volcanoes of Kamchatka, - Physicochemical parameters - major and trace elements - stable and radiogenic isotopes	Institute of Volcanology and Seismology (in charge: Deputy Director for scientific work Ph.D. Kalacheva Elena Gennadevna) tel. +7 4152 202102 e-mail: keg@kscnet.ru
Sea level monitoring	Tide gauge stations Time span of data: 1957–2019	https://www.psmsl.org/data/obtaining/stations/824.php

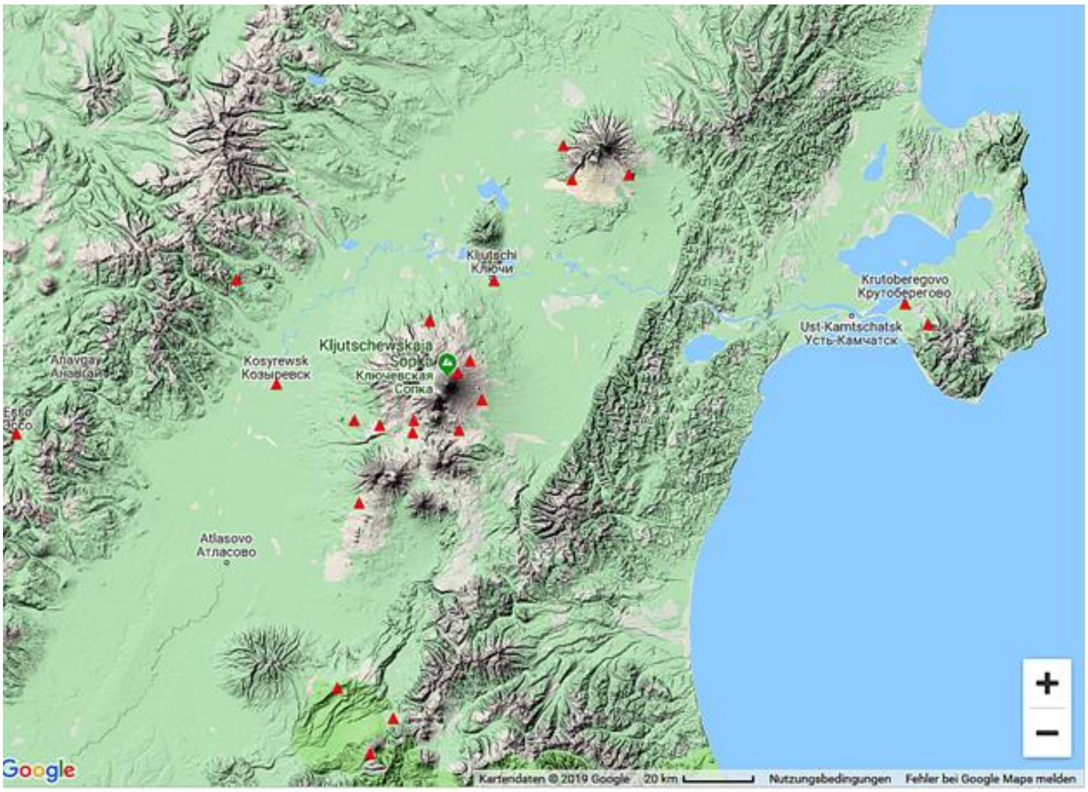
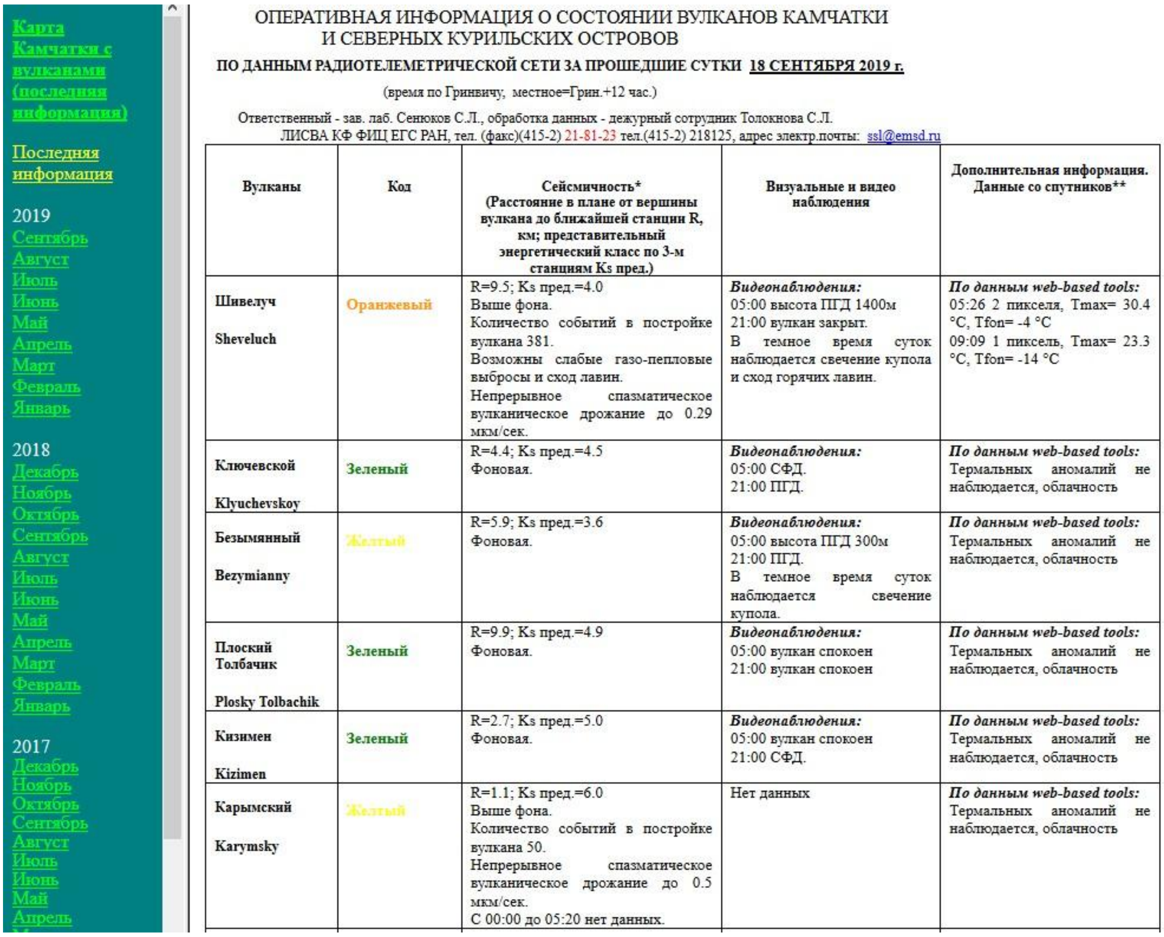


Figure 11. Ground based (seismic) monitoring network (red triangles) in northern Kamchatkan region, focussing on the few but most dangerous volcanoes. All the stations are available from the partner institution website at GFZ: Geofon.

Station Code	Station Name	Latitude	Longitude	Data Center(s)
BDR	Station Monitoring station BDR	56.568	161.208	GEOFON
BZG	Station Monitoring station BZG	55.9399	160.6961	GEOFON
BZM	Station Monitoring station BZM	55.935	160.49	GEOFON
BZW	Station Monitoring station BZW	55.965	160.4965	GEOFON
CIR	Station Monitoring station CIR	56.115	160.748	GEOFON
ESO	Station Monitoring station ESO	55.9322	158.6948	GEOFON
KBG	Station Monitoring station KBG	56.2584	162.7127	GEOFON
KBT	Station Monitoring station KBT	56.208	162.819	GEOFON
KIR	Station Monitoring station KIR	55.953	160.342	GEOFON
KLY	Station Monitoring station KLY	56.3167	160.8574	GEOFON
KMN	Station Monitoring station KMN	55.756	160.247	GEOFON
KOZ	Station Monitoring station KOZ	56.0576	159.8721	GEOFON
KPT	Station Monitoring station KPT	55.966	160.222	GEOFON
KRS	Station Monitoring station KRS	56.217	160.565	GEOFON
KRY	Station Monitoring station KRY	54.036	159.449	GEOFON
KZV	Station Monitoring station KZV	55.1132	160.2938	GEOFON
LGN	Station Monitoring station LGN	56.083	160.69	GEOFON
MKZ	Station Monitoring station MKZ	54.556	161.73	GEOFON
SMK	Station Monitoring station SMK	56.582	161.468	GEOFON
SRD	Station Monitoring station SRD	56.319	159.693	GEOFON
SRK	Station Monitoring station SRK	56.654	161.168	GEOFON
TUM	Station Monitoring station TUM	55.283	160.146	GEOFON
TUMD	Station Monitoring station TUMD	55.2026	160.3989	GEOFON
ZLN	Station Monitoring station ZLN	56.017	160.803	GEOFON

Table 2. GEOFON station.



Карта Камчатки с вулканами (последняя информация)

Последняя информация

2019
Сентябрь
Август
Июль
Июнь
Май
Апрель
Март
Февраль
Январь

2018
Декабрь
Ноябрь
Октябрь
Сентябрь
Август
Июль
Июнь
Май
Апрель
Март
Февраль
Январь

2017
Декабрь
Ноябрь
Октябрь
Сентябрь
Август
Июль
Июнь
Май
Апрель

ОПЕРАТИВНАЯ ИНФОРМАЦИЯ О СОСТОЯНИИ ВУЛКАНОВ КАМЧАТКИ
И СЕВЕРНЫХ КУРИЛЬСКИХ ОСТРОВОВ

ПО ДАННЫМ РАДИОТЕЛЕМЕТРИЧЕСКОЙ СЕТИ ЗА ПРОШЕДШИЕ СУТКИ 18 СЕНТЯБРЯ 2019 г.

(время по Гринвичу, местное=Грин.+12 час.)

Ответственный - зав. лаб. Сенюков С.Л., обработка данных - дежурный сотрудник Толокнова С.Л.
ЛИСВА КФ ФИЦ ЕГС РАН, тел. (факс)(415-2) 21-81-23 тел.(415-2) 218125, адрес электр.почты: ssl@emsd.ru

Вулканы	Код	Сейсмичность* (Расстояние в плане от вершины вулкана до ближайшей станции R, км; представительный энергетический класс по 3-м станциям Ks пред.)	Визуальные и видео наблюдения	Дополнительная информация. Данные со спутников**
Шивелуч Sheveluch	Оранжевый	R=9.5; Ks пред.=4.0 Выше фона. Количество событий в постройке вулкана 381. Возможны слабые газо-пепловые выбросы и сход лавин. Непрерывное спазматическое вулканическое дрожание до 0.29 мкм/сек.	*Видеонаблюдения:* 05:00 высота ПГД 1400м 21:00 вулкан закрыт. В темное время суток наблюдается свечение купола и сход горячих лавин.	*По данным web-based tools:* 05:26 2 пикселя, Tmax= 30.4 °C, Tfon= -4 °C 09:09 1 пиксель, Tmax= 23.3 °C, Tfon= -14 °C
Ключевской Klyuchevskoy	Зеленый	R=4.4; Ks пред.=4.5 Фоновая.	*Видеонаблюдения:* 05:00 СФД. 21:00 ПГД.	*По данным web-based tools:* Термальных аномалий не наблюдается, облачность
Безымянный Bezymianny	Желтый	R=5.9; Ks пред.=3.6 Фоновая.	*Видеонаблюдения:* 05:00 высота ПГД 300м 21:00 ПГД. В темное время суток наблюдается свечение купола.	*По данным web-based tools:* Термальных аномалий не наблюдается, облачность
Плоский Толбачик Plosky Tolbachik	Зеленый	R=9.9; Ks пред.=4.9 Фоновая.	*Видеонаблюдения:* 05:00 вулкан спокоен 21:00 вулкан спокоен	*По данным web-based tools:* Термальных аномалий не наблюдается, облачность
Кизимен Kizimen	Зеленый	R=2.7; Ks пред.=5.0 Фоновая.	*Видеонаблюдения:* 05:00 вулкан спокоен 21:00 СФД.	*По данным web-based tools:* Термальных аномалий не наблюдается, облачность
Карымский Karymsky	Желтый	R=1.1; Ks пред.=6.0 Выше фона. Количество событий в постройке вулкана 50. Непрерывное спазматическое вулканическое дрожание до 0.5 мкм/сек. С 00:00 до 05:20 нет данных.	Нет данных	*По данным web-based tools:* Термальных аномалий не наблюдается, облачность

Figure 12. Prompt information on the state of Kamchatkan volcanoes based on radio telemetric seismic data from Kamchatka branch of the Geophysical Service http://www.emsd.ru/~ssl/monitoring/main.htm.

Figure 13. The eruption response team is using available data for color flagging volcanic activities, such as seismic data and webcam data (as illustrated here), http://www.kscnet.ru/ivs/kvert/index_eng.php, providing one possible product for end users.

A.7 Supersite activity work plan

Synthetic aperture radar data is of especially high value due to the frequent cloud cover of the region, and the possibilities to detect ground movements, changes and deposition of new materials, and therewith to map hazard zones at the volcanoes. Important for a large number of studies is the acquisition and generation of accurate digital surface models (DSM). Available Tandem-X and Gtopo data are not providing resolutions to detect subtle changes or to develop appropriate hazard maps. Therefore the past activities of IVS was to gather aerophotos, but as helicopter prices have increased, satellite imagery is highly demanded. Here we propose to rely on tri-stereo Pleiades imagery for DEM extraction.

The Supersite plan for the coming years is including the following:

1. To create interest for the scientific problems among the international community.
2. To improve our understanding of volcanic hazards, such as volcano interactions, primary and secondary effects, from caldera-forming eruptions to lahar pathways.
3. Work to attract funds from local and international sources, following an integrated approach.
4. Closely work with the help of the GSNL, GEO, and CEOS, and to establish the technological means for sharing the Supersite data.

Specifically, we plan on addressing hazard related problems outlined in the proposal at the priority 1 and priority 2 volcanoes first, where the following working steps are foreseen:

1. Obtaining selected SAR and Tri-stereo Pleiades images.
2. Processing data with SNAP and SARscape software, and with Erdas Imagine software.
3. Analysing changes in amplitude, coherence and phase and determining morphologic changes by comparison to previous digital elevation models, calculating parameters of eruptions (increase in volume, extrusion rates, etc.), describing morphological changes.
4. Releasing updated topographic datasets for improved InSAR processing (especially for x-band satellites CSK and TSX) by Supersite community.
5. Hazard estimation by slope and steepest descent path simulation modelling.
6. Communicating with local authorities, reserves administrations, and tourist agencies.
7. Creating information brochures for tourists.
8. Host applications for international conferences at the *International Association of Volcanology and Chemistry of the Earth's Interior* (IAVCEI) in the next 5 years.

A.8 Available Resources

As a government research institute, IVS benefits from a budget that pays the salaries of scientists. Currently resources for field works are limited and include few daily allowances during field works, payments for purchased equipment, and helicopter overflights (no more than once per year at a single volcano due to very high prices). However, research activities are greatly benefiting from cooperation with scientists on the mainland (Moscow, Novosibirsk) and internationally (USA, Germany, France, Italy, Japan, China, and others).

IVS hosts a large research building in Petropavlosk-Kamchatsky, with office space available for guests, and runs a large number of external observatory posts at active volcanoes (Priority 1 volcanoes in this proposal). These include buildings close to the volcanoes, which are equipped with all needs for successful field operations. In addition, the IVS hosts research vehicles (4WD) and contacts to experienced helicopter pilots allowing overflights even at highly elevated volcanoes.

Due to the high visibility of the Supersites Initiative we expect to be able to attract more resources within a time frame of 2-4 years.

The partner institute GFZ Potsdam in Germany, the governmental lab for geosciences belonging to the Helmholtz Centres, is supporting the Supersites Initiative by releasing available campaign data, offering distribution and training in data analysis and modelling tools. It is further financing regular expeditions to selected volcanoes in Kamchatka, and is stimulating student and staff exchange through internal funds. Extramural fund acquisition is relevant for the GFZ staff, so that close interaction and coordination of projects such as in the Supersites framework are strongly supported, increasing visibility and scientific efficiency.

A.9 EO data requirements

COSMO-SkyMed

	Information	Notes
Image mode	Stripmap/spotlight (tbd)	COSMO SkyMED is intended for near real time monitoring with InSAR Spotlight coverage might be requested for limited time and specific high resolution needs
Orbit pass	Descending and ascending passes	
Look direction		

Beam or incidence angle (range)	tbd	
Polarization		
Type of Product	SLC	
Number of archive images requested	The entire archive over the AOI prior 1, it is about 700 images	
Number of new images requested, per year	ca 100 SAR images (every 2 weeks during quiescence periods, plus maximum temporal coverage during unrest or eruption)	

TerraSAR X / TanDEM X:

	Information	Notes
Image mode	Stripmap for large volcanoes, Spotlight for domes Experimental modes (staring spotlight) at 2 volcanoes (tbd)	TerraSAR X (TanDEM X) is mostly for high resolution monitoring during the quiescent periods and DEM production at the selected sites.
Orbit pass	Descending and ascending passes	
Look direction		
Beam or incidence angle (range)	tbd	
Polarization	HH or VV	
Type of Product	SLC	

Number of archive images requested	The entire archive over the AOI prio 1, it is about 100 images	
Number of new images requested, per year	ca 100 SAR images	

ALOS 2:

	Information	Notes
Image mode	Stripmap, Wide Swath	ALOS-2 is intended for near real time monitoring with InSAR; fundamental for highly vegetated areas.
Orbit pass	Descending and ascending passes	
Look direction		
Beam or incidence angle (range)	tbd	
Polarization	dual-polarization	
Type of Product	SLC	
Number of archive images requested	The entire archive over the AOI prio 1, it is about 400 images	
Number of new images requested, per year	ca 50 SAR images	

RADARSAT 2:

	Information	Notes
Image mode	Stripmap, Wide Swath	Rsat 2 is used for continuous monitoring in the

		quiescent periods. It will complement Sentinel 1 with images with different line of sights, useful to determine the 3D deformations. This could be possible if ESA provides acquisitions with 6-day interval from the Sentinel-1 track.
Orbit pass	Descending and ascending passes	
Look direction		
Beam or incidence angle (range)	tbd	
Polarization		
Type of Product	SLC	
Number of archive images requested	The entire archive over the AOI prio 1, it is about 200 images	
Number of new images requested, per year	ca 50 SAR images	

Pleiades:

	Information	Notes
Image mode	Tristereo	Optical images are intended for detection of morphological changes (e.g., variations of craters, calderas and domes, glacier response to subglacial ice-melting; slow slope failure, etc.). Sub-meter DEMs from the tri-stereo are important for sin- and post-eruption

		changes in summit areas.
Orbit pass	tbd	
Look direction		
Beam or incidence angle (range)	tristereo	
Polarization		
Type of Product		
Number of archive images requested	Prio 1 - 10 volcano sites, Prio 2-5 volcano sites, Prio 3 (one time only) are 60 volcano sites	
Number of new images requested, per year	10 images	

A.10 Declaration of commitment

The Supersite is intended to provide open access to data to all scientists. We want to share the data, either collected by IVS, or by other institutions, or provided by the space agencies according to a Data Policy to be defined. The data policy which will be agreed among all data contributors in the Supersite and will be compliant to the Data Policy Principles of the GEOGSNL Initiative. The data will remain the property of the owner, who will be given proper attribution using Persistent Identifiers, and will be shared according to rules set in data-specific licenses. We anticipate that during volcanic emergencies there could be temporary data access restrictions. Moreover, since one of the goals of the Supersite is to improve capacity building of the local monitoring/scientific community, the data policy will set rules to stimulate scientific collaboration with the local scientists.

A.11 Further comments

Later, we would like to include more scientists to the core team of Kamchatka/Kuriles Volcanoes Supersite.