www.earthobservations.org/gsnl.php

Geohazard Supersites and Natural Laboratories Initiative

A.1 Proposal Title:

Volcano-tectonic Geohazard Interaction within the Nicaraguan Depression

Volcanoes: Cosiguina, San Cristóbal, Telica, Cerro Negro, Momotombo, Península de Chiltepe, Masaya and Concepción

A.2 Supersite Coordinator

Email (Organization only)	iris.cruz@ineter.gob.ni
Name:	Iris Valeria
Surname:	Cruz Martínez
Position:	Director General of Geology and Geophysics
Personal website:	*<In case a personal web page does not exist, please provide a CV below this table>*
Institución:	Instituto Nicaragüense de Estudios Territoriales-INETER-Nicaragua
Type of institution (Government, Education, other):	Government
The institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua
Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761 Fax +505-22491082

A.3 Core Supersite Team

Email (Organization only)	co-direccion@ds.ineter.gob.ni
Name:	Federico Vladimir
Surname:	Gutiérrez Corea
Position:	Director of the Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Personal website:	http://www.vlado.es/ http://uni.academia.edu/FedericoVLADIMIRGutierrez/CurriculumVitae
Institution:	Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Type of institution (Government, Education, others):	Government
Institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua
Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761 Fax +505-22491082

Email (Organization only)	pcl11@psu.edu
Name:	Peter
Surname:	La Femina
Position:	Associate Professor of Geosciences (volcanism and tectonics)
Personal website:	Curriculum Vitae *https://www.geosc.psu.edu/academic-faculty/lafemina-peter*
Institution:	The Pennsylvania State University
Type of institution (Government, Education, others):	Education
Institution's web address:	www.psu.edu
Address:	201 Old Main
City:	University Park
Postal Code/Postal Code:	16802
Country:	United States

Province, Territory, State or County:	Pennsylvania
Phone number:	814-865-7326

Email (Organization only)	robin@geofisica.unam.mx
Name:	Robin
Surname:	Campion
Position:	Researcher- *Satellite measurements of volcanic gases, dynamics of lava domes and lava lakes.*
Personal website:	*http://robindesvolcans.overblog.com/* *https://www.researchgate.net/profile/Robin_Campion*
Institution:	Instituto de Geofísica, Universidad Nacional Autónoma de México
Type of institution (Government, Education, others):	Education
Institution's web address:	http://www.geofisica.unam.mx/
Address:	Instituto de Geofísica Circuito Exterior s.n. Colonia UNAM C.U.
City:	Coyoacan
Postal Code/Postal Code:	04510
Country:	Mexico
Province, Territory, State or County:	Ciudad de México
Phone number:	+5215527319020

Email (Organization only)	b.vanwyk@uca.fr
Name:	Benjamín
Surname:	van Wyk de Vries
Position:	Professor
Personal website:	Curriculum Vitae *: see below*
Institution:	Université Clermont Auvergne, Observatoire du Physique du Globe de Clermont, Laboratoire Magmas et Volcans
Type of institution (Government, Education, others):	Education, Research, Observatory
Institution's web address:	https://www.uca.fr/
Address:	Campus Universitaire des Cézeaux, 6 Avenue Blaise Pascal, TSA 60026 - CS 60026, 63178 AUBIERE Cedex,
City:	Clermont Ferrand

Postal Code/Postal Code:	63178
Country:	France
Province, Territory, State or County:	Auvergne Rhone Alps
Phone number:	+33 660206927

A.4 Supersite team and organization

The research team of the Directorate of Volcanology of INETER, is made up of specialists who have experience working with different techniques of monitoring, analysis, data processing and research that serve for volcanic monitoring. Below is a list of specialists with their role and experience:

Email (Organization only)	eveling.espinoza@ineter.gob.ni
Name:	Eveling Patricia
Surname:	Espinoza Jaime
Position:	*Responsible for the direction of Volcanology* *Geological studies and mapping of volcanic hazards/numerical modeling and stratigraphic surveying of volcanic deposits.*
Personal website:	*<In case a personal web page does not exist, please provide a CV below this table>*
Institution:	Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Type of institution (Government, Education, others):	Government
Institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua
Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761 Fax +505-22491082

Email (Organization only)	armando.saballos@ineter.gob.ni
Name:	José Armando
Surname:	Saballos Pérez
Position:	*Vulcanology advisor-PhD. Geophysicist and volcanologist, specialist in volcanic deformation and numerical modeling of volcanic phenomena.*

Personal website:	*<In case a personal web page does not exist, please provide a CV below this table>*
Institution:	Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Type of institution (Government, Education, others):	Government
Institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua
Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761 Fax +505-22491082

Email (Organization only)	teresa.olivares@ineter.gob.ni
Name:	Teresita de la Concepción
Surname:	Olivares Loaisiga
Position:	*Geologist, performs stratigraphic surveys of volcanic deposits in the different volcanic structures, for the construction of maps of volcanic hazards.*
Personal website:	*<In case a personal web page does not exist, please provide a CV below this table>*
Institution:	Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Type of institution (Government, Education, others):	Government
Institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua
Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761 Fax +505-22491082

Email (Organization only)	martha.ibarra@ineter.gob.ni

Name:	Martha Lizette
Surname:	Ibarra Carcache
Position:	*volcanologist, responsible for the measurements and processing of sulphur dioxide and carbon dioxide flow data in active volcanoes in Nicaragua.*
Personal website:	*<In case a personal web page does not exist, please provide a CV below this table>*
Institution:	Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Type of institution (Government, Education, others):	Government
Institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua
Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761 Fax +505-22491082

Email (Organization only)	dodanis.matus@ineter.gob.ni
Name:	Dodanis
Surname:	Matus Sánchez
Position:	*Chemical, responsible for SO2, CO2 and H2S measurements, with the most successful equipment in Nicaragua's active volcanoes.*
Personal website:	*<In case a personal web page does not exist, please provide a CV below this table>*
Institution:	Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Type of institution (Government, Education, others):	Government
Institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua
Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761

	Fax +505-22491082

Email (Organization only)	david.chavarria@ineter.gob.ni
Name:	David Salvador
Surname:	Chavarría González
Position:	*volcanic monitoring, performs temperature measurements, thermal imaging and visual observations on active volcanoes in Nicaragua.*
Personal website:	*<In case a personal web page does not exist, please provide a CV below this table>*
Institution:	Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Type of institution (Government, Education, others):	Government
Institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua
Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761 Fax +505-22491082

Email (Organization only)	Elvis.mendoza@ineter.gob.ni
Name:	Elvis Leif
Surname:	Mendoza Rivera
Position:	*Electronics, currently responsible for the maintenance of the different instruments installed for* volcanic *monitoring (Sismo-volcanic stations, gas stations and webcams).*
Personal website:	*<In case a personal web page does not exist, please provide a CV below this table>*
Institution:	Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Type of institution (Government, Education, others):	Government
Institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua

Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761 Fax +505-22491082

Email (Organization only)	Rinath.cruz@ineter.gob.ni
Name:	Rinath José
Surname:	Cruz Talavera
Position:	*Geologist, performs stratigraphic surveys of volcanic deposits in the different volcanic structures, for the construction of maps of volcanic hazards.*
Personal website:	*<In case a personal web page does not exist, please provide a CV below this table>*
Institution:	Nicaraguan Institute of Territorial Studies-INETER-Nicaragua
Type of institution (Government, Education, others):	Government
Institution's web address:	https://www.ineter.gob.ni/
Address:	Front of Solidarity Hospital
City:	Managua
Postal Code/Postal Code:	2110 Managua, Nicaragua
Country:	Nicaragua
Province, Territory, State or County:	Managua
Phone number:	Tel. +505-22492761 Fax +505-22491082

A.5 Other supersite research teams

Email (Organization only)	cuw25@psu.edu
Name:	Christelle
Surname:	Wauthier
Position:	Associate Professor of Geosciences- *Volcanism and tectonics.*
Personal website:	*http://www.geosc.psu.edu/academic-faculty/wauthier-christelle*

Institution:	The Pennsylvania State University
Type of institution (Government, Education, others):	Education
Institution's web address:	www.psu.edu
Address:	201 Old Main
City:	University Park
Postal Code/Postal Code:	16802
Country:	United States
Province, Territory, State or County:	Pennsylvania
Phone number:	814-865-7326

Email (Organization only)	nbobrows@iup.uni-heidelberg.de
Name:	Nicole
Surname:	Bobrowski
Position:	Research Assistant
Personal website:	Curriculum Vitae *o link*
Institution:	Institute of Environmental Physics, University Heidelberg- *volcanic degassing - particular focus on halogens.*
Type of institution (Government, Education, others):	University
Institution's web address:	https://www.iup.uni-heidelberg.de
Address:	INF 229
City:	Heidelberg
Postal Code/Postal Code:	69120
Country:	Germany
Province, Territory, State or County:	Baden-Württemberg
Phone number:	0049 6221546309

Email (Organization only)	hugo@geofisica.unam.mx
Name:	Hugo
Surname:	Delgado Granados
Position:	Director
Personal website:	Curriculum Vitae *o link*

Institution:	Instituto de Geofísica, Universidad Nacional Autónoma de México
Type of institution (Government, Education, others):	Education
Institution's web address:	http://www.geofisica.unam.mx/index.html
Address:	Av. Universidad 3000, Circuito Científico s/n, Ciudad Universitaria, Coyoacán 04510 CDMX
City:	Mexico City
Postal Code/Postal Code:	04510
Country:	Mexico
Province, Territory, State or County:	Mexico City
Phone number:	+52-55-5622-4122

Email (Organization only)	denis@geofisica.unam.mx
Name:	Denis Legrand
Surname:	
Position:	Researcher
Personal website:	Curriculum Vitae *o link*
Institution:	Universidad Nacional Autónoma de México- *volcanic seismology*.
Type of institution (Government, Education, others):	Estatal
Institution's web address:	www.geofisica.unam.mx
Address:	Av. Universidad 3000, Coyoacan
City:	Ciudad de México
Postal Code/Postal Code:	04510
Country:	México
Province, Territory, State or County:	
Phone number:	

A.6 Region of Interest

The area of interest, focuses on the Depression of Nicaragua where the chain of active volcanoes or Nicaraguan volcanic front that has an NW-SE trend (Figure 1) is located, extending from the Cosigüina Volcano to the Maderas Volcano, on the island of Ometepe (Lake Nicaragua). The Nicaraguan volcanic chain is divided into two main segments, the NW segment, extends approximately 170km from the Cosigüina volcano, in the Gulf of Fonseca to the Apoyeque volcano, on the NO edge of Managua; and Segment SE, extends for 150km from the Masaya volcano, located at the SE end of Managua, to the Maderas volcano on the island of Ometepe, within Lake Nicaragua. In the last 40 years, there has been eruptive activity interrupted in six volcanoes, namely: San Cristobal, Telica, Cerro Negro, Momotombo, Masaya and Concepción.

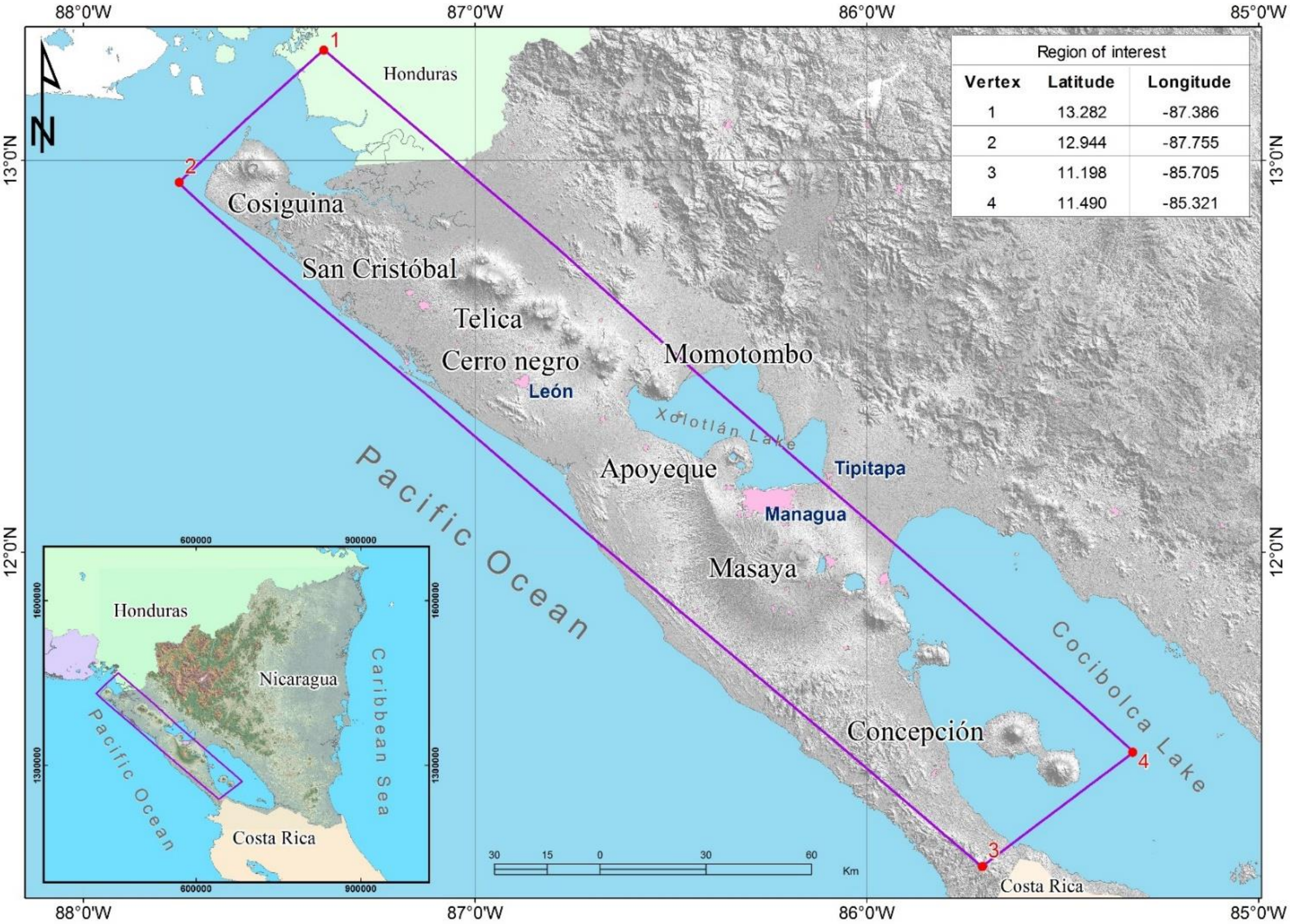

Figure 1. The Map shows the region of interest to the Nicaraguan Supersite denoted with the purple rectangle, with the distribution of the eight active volcanic structures monitored by INETER.

A.7 Supersite motivation

Nicaragua is part of the Cinturon de Fuego or Circum Pacífico, whose main feature is the occurrence of intense seismic and volcanic activity around the Pacific Ocean. These processes reflect the sinking of the Cocos ocean plate below the Caribbean continental plate, in a convergent tectonic subduction regime. The active regional geological structure that predominates in Western Nicaragua is a large rupture zone known as depression of Nicaragua, which represents a new geological terrain of ocean cortex nature and concentrates almost all quaternary volcanism. Its location is linked to the change of inclination of the Cocos Plate in subduction caused by the subduction of the Cocos bib, from the Middle to Late Miocene.

Over the past three decades, the most outstanding volcanic activity in Nicaragua has been observed in the Cerro Negro, Momotombo and Masaya volcanoes. The first erupted three times during the 1990s with a declining intensity over time, in 1992 the eruption had a VEI 3, in 1995 an VEI 2 and in 1999 the eruption was a VEI 1 [Hill et al., 1998; INETER, 1999; La Femina et al., 2004]. The eruptions of the Cerro Negro volcano are usually Strombolian, and sometimes form satellite vents. After the 1999 eruption, this volcano only shows a low-level seismicity [INETER, 1999; INETER, 2004].

The other active volcanoes produce gas and ash explosions almost annually, except for the Concepción volcano that has not erupted since 2010. However, it is not uncommon for this volcano to show swarms of tectonic volcanic earthquakes without other manifestations of restlessness, even Sulphur dioxide emission levels (SO2) are very low, below 250 ton/day [Saballos et al., 2013; 2014].

The Telica volcano experienced a six-month phase less eruption from May to November 2015, and experienced 819 explosions, 104 of which were loaded with ash [INETER, 2015a]. This eruption phase was low energy, and the ash clouds were less than 1 km high above the volcano crater. After this activity, Telica produces ash emissions approximately twice a year, and has a variable flow of SO2 below 800 ton/d, as measured by mini-DOAS instruments.

The Momotombo volcano erupted on December 1, 2015 after 110 years of rest. This last eruption was Strombolian type that lasted 3 days and formed a lava flow 3.5 km long. Energy explosions, ranging from violent Strombolian to weak Vulcaniana, occurred almost daily until early April 2016. After that, this volcano only shows seismicity and low SO2 emission (below 600 ton/day [INETER, 2015a, 2015b]).

In December 2015, a lava lake was set at the bottom of Santiago Crater, Masaya Volcano [INETER, 2015a, 2015b]. Prior to this site, the last time a lava lake was seen in the crater of Santiago was in December 1999, although it was not officially reported. Aiuppa et al. [2018] discovered that before the appearance of the lava lake, the composition of the volcanic gas column became unusually rich in CO2, and the CO2 flow peaked in November 2015 (average: 81.3 x 40.6 kg/s; maximum: 247 kg/s). They proposed that the high supply of gas bubbles destabilize the Masaya magma reservoir (<1 km), which would lead to an upward migration of vesicular resident magma (floating) and, ultimately, to the (re) formation of the lava lake on 11 December 2015 (limited by satellite-based MODIS thermal observations).

Currently, lava lake Masaya is still active and has declined somewhat (the fall has not yet been quantified with any instruments) compared to the observations of 2015-2017. In recent years, the flow of SO2 measured with mini-DOAS varies throughout the year between 500 and 2,000 tons / day.

The year 2015 was the busiest year we had in the last two decades, because the Momotombo volcano erupted for the first time in the last 110 years, a lava lake was at the bottom of Santiago Crater (Masaya volcano), and the Telica volcano experienced a groundwater phase from May to November. Despite the progress made, we still have many challenges for the near future that we hope to achieve with national resources and the international geoscientific community.

During a volcanic crisis, we implement the already established protocol, which specified that the Volcanology Directorate at INETER is the entity in charge to interpret the level of severity of the ongoing events characterizing the crisis. Based on that the head of the volcanology direction inform the head of DGGG, which in turn inform the INETER's highest authorities suggesting the measures to be taken. INETER then pass the information to the presidency of the Republic of Nicaragua and to the Sistema Nacional de Prevención de Desastres (SINAPRED) in charge of national prevention and mitigation of disasters, who inform the public above the volcanic crisis and direct the measures to be taken.

As part of SINAPRED, INETER interacts with a number of governmental, educational and private institutions, including civil defense, local authorities, people living in communities in volcanic hazard zones, schools, tourism companies, etc. At INETER, we conduct different outreach activities within the communities threatened by volcanic hazards together with the local governmental and involved private sectors. On a regular basis we run drills so that the people know what to do during a given scenario related to volcanic activity. For instance, we are currently working with the communities around Telica, San Cristóbal, Concepción and Maderas volcanoes to develop eruption response plans. These response plans are presented to the communities using several methods, such as public presentations on hazards related to the volcano in question, using our three levels of volcano hazard (low, medium, and high), and the production of an evacuation route map, which clearly shows the routes each community should take to an existing shelter in a "safe" place where there will be logistics already established between the governmental and the private sector.

Some results are included in the monthly and yearly bulletins that are made available on our webpage (https://webserver2.ineter.gob.ni/sis/bolsis/bolsis.html), while others are shared with other institutions like SINAPRED and accessible through their webpage (http://www.sinapre/-*d.gob.ni/). Any remaining results are available on our data server (https://webserver2.ineter.gob.ni). All communication of the generated information is published through the website (https://www.ineter.gob.ni/) and television programs via the president's office.

INETER also works in collaboration with the international scientific community, mainly universities and research centers in the United States of America (United States the Servicio Geológico de Estados Unidos (USGS), Volcano Disaster Assistance Program (VDAP), University of South Florida, Pennsylvania State

University, University of Arlington at Texas, University of New Mexico, University of Columbia, University NAVSTAR Consortium (UNAVCO), Carnegie Institute of Washington, among others), in Europe (University of Bristol, King's College London, University of Edinburgh, University of Manchester, University of Kiel, GEOMAR Helmholtz Centre for Ocean Research Kiel, Universidad de Cádiz), and in Latin America (Universidad Nacional Autónoma de México, Centro Nacional de Prevención de Desastres (CENAPRED) in Mexico, Servicio Nacional de Geología y Minería (SERNAGEOMIN) in Chile, Universidad de Puerto Rica en Mayagüez, Ministerio de Medio Ambiente y Recursos Naturales of El Salvador, Instituto Nacional de Sismología, Vulcanología, Meteoreología e Hidrología (INSIVUMEH), Coordinadora Nacional para la Reducción de Desastres (CONRED) in Guatemala, Observatorio Vulcanologíco y Sismologíco de Costa Rica (OVSICORI) in Costa Rica. This international collaboration benefits INETER and Nicaragua in different ways, since it provides training to the INETER's personnel, funding for field work and equipment maintenance, technology transfer, etc.

The main objective of being part of the Geohazard Supersites and natural laboratory initiative under the Group on Earth Observation (GEO) focuses mainly on obtaining satellite data which will be used for scientific monitoring and surveillance allowing INETER to generate scientific information for public decision makers. The latter need this information to provide a timely response to the Nicaraguan population that is located in the vicinity of the active volcanic structures. Likewise, increase international scientific collaboration and open data exchange, as a medium-term objective subject to limitations during emergencies.

Approximately 3,600,000 inhabitants live and/or work at the base of an active volcano in Nicaragua. According to Nicaragua's last official census (INEC 2005), this corresponds to approximately 70% of Nicaragua's population. As a result, the risk of volcanic activity is very high in Nicaragua. In this challenging context, the study and monitoring of volcanic activity becomes a priority for the development of effective risk reduction strategies.

A.8 In situ Data

Currently THE INETER, through the Directorate General of Geology and Geophysics, and the areas of volcanology and seismology, maintains a 24/7 watch in eight active volcanic structures (San Cristobal, Telica, Cerro Negro, Momotombo, Masaya and Concepción, as well as the Cosigüina and Apoyeque volcano) (Figure 2). These volcanoes are distributed throughout the Pacific of Nicaragua, where there is a population exposed to varying degrees of danger from a volcanic eruption. It also keeps monitoring temperature data in five hydrothermal sources located in the municipality of Managua y León; Tipitapa Hot Springs, San Jacinto- Tizate, San Francisco Libre, El Ajo and Aguas Claras.

Figure 2. Distribution of active volcanic structures monitored by the Department of Volcanology of INETER.

The data transmitted in real time to main office of INETER in Managua reaches different servers for instant viewing over the Internet, automatic location (and post-processing) of seismic events and storage. The data is displayed on the INETER website. More products such as threat maps, location on the map of the latest seismic events, monthly and annual newsletters, and project summaries are also available through the website.

INETER monitors Nicaraguan volcanoes using different techniques. Table 1 shows a summary of the instrumentation deployed on each volcano. Seismic monitoring is performed with broadband seismometers and short period seismometers, and there are different amounts of instructions each volcano, see Figure 3. There are also webcams that take images at different time intervals (between three and five minutes) of the volcanoes San Cristobal, Telica, Cerro Negro, Momotombo, Masaya and Concepción. With regard to geodesic techniques, there is at least one Global Navigation Satellite System (GNSS) per volcano, and Momotombo has the most GNSS stations around it, with seven in total. Data from these instruments is processed later and plans are to perform real-time processing soon.

We have learned that the surface deformation produced by Nicaraguan volcanoes during volcanic activity is very small, mainly in a long-term perspective, and when they show a detectable deformation, it is elastic. Saballos et al. [2013; 2014] discovered that the Concepción volcano experienced a GNSS baseline deformation of approximately 4 cm (extension of the baseline associated with volcano inflation) during the March to May 2010 eruption phase, and after the volcano ceased its eruption activity, the deformation recovered (the contraction of the GNSS baseline related to volcano deflation).

The Masaya volcano has a fixed differential optical absorption spectroscopy (DOAS) and a multigas instrument that records and transmits data daily. According to DOAS data, the average SO2 flow emitted by Santiago Crater in the Masaya volcano is between 1,000 and 2,000 tons/day. Figure 2 shows the location of monitoring instruments in volcanoes, as well as the seismic instruments that are part of Nicaragua's monitoring network.
Data gathered during field work on the active volcanoes of Nicaragua are used to produce geologic maps and also as input data for numerical software to simulate volcanic hazards. These field data are also valuable for the validation of numerical probabilistic models that are then employed to simulate different volcanic activity scenarios. The final products are maps of multiple hazards from lava flows, tephra fall, ballistic impacts, pyroclastic flows, lahars, and active faulting (Figure 3). We have recently updated the hazard maps for five of the main active volcanoes: San Cristóbal, Telica, Momotombo, Masaya and Concepción, using different probabilistic numerical models, with geological data and different parameters of the field work to evaluate possible volcanic hazard scenarios. These maps are not currently available on the website, and distribution must first be authorized by the director of INETER. Whenever possible, we try to validate the models with field data. The modeling tools that are frequently used for hazard assessment are those freely available offline and online at the *vhub.org* website (Titan2D, Tephra2, Energy Cone). Other methods published in the scientific literature such as Scoops3D (Reid et al., 2015), DOWNFLOW (Favalli et al., 2005), and LAHARZ_py (Schilling, 2013) are employed to develop probabilistic scenarios. Layers of georeferenced thematic data (GIS) are usually combined to produce thematic maps on a given scale for a specific geographic region.

Additionally, there is at least one Global Navigation Satellite System (GNSS) station per volcano, and Momotombo volcano has the largest number of GNSS stations, with five in total. The GNSS data are currently post-processed using GYPSY-OASIS II software, and plans are in place to perform real-time processing in the near future.

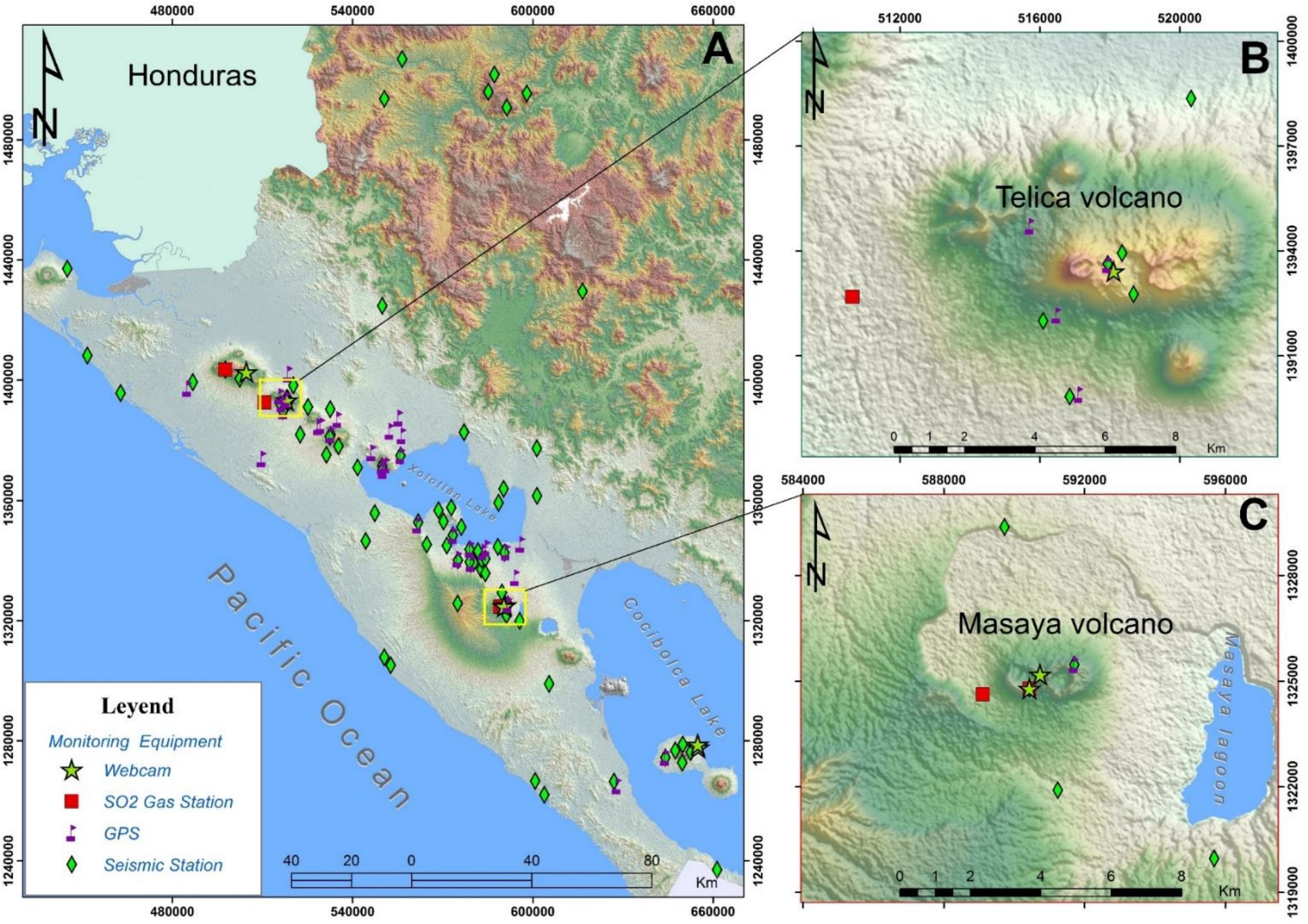

Figure. 3– Distribution map of the different monitoring instruments at the national level. INETER-Nicaragua

Volcano name	**Tracking instruments/ Data type**					
Volcán	Webcam	Multigas	DOAS fijos	Gnss	Estación sísmica	Total
Cosigüina	-	-	-	1	2	3
San Cristóbal	2	-	1	2	3	8
Telica	2	-	1	2	7	12
Cerro Negro	1	-	-	-	6	7
Momotombo	3	-	1	7	5	16
Apoyeque	-	-	-	-	4	4
Masaya	3	1	1	3	5	13
Concepción	2	-	1	2	4	9

Table 1. *Summary of volcanic monitoring instruments operated by INETER, Nicaragua*

Type of data	**Data source**	**Data access**
Seismic waveforms	*INETER network (32 stations)*	*Open access to GSNL scientists upon request and authorization from the INETER Senior Directorate.*
Geodetic data from 14 GPS--GNSS	*INETER Network (14) and campaigns GPS*	*Open access to GSNL scientists upon request and authorization from the INETER Senior Directorate.*
Volcanic gas measurements-Multigas	*Network INETER (1)*	*Open access to GSNL scientists upon request and authorization from the INETER Senior Directorate.*
Fixed DOAS volcanic gas measurements	*Network INETER (5)*	*Open access to GSNL scientists upon request and authorization from the INETER Senior Directorate.* .
Webcam	*Network INETER (13)*	*Open access to GSNL scientists upon request and authorization from INETER's Senior Directorate.*

A.9 Supersite Activity Work Plan

Based on the need for continuous monitoring of Nicaragua's active volcanoes through satellite tool analysis, increase International collaboration and open sharing the following work plan is proposed:

1. The Supersite data will complement existing data that are collected by the seismic and volcanic monitoring network operated by INETER, which will serve to provide more comprehensive responses in periods of volcanic crisis and the approach of volcanic hazard scenarios.
2. A systematic analysis of soil deformation produced by short-, medium- and long-term volcanic and tectonic activity, which will allow us to anticipate in some cases the occurrence of dangerous tectonic and volcanic events in the Pacific region of Nicaragua.
3. Products that can be derived from radar images can also serve as inputs for running numerical models of volcanic and tectonic phenomena.
4. Development of a satellite data platform with the help of LNG, so that it is freely accessible to the scientific community.

A.10 Available Resources

The Nicaraguan Institute of Territorial Studies (INETER) is the institution responsible for volcanic surveillance in Nicaragua. The INETER's volcanology (DV) division currently monitors thirteen active volcanoes by different methods, such as seismicity, SO2emissions, optical cameras, visual observations, temperature measurements in situ and by satellite imagery and soil deformation using GNSS. The volcano monitoring network maintained by INETER is in continuous expansion and modernization.

INETER's volcanic monitoring network consists of 32 seism-volcanic stations, 14 GPS stations, 5 NOVAC gas stations and 13 webcams in the area of interest. A team of specialists oversees the processes and analysis of this data that arrives by telemetry at the INETER Monitoring and Surveillance plant in Managua. Other scientific advisors also take part in the analysis. The annual budget for this task is**. US$ 33,787,000.**

The INETER has an installed infrastructure from which the supersite will operate and is located in the central facilities of the institution in Managua, consists of computer equipment and accessories, Software, seismic equipment, infrastructure and furniture for an amount of **U$ 340,852.**

With funds from the national treasury, INETER will contribute to the implementation of the program with technical staff in the specialties of seismology, geology, geophysics, geography and computer information systems for an amount of **U$ 115,342.000.**

A.11 EO data requirements

COSMO-SkyMED:

	Information	Notes
Image mode	Stripmap/spotlight (tbd)	COSMO SkyMED is designed for near real-time monitoring with InSAR
Orbit Pass	mostly descending, but some ascending passes.	
Look direction	Right	
Beam angle or incidence (rango)	To be planned	
Polarization	No preference	
Product type	SLC	
Number of archive images requested	500 products	Priorities on volcanoes Masaya, Telica and San Cristóbal.
Number of new images requested, per year	200 products/year	*Especially for the six volcanic centers (stratovolcanoes) with signs of disturbances; areas where the seismicity is concentrated or the surface deformation recorded by GPS; or areas under obvious slope instability)*

TerraSAR X / TanDEM X:

	Information	Notes
Image mode	Stripmap	*Constant coverage of Telica, ,and Momotombo volcanoes for deformation analysis, monitoring of dome growth.*
Orbit Pass	Ascending and descending	
Beam or incidence angle (range)		
Polarization		
Product type	Slc	
Number of archive images requested		
Number of new images requested, per year	132 scenes	*To cover 2 volcanic centers with intermittent activity, with 11 day repeat pass, from ascending and descending orbits*

ALOS 2:

	Information	Notes
Image mode	Stripmap, Wide Swath	ALOS-2 would be needed for near real-time monitoring with InSAR; fundamental for areas with vegetation.
Orbit Pass	Ascending and descending	
Look direction		
Beam or incidence angle (range)		
Polarization		
Product type		
Number of file images requested		
Number of new images requested, per year	We acknowledge that JAXA has suspended its support to CEOS initiatives for the time being, but we hope this situation can change in the future, since ALOS 2 L band data would be extremely useful for volcano monitoring in Nicaragua	*To cover volcanic centers (stratovolcanoes) but especially those with intermittent activity.*

RADARSAT 2:

	Information	Notes
Image mode	Tbd	Radarsat 2 may be used for continuous monitoring during rest periods. It complements Sentinel 1 with images with different sight lines, useful for determining 3D deformations.
Orbit Pass	Ascending and descending	
Look direction		
Beam or incidence angle (range)		
Polarization		
Product type	Slc	
Number of archive images requested	The entire archive over the AOI	
Number of new images requested, per year	We acknowledge that CSA has suspended its support to CEOS initiatives for the time	*For each volcanic center*

	being, but we hope this situation can change in the future, since Radarsat and RCM data would be very useful for volcano monitoring in Nicaragua	

PLÉIADES:

	Información	Notas
Image mode	Nadiral	VHR optical images are needed for the detection of morphological changes (e.g. variations of craters and lava lakes, failed slopes, etc.). They may be used also for DEM generation to assess post-eruption changes in summit areas.
Product type		
Number of archive images requested		
Number of new images requested, per year	*4000 sq km of coverage in monoscopic imagery, per year.*	*For all volcanic centers and volcanic calderas.*

A.12 Declaration of commitment

Currently the General Management of Geology and Geophysics of INETER openly shares some of the data generated by the monitoring networks and those product of collaboration agreements with institutions, universities and volcanological observatories. Data that is not openly shared could be shared by members of the Supersite by means of a formal request letter to the top address of the INETER.

The data policy to be agreed among all Supersite data contributors will comply with the GEO-GSNL Data Policy Principles.

A.13 Further comments

This proposal is a first step in Nicaragua aimed at connecting space-based technology with terrestrial techniques for monitoring and researching geological risks (mainly volcanic risks) in near real time. It would also be an exercise in mass exchange of data acquired by INETER networks on a global scale. We look forward to contributing both to improved monitoring capacity (merging data and leveraging experience in the global scientific community) and to a better understanding of some key geological processes.

The data indicated in section A6 will be available upon request or appropriately. Funding for regular activities would be obtained from national and international projects / active research programs led by leading scientists in the first stage.