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COCONet

Workshop Report

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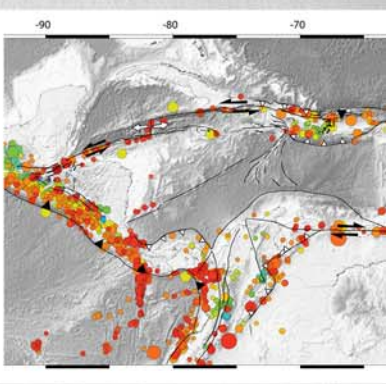
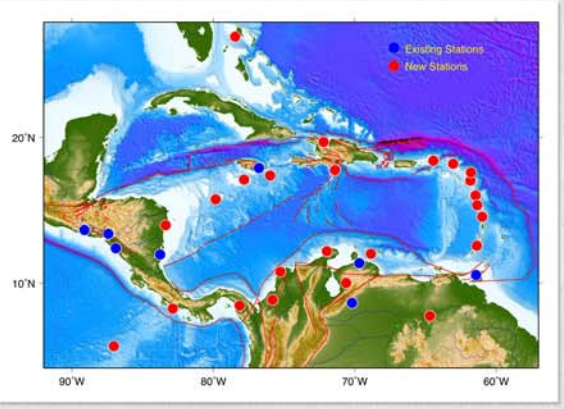
RIO GRANDE, PUERTO RICO





Sponsors

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The COCONet project was awarded by the National Science Foundation to UNAVCO and UCAR with formal participation by Purdue University and University of Puerto Rico. Its success hinges on engagement and participation by an international community of scientists with interests in the Caribbean region and geodesy.

Report on the activities of the COCONet Workshop for Community Science, Station Siting, and Capacity Building

February 2-4, 2011

San Juan, Puerto Rico

By the COCONet Workshop Organizing Committee

UNAVCO

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Introduction

The beauty and diversity of the Caribbean region results from geological and atmospheric processes that also pose serious threats to a large population living within reach of seismogenic faults, hurricane tracks, sea-level change, tsunami inundation, and other natural forces. The capacity to understand, prepare for, adapt to, mitigate the impact of, and possibly even forecast or predict these natural hazards requires Earth observations on both large and small scales. To do this, we must build on the foundation of widespread intellectual capital in the regional science community, effectively communicate the nature of these hazards to improve public awareness, and help prepare the social and political institutions that plan for and respond to such hazards.

The Haiti Earthquake of January 12, 2010 focused world attention with its solemn reminder of the devastating power that natural hazards can unleash. The international geophysics community was humbled by the human and economic impact of a single Mw=7.0 earthquake, one among the 15 or so that strike globally each year. The proximity of circum-Caribbean nations with burgeoning populations to the active plate boundaries that circumscribe the Caribbean plate gives rise to escalating regional exposure.

To advance the understanding of and continue to develop the regional capacity for hazard identification and risk mitigation, the National Science Foundation funded the Continuously Operating Caribbean GPS Observational Network (COCONet). This project will strengthen and complement existing large-scale, state-of-the-art geodetic and meteorological infrastructure in the Caribbean. A strengthened monitoring network will provide the observational backbone for a broad range of Earth and atmospheric science investigations and enable research on process-oriented science questions with direct relevance to geohazards. The observational infrastructure will serve as a regional platform for more focused topical geophysics studies by members of an international community of scientists. Related observations, instrumentation, and analyses from other groups such as the seismological community and those working on long-term or tsunami-related sea-level change will complement the geodetic observations that come directly from COCONet. The infrastructure will also serve as a platform for international partnerships for science and societal applications.

To provide broad international input on the infrastructure plan and building partnerships for related initiatives, a *COCONet Workshop for Community Science, Station Siting, and Capacity Building* was convened near San Juan, Puerto Rico,

February 2-4, 2011. Lead support for the workshop came from the NSF-Geosciences COCONet award through the Earth Sciences Instrumentation and Facilities program. The broad interest in COCONet shown by scientific and hazards communities throughout the Americas drew additional support from the NSF Office of International Science and Engineering, Atmospheric and Geospace Sciences and several programs within the Earth Sciences Directorate including Tectonics and Education & Human Resources, along with further augmentation from EAR Instrumentation and Facilities. The workshop attracted 109 participants from a diverse and international community of scientists and students interested in advancing COCONet's goals.

The workshop provided broad science input to support the following goals:

- Refine the overarching science plan for pan-Caribbean GPS/GNSS infrastructure.
- Revise the station siting plan in light of science goals and existing open-data infrastructure.
- Develop a mechanism for ongoing science oversight.
- Define activities and funding mechanisms to support partnerships and capacity building, including development of the scientific and technical capacity of the international and in-country community conducting research in the Caribbean, and ensuring a climate of free and open access to COCONet geodetic data.

COCONet Overview

COCONet is a five-year project funded by an NSF grant for Caribbean-wide regional GNSS observations. The award is based on a community proposal cooperatively developed by an international set of investigators, and forwarded by the UNAVCO and UCAR consortia, with participation by Purdue University and the University of Puerto Rico.

The planned Continuously Operating Caribbean GPS Observational Network (COCONet) includes 50 new cGNSS and meteorology stations designed to augment data acquired from 50 existing GNSS stations already operating in the region. The intent is for COCONet to provide free, high quality, low-latency, openly-available data and data products for researchers, educators, students, and the private sector for all 100 stations. Community data products will include raw GNSS observations, water vapor estimates, time series of daily positions, and a surface velocity field to support geoscience investigations by an international community engaged in understanding process-oriented science questions with direct relevance to geohazards in Earth and atmospheric sciences. The COCONet regional framework will facilitate additional experiments of higher spatial density that address specific science problems. These include solid Earth processes such as plate kinematics and dynamics, and plate boundary interaction and deformation, including earthquake cycle processes. COCONet will also provide precise estimates of column integrated tropospheric water vapor to enable better forecasting of the dynamics of airborne moisture associated with the yearly Caribbean hurricane cycle, and will provide a regional framework for other atmospheric science objectives. Because of its open data design, COCONet will have broad impact with unanticipated science applications and commensurate societal benefits.

The workshop also identified opportunities for COCONet to facilitate regional and international coordination of research, education, and outreach partnerships, as well as potential civic, commercial, and recreational applications that build on the geodetic infrastructure.

Science Motivation and Objectives

COCONet will provide a backbone of high-quality GNSS/meterological infrastructure with freely available data and data products based on the EarthScope Plate Boundary Observatory (PBO*) model to serve as a framework for solid Earth and atmospheric science studies around the entirety of the Caribbean plate and its complex boundaries. The COCONet proposal identified an initial set of science questions as part of an overarching plan that focuses on solid Earth and atmospheric natural hazards (Appendix IV). A central goal for the San Juan workshop was to refine that science plan in light of broader community input. The following topics emerged in that discussion.

Solid Earth Science

Tectonic and volcanic activity along the boundaries of the Caribbean plate have formed a geography where the vast majority of the Caribbean population lives within reach of major active faults that are capable of producing significant and potentially damaging earthquakes and associated tsunami, as well as volcanoes capable of significant eruptions that put local and regional populations at risk.

The international tectonics and geophysics community has long recognized that the highly diverse tectonic context of the circum-Caribbean makes it a prime locale for process-oriented studies. Many existing research projects are targeted to address specific regions or processes. COCONet, however, is synoptic in scale and therefore will help address fundamental questions about the kinematics of the Caribbean domain and the level of rigidity of the Caribbean plate. COCONet will provide a reference frame appropriate for studies of faults and volcanoes that define the boundaries of the Caribbean plate.

In addition, COCONet will help constrain tectonic models in areas of distributed deformation such as the tectonically complex regions of Venezuela, Colombia, and the northeastern Caribbean. It will add to the study of large-scale plate boundary processes such as arc-continent collision, as evidenced in Panama, the oceanic Cocos Ridge collision farther north in Costa Rica, or the complex interaction related to the collision of the Bahamas with the Greater Antilles. COCONet will contribute to the measurement of strain accumulation and release at the principal plate boundary faults, including

* The Plate Boundary Observatory (PBO) is the geodetic component of EarthScope, operated by UNAVCO, and funded by the National Science Foundation. PBO consists of several major geodetic observatory components: a network of 1100 permanent, continuously operating Global Positioning System (GPS) stations, 78 borehole seismometers, 74 borehole strainmeters, 28 shallow borehole tiltmeters, and six long baseline laser strainmeters. These instruments are complemented by InSAR (interferometric synthetic aperture radar) and LiDAR (light detection and ranging) imagery and geochronological dating acquired as part of the GeoEarthScope initiative. PBO also includes comprehensive data products, data management and education and outreach efforts.

spatial and temporal variations of mechanical coupling, in order to help resolve how these phenomena relate to the occurrence of large earthquakes.

Geodetic constraints on regional deformation will also contribute to the systematic investigation of episodic tremor and slow slip events such as those recently observed along the Central America subduction interface and, together with seismological observations, will contribute to the understanding of the mechanisms that drive them. While episodic tremor and slip have been recognized and extensively documented elsewhere (*e.g.* in Cascadia), plate kinematics, geometry, and other factors are different in Central America and thus provide an opportunity to independently test emerging models for tremor and slow slip generation. In addition, COCONet has the potential to provide high-rate/low-latency data of high value for earthquake source studies and tsunami warning systems.

Collocation of GPS stations with those of the circum-Caribbean tide gauge network will further provide a crustal reference for long-term sea level monitoring, a critical issue in the Caribbean where a large portion of the population and economic activity resides in low-lying coastal areas. New and appropriately retrofitted COCONet sites should provide a robust dataset for evaluation of vertical deformation and thus help separate tectonic deformation from other loading effects such as groundwater changes or slope instabilities.

COCONet will also provide infrastructure for leveraging new science initiatives while capitalizing on existing high-quality infrastructure installed by our Caribbean collaborators. More focused, add-on experiments directly related to its research objectives may include:

- A systematic LIDAR survey of major active faults to provide high-resolution areal geomorphologic data important to complement short-term point geodetic observations. The COCONet GNSS infrastructure would provide reference data for kinematic control of airborne surveys.
- As most of the Caribbean domain lies below sea level, opportunities to develop and apply the emerging technical capabilities of sea-floor geodesy to complement and enhance COCONet science goals.
- COCONet collaboration with InSAR supersite initiatives (*e.g.*, Hispaniola) to improve the spatial resolution of the deformation products in key areas, in particular those highly exposed to major earthquake hazards.
- Opportunities to complement COCONet with strainmeter and tiltmeter measurements in areas of strategic importance for COCONet's science goals, including possible use of instruments currently available from the PBO receiver pool.

These additional add-on experiments, while important for enhancing COCONet science, will require specific funding from appropriate NSF programs as well as other sources.

Atmospheric Science

The Caribbean is a region of complex physical interaction between the ocean, land and atmosphere. In summer, easterly winds on the southern limb of the North Atlantic Subtropical High (NASH) blow across the Gulf of Mexico and eastern Pacific Ocean (the Western Hemisphere Warm Pool) sweeping Atlantic moisture and tropical storms westward through the Caribbean and northward through the Gulf of Mexico, eventually affecting North America. This flow also crosses Central America into the eastern North Pacific, contributing to the moisture source for the North American summer monsoon.

Errors in analyses of atmospheric moisture and in seasonal forecasts are anomalously high in the Caribbean region, suggesting that current models may not fully capture all the essential atmospheric physics and that the low spatial density of data used to condition these models may also be a problem. COCONet will help address the latter constraint by providing continuous observations of total integrated column water vapor, surface pressure, temperature, relative humidity, horizontal winds, and precipitation from each of the 50 planned new stations. Depending on the proximity of existing stations to meteorology instrumentation, the total number of COCONet stations useful for meteorology may approach 100. COCONet observations will be used to address a number of key questions in the region, including:

- What are the sources and predictability of climate anomalies in the Caribbean?
- What are the structure and dynamics of the regional atmospheric circulation and low-level jets? How does this flow depend on and interact with boundary conditions like the Western Hemisphere Warm Pool, land heating, and topography to modulate precipitation and storms?
- How can predictions of important weather phenomena within the region, such as tropical cyclogenesis and rapid intensification events, be improved?
- Why are model and analysis precipitation fields biased in the region? Do convective parameterizations developed for the western Pacific need substantial adjustment for studying Caribbean atmosphere?

Better observations are critical for making progress in this data-sparse region, both to improve initial conditions for NWP forecasts and to provide constraints that improve important model details related to precipitation and latent heat transport. The distribution of stations across the Caribbean basin will allow both large and small-scale processes to be studied: stations along the boundary of the Caribbean sea will be important in evaluating regional transport of moisture; North-South transects on both the eastern and western edges will measure seasonal difference in moisture distribution related to low level jets and transport of water from the tropics to the mid-latitudes; and data from land masses ranging in scale from cays to islands to the continental areas of Central and South America will reveal details of the interaction between the ocean, land, and atmosphere. Supplementing planned land-based observations with ocean-based GNSS buoys would further strengthen these observations.

An added benefit of COCONet is that its observations will significantly augment GNSS coverage in the Caribbean and Central America, contributing to investigation of electron content and high frequency scintillations in the ionosphere.

In summary, COCONet will constrain key processes in the Caribbean region tied to ocean-atmosphere coupling, transport of moisture and convergence, and precipitation, and it will enable better hazard prediction and preparation related to heavy precipitation, storm surge, winds and tropical cyclones.

Collateral Benefits

The versatility and broad applications supported by GPS/GNSS present opportunities for synergies beyond the science goals advanced by COCONet.

COCONet has the potential to spur better integration of the Caribbean research and surveying communities (including national geodetic and mapping efforts) and to promote applications that provide benefits to a much broader cross-section of users than just the science and hazard communities. Some COCONet stations will provide real-time data via NTRIP (an open-source channel for distribution of real-time data at centimeter-level precision) that can be used in surveying applications such as cadastral mapping, subsidence monitoring, construction stakeout and machine control, LIDAR and aerial photo flights, fleet route optimization, and utilities resources inventory and management. In addition, the provision of differential corrections for real-time COCONet GNSS stations could greatly benefit the less-specialized community of users who need meter-level positioning, particularly in marine applications spanning the commercial, recreational, and public safety sectors. This is a service that could easily be provided by local entrepreneurs. Ultimately, COCONet could be used to implement a GNSS RTK VRS network that is widely open to every user in the Caribbean region community.

COCONet data and geodetic solutions (e.g. precise positions and velocities in a global reference frame such as ITRF) will contribute to the definition of regional geodetic datum, while collocations with tide gauges will help the definition of a vertical datum. COCONet will contribute to other international initiatives that share these goals, in particular the SIRGAS project (http://www.sirgas.org/), which aims at providing a geocentric reference frame for South America and the Caribbean from GNSS observations. Collaboration could involve data exchange, closer involvement of national geodetic and mapping agencies, comparison of geodetic processing schemes and reference frame analysis, inclusion of COCONet solutions into SIRGAS, as well as fostering collaborations on geoscience research products (geodynamics and atmospheric science).

COCONet investigators should also engage with international organizations such as the IGS. As a first step, COCONet PIs should present a summary of their activities at IGS regular meetings and volunteer stations to be included in the IGS global network.

Any enhancements to COCONet will require careful planning and strong partnerships to avoid putting the core science goals of COCONet at risk. Should broader applications be

practical, enhancements could support longer-term sustainability (in the form of site maintenance, data from additional GNSS stations, etc.) that would benefit COCONet's science objectives.

Siting plan

We recognize that the devastating Jan 12th 2010 Earthquake in Haiti provided significant motivation for NSF funding of COCONet to facilitate the development of a regional consortium based on shared and open data access, long-term capacity building, and useful community data products for wide ranging applications. The COCONet Workshop provided an opportunity for additional input from a broader community of regional stakeholders in the circum-Caribbean, including several institutions and organizations that had not participated in the initial planning for COCONet.

The original COCONet siting plan was based on information available to NSF-funded PIs who maintain existing regional cGNSS sites as well as a review of open data archives for available data of appropriate quality and utility for the overarching science goals. This process produced a preliminary siting plan, which identified 50 possible locations for new station installations along with 50 existing sites that could provide raw GNSS data with appropriate characteristics (*e.g.* a geodetic quality antenna, receiver, and monument, data reliability, and low transmission latency). The COCONet Workshop provided an opportunity for local investigators and regional network operators to help modify siting decisions with the benefit of detailed local knowledge and full consideration of regional logistics, political feasibility, and other factors.

Workshop discussions resulted in a list of acceptance criteria for including an existing station in COCONet. Acceptable stations will incorporate:

- A geodetic-quality monument and antenna mount, including braced types (SDBM, DDBM), some rooftop installations on reinforced concrete buildings (provided the antennas are mounted securely), and some pillar monuments. Mast-mounted antennas are considered inadequate for precise geodetic applications.
- Adequate and robust power, sufficient to keep the station running for up to 6 months without regular maintenance.
- A data communication system that is capable of handling the daily download of 15-second observation files and, where possible, bandwidth appropriate for low latency data streaming. Raw GPS/GNSS data should be posted on an FTP site with a latency of less than 24 hours of acquisition.
- An established GPS time series of daily positions that indicates a stable monument, a high-precision geodetic antenna, and data continuity with minimal station malfunctions.
- Free and open data/metadata access and a willingness to collaborate as a COCONet partner.

Additional considerations include:

- Collocation with other instruments, particularly tide gauges, radiosondes, meteorological sensors, or seismometers.
- Commitment to station operation from the local network operator, property owner, or hosting facility by permit, MOU, or other formal mechanism.

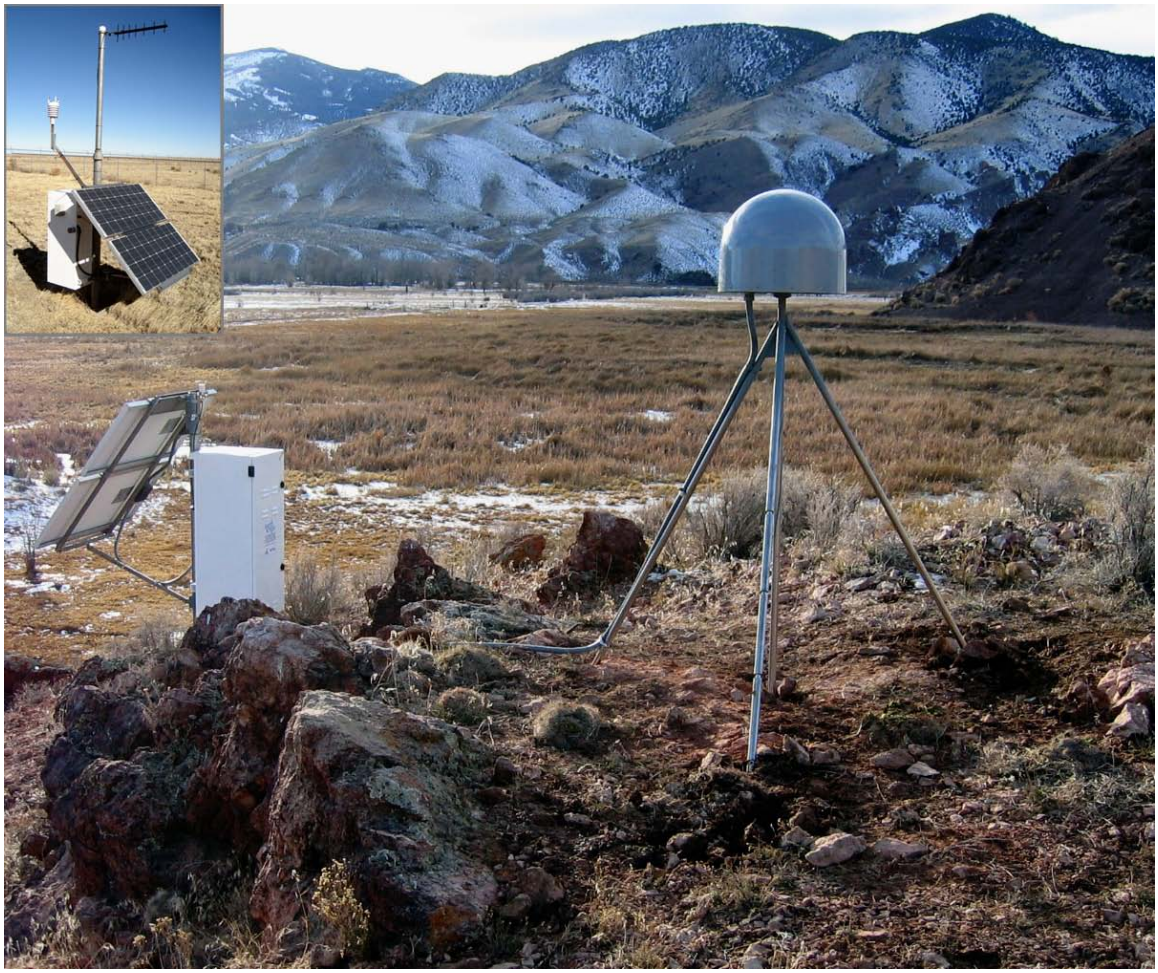

Figure 1. PBO station P009 near Marysvale, Utah. This station combines a short drilled-braced monument with a radome housing the geodetic antenna (right) and the receiver and data communications enclosure and solar panels (left). A similar monument style will be utilized on COCONet where competent bedrock exists. Other monument options include building mounts and concrete pillars where there is no suitable bedrock. Inset illustrates a met pack installation.

The COCONet Workshop discussion of the proposed siting plan revealed that regional networks in the circum-Caribbean had many more cGNSS sites either already operational or planned for immediate installation. Other discussions and presentations during the workshop clearly indicated that many regional institutions need only a modest infusion of resources (in the form of hardware or technical support) to rehabilitate formerly active sites or to distribute data from existing networks. In addition, during a breakout session to plan station siting, local experts identified a

number of potential locations for new stations that could optimize network design for science goals or logistics.

During the course of many frank and open discussions during the workshop, it was suggested that the original site model of 50 'new' plus 50 'existing' sites could be modified to be more flexible and responsive to the needs and interests of regional partners. Regional network operators expressed further concern about the resources that would be required for participation in COCONet, as well as the level of commitment needed to keep maintain stations after construction. COCONet PIs agreed to evaluate how to meet the project goals in light of these discussions and concerns, and to work with regional network operators in a follow-on meeting later this year.

The goal of the siting breakout session was to work with NSF investigators and Caribbean regional network operators to develop a short list of 1.) sites suitable for immediate station installation and 2.) sites that have existing operational GPS stations that could easily be incorporated into the COCONet network, while maintaining the geographical distribution required to meet the meteorological and solid Earth science goals of the project. This newly-developed short list of sites provides UNAVCO staff the ability to move forward rapidly to initiate site installations and data capture from existing stations. It includes an intentional mix of characteristics, including some with anticipated difficulty in installation.

Revised COCONet Siting Plan and Future Activities

The revised list of COCONet sites includes a combination of easy, moderately difficult, and difficult sites in terms of permitting, installation, and logistics. Initiating the COCONet reconnaissance efforts with sites of varying degree of difficulty will give COCONet engineers the best chance to meet the construction milestones outlined in the NSF proposal. Table 1 lists 32 stations designated in one of three ways: new locations (N), existing stations that require minimal hardware upgrades to bring them up to COCONet standards (E), or stations that were operational in the past, but now require significant hardware upgrades to become operational (R). Figure 2 shows the geographic distribution of these sites together with regional topography, bathymetry, and major structural and tectonic features. The widespread use of a less expensive geodetic antenna in lieu of the Dorne Margolin choke ring has been suggested to provide savings that will allow for additional station installations.

Regional operators agreed that the initial siting plan should be revisited at a meeting to be convened in three months as part of the ongoing management of site installation and evaluation. Among the goals of this upcoming meeting are the revision and refinement of the siting plan presented here, identification of additional sites and site issues that were raised but not fully discussed during the San Juan workshop, and completion of plans for a change control process that is responsive to science priorities during network construction. To support this effort, an inventory of existing geodetic stations will be initiated for evaluation of technical issues and of their relationship to the science plan.

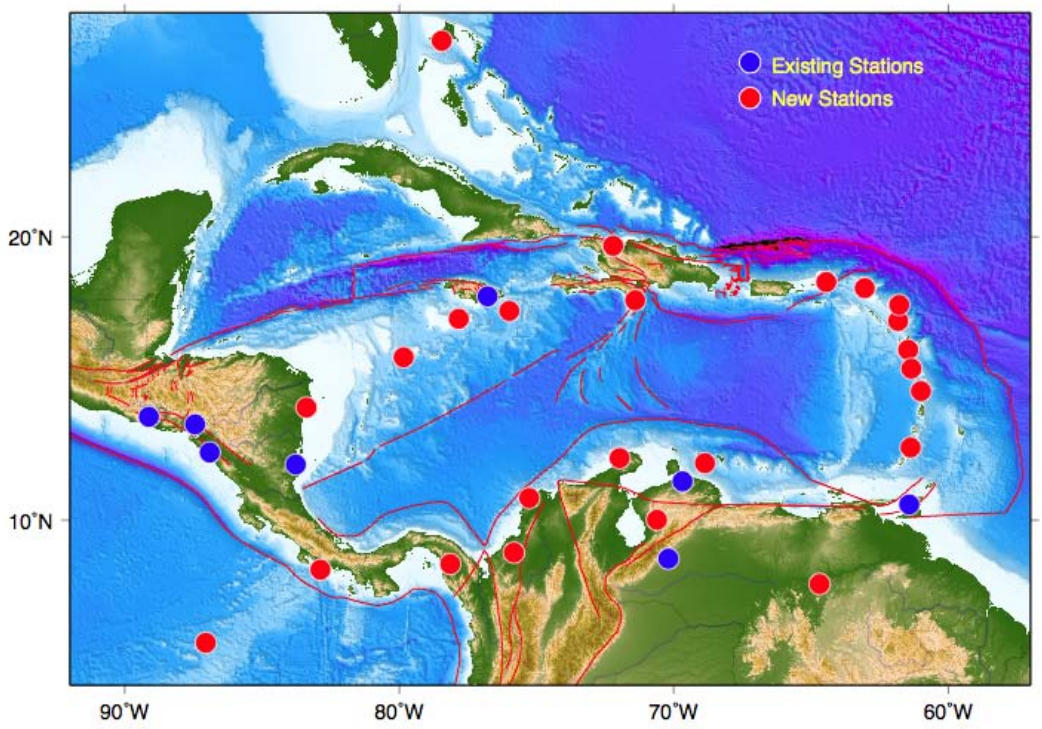

Figure 2. Proposed phase one for COCONet site installations. This revised plan shows the locations for new (red) installations and existing (blue) stations suitable for upgrade or inclusion in the first stage of network installations. The siting plan was developed during workshop working group discussions and follow-up. The full complement of candidate COCONet stations will be inventoried and evaluated during a follow-on meeting with existing regional network operators planned for later this year. Additional site details may be found in Table 1 in the appendix. The major tectonic boundaries and mapped faults of the Caribbean are shown as red lines. Topography and bathymetry are from ETOPO2.

International Partnerships for Broad Impact

In addition to the new observations and processed data products discussed above, the COCONet project will also serve as a focal point for leveraging regional infrastructure, enhancing international research collaboration, and augmenting international partnerships. Activities were identified in four areas: additional scientific opportunities beyond the geodetic and atmospheric sciences (discussed above, in the science summary); efforts to enhance collaborative acquisition, sharing and analysis of data; strategies to nurture a new generation of researchers; and efforts to share scientific outcomes and processes with non-scientific stakeholders, including teachers, emergency managers, policy and decision makers, professionals (*e.g.* surveyors), and other public constituencies.

Three broad themes emerged from presentations and discussions during the workshop. The first centered on the need for careful implementation of COCONet so that it can effectively complement, augment and extend geodetic infrastructure, technical capabilities, and regional networks. It is critical that in-country sponsors and policymakers understand and support the roles of the institutions, observatories, and experts who serve as key parts of the existing intellectual capacity and geodetic networks in the Caribbean region. COCONet partners will play leading roles in transforming the data obtained through the COCONet investment into concrete benefits for hazards

mitigation and scientific advancement. For this reason, a consensus quickly emerged that COCONet activities, including siting, training, and communication, need to be aligned with and deeply rooted in ongoing regional efforts, and that they augment rather than supplant existing efforts to build and maintain regional geodetic/meteorological instrument networks.

Table 1. COCONet Siting - Phase 1. Stationed prioritized for the first phase of reconnaissance, permitting, and installation. The full siting plan will be completed during a follow-on meeting for regional network operators anticipated to be held in the early summer, 2011.

Station Name	Country	Status	Difficulty	Primary Justification
Grand Bahamas	Bahamas	New	Easy	Atmospheric sciences
Cocos Island	Costa Rica	New	Difficult	Tectonics/Atmospheric
Burica	Panama	Existing	Easy	Tectonics
Cabo Rojo	Dominican Republic	New	Moderate	Tectonics/Atm./Sea Level
Puerto Cabeza	Nicaragua	New	Moderate	Tectonics/Atm./Sea Level
Leon Meteo	Nicaragua	Existing	Easy	Tectonics
Bluefields	Nicaragua	Retrofit	Easy	Tectonics/Atm./Sea Level
La Palma	Panama	New	Difficult	Tectonics
Monteria	Colombia	New	Moderate	Tectonics
Galerazamba	Colombia	New	Moderate	Tectonics/Atm./Sea Level
Puerto Bolivar	Colombia	New	Moderate	Tectonics/Atm./Sea Level
SSIA	El Salvador	Retrofit	Easy	Tectonics
SLOR	El Salvador	Retrofit	Easy	Tectonics
Barinas	Venezuela	Retrofit	Easy	Tectonics
Mapire	Venezuela	New	Moderate	Tectonics
Coro	Venezuela	Retrofit	Moderate	Tectonics/Atm./Sea Level
Curacau	Netherlands Antilles	New	Moderate	Tectonics/Atm./Sea Level
New Venezuela	Venezuela	New	Moderate	Tectonics
JAMA	Jamaica	Retrofit	Easy	Tectonics/Atmospheric
Pedro Cay	Jamaica	New	Difficult	Tectonics/Atm./Sea Level
Morant Cay	Jamaica	New	Difficult	Tectonics/Atm./Sea Level
Seranilla Island	Colombia	New	Difficult	Tectonics/Atmospheric
SUWI	Trinidad	New	Moderate	Tectonics/Atmospheric
Carriacou	Grenada	New	Easy	Tectonics/Atm./Sea Level
Martinique	France	New	Easy	Tectonics/Atmospheric
Dominica	Comm. of Dominica	New	Easy	Tectonics/Atmospheric
Guadaloupe	France	New	Easy	Tectonics/Atmospheric
Antigua	Antigua and Barbuda	New	Easy	Atmospheric sciences
Barbuda	Antigua and Barbuda	Existing	Easy	Tectonics/Atm./Sea Level
Anguilla	Anguilla	New	Moderate	Tectonics/Atm./Sea Level
GORD	British Virgin Islands	New	Moderate	Tectonics/Atmospheric
CN09	Haiti	New	Difficult	Tectonics

The second theme that emerged was the need to bridge the gap between scientific understanding and knowledge and the application of that knowledge for public benefit. As COCONet advances science, it should also be used to improve public use of the acquired knowledge. In this regard, primary-school students and hazards professionals were identified as key audiences for COCONet outreach. The recommendations that emerged concentrated attention on identifying the priorities of external stakeholders, training for students interested in experience at the interface between data acquisition and knowledge application, and the design of specific products and applications in partnership with external stakeholders such as educators.

A final theme, closely aligned with the first, was the need for bidirectional scientific partnerships. Consensus emerged that knowledge flow from COCONet activities should work in multiple directions – from and among Caribbean nations as well as between all of the project's international stakeholders. Proposed mechanisms for promoting intellectual exchange included traditional opportunities such as bringing students from the Caribbean to the North America for advanced training or graduate school. New avenues are also needed: fostering the development of Caribbean training centers, bidirectional science exchanges, and field campaigns that include partners from across the Americas.

Specific initiatives that emerged under each theme are listed below. It was noted that COCONet documents and resources should reflect all of the countries and institutions that participate in this initiative, and also acknowledge all sponsoring agencies.

Theme 1 – Align with and complement existing activities and institutions

- Build a community portal so that institutions and countries can effectively share information about priorities, capabilities, and needs in the areas of communication facilities, locations, management/contact information, data availability, educational resources, partnerships, and other topics of mutual interest.

- Explore means to support development of regional COCONet data centers, located within the circum-Caribbean region, which provide access, products, and instrument pools for regional campaign studies.

- Identify plans and possible sponsors for COCONet support of regional primary and secondary teachers and classrooms.

- Establish international internships and summer schools for undergraduate students at locations in the Caribbean region.

Theme 2 – Bridge the gaps

- Identify and work with local teacher networks to develop teacher contacts, adapt material to local contexts, and to help students become aware of local hazards and career opportunities.

- Coordinate with national and international agencies with related interests and goals, including regional NGOs focused on disaster risk reduction. Examples might include the Red Cross, Engineers Without Borders, Caribbean Disaster Emergency Management Agency (CDEMA), Teachers Without Borders, Centro de Coordinación para la Prevención de Desastres Naturales en América Central (CEPREDENAC). A new COCONet web site should provide links to existing groups that promote disaster risk reduction in the region and around the globe.

- Create opportunities and encouragement for students who want to work at the interfaces of research and applications.

- Develop real-time data streams and data access customized for users in surveying, planning, hazards, primary education and other specialties identified in conversations with regional and local stakeholders.

Theme 3 – Establish multidimensional partnerships

- Investigator-driven initiatives should incorporate graduate students from the Caribbean and North America, funded through NSF and NSF-USAID programs and national aid programs of other countries, in investigations that build on COCONet infrastructure. Individual initiatives should contribute to a coordinated effort to enhance regional strengths in secondary and professional education.

- For example, strategic education partnerships might allow US and Caribbean undergraduates to work together on research projects at regional and local scales, building on COCONet infrastructure. These partnerships could bring additional educational resources and experiences (short courses, lectures, field programs, etc.) into the region to globalize the student research and education experience. COCONet community activities might also increase the visibility of geophysics in undergraduate and graduate education at institutes that lack a course of study in geosciences. Potential partners include local graduate programs and IRIS/MAW science projects. Finally, based on reports of good access to Internet services, COCONet partners may take advantage of remote training opportunities, relying on video and online technology offered in an appropriate range of language(s).

- An opportunity for knowledge transfer also exists through the engineering and data processing effort that will be required to build and operate COCONet. Three potential areas of technical training for COCONet partners were identified: (1) station instrumentation, monumentation, power & communications installation and maintenance; (2) data acquisition and processing; and (3) post-processing of data, analysis, and interpretation. International visits among the partners – to local Caribbean networks, PBO, USArray, and UCAR could further exploit opportunities for technology transfer.

- Collectively, these activities should support the regional community of investigators as they form a network of researchers who advance common goals

that span local, regional and international interests within and around the Caribbean. Support for the coordination, community building, and science interactions of this group will be essential to ensuring the value of COCONet and its data products both within the Caribbean and across the Americas.

- In summary, COCONet will provide an infusion of GNSS infrastructure as well as the potential to strengthen the visibility and utility of regional networks. Workshop participants recognized the great potential to build on these gains to strengthen regional and international partnerships. Success will depend on synergies, some already in place and others still to be developed, and will be shaped by initiatives that address shared goals for COCONet stakeholders and the agencies or NGOs positioned to support them. As for science augmentations, any new initiatives will rely on the infrastructure of COCONet observations and scientists for their advancement.

Summary

More than one hundred scientists representing twenty-five countries attended the NSF-sponsored *COCONet Workshop for Community Science, Station Siting, and Capacity Building* during early February 2011. Additional support was provided by the United Nations Development Programme (UNDP) to ensure full participation by the Haitian delegation. Through a series of plenary and breakout sessions, community scientists further shaped and refined the solid Earth and atmospheric science goals that motivate the coordination and expansion of Caribbean infrastructure. The initial phase of new installations was prioritized based on the science goals. Finally, workshop participants developed concepts for initiatives to:

- strengthen resources and technical capabilities for regional Caribbean geodetic networks.
- identify outreach opportunities related to the COCONet project.
- build an international science community around shared infrastructure, data sets, and science initiatives.

Appendices

I. Organizing Committee

Tim Dixon (Chair), University of Miami

Richard Robertson (Vice Chair), Seismic Research Centre,
The University of the West Indies

John Braun, University Consortium for Atmospheric Research (UCAR)

Eric Calais, Purdue University & UNDP Haiti

David Carlson, UNAVCO

Mike Jackson, UNAVCO

Rob Kursinski, University of Arizona

Glen Mattioli, University of Texas, Arlington

M. Meghan Miller, UNAVCO

Hector Mora-Paez, INGEOMINAS

Rajul Pandya, University Consortium for Atmospheric Research (UCAR)

Guoquan (Bob) Wang (Local Host), University of Puerto Rico, Mayaguez

II. Agenda

Workshop goals:

- Refine the overarching science plan for pan-Caribbean infrastructure.
- Revise the GPS station siting plan in light of science goals and existing open-data GPS infrastructure.
- Develop a mechanism for ongoing science oversight.
- Define capacity building activities and funding mechanisms, including development of the scientific and technical capacity of the international and in-country community conducting research in the Caribbean, and ensuring a climate of free and open access to COCONet geodetic data.

Wednesday, 2 February – Arrival /Check in & MAW Working Group Chairs follow up meeting

All day	Participant Check in ..... Hotel Lobby
3:00pm - 9:00pm	IRIS - MAW Working Group Chairs follow up meeting (closed) .....Puerto Rico 1

Thursday, 3 February - Day 1 – Ballroom – Puerto Rico 3

7:00am – 8:0am	*Breakfast* .....*Puerto Rico 1*
General Session I:	Science Objectives and Natural Hazards Research Enabled by COCONet
Chairs:	John Braun, Eric Calais
Objective:	Provide introductory summaries of the science plan and broader impacts of COCONet
8:00am – 8:10am	Welcome/Intro ..... M. Miller
8:10am – 8:20am	Comments from the sponsor ..... R. Kelz
8:20am – 8:40am	Science Rationale for COCONet .....E. Calais/J. Braun
8:40am – 9:10am	Tectonics and Hazards of the Caribbean .....C. DeMets
9:10am – 9:40am	State of Caribbean Climate Science .....C. Fuller
9:40am – 9:45am	Charge to Breakout sessions .....J. Braun/E. Calais
9:45am – 10:00am	*Coffee break*.....*Puerto Rico 1*
10:00am - 11:30am	Breakout Sessions Atmospheric, R. Kurzinski, Braun, Douglas ..... San Juan 1 Solid Earth, P. La Femina (Scribe: A. Lopez) ..... Puerto Rico 3 Broader Impacts and Capacity Building, T. Dixon .....San Juan 2
11:30am – 12:00pm	Reports from Breakout Sessions ..... Puerto Rico 3
12:00pm – 1:00pm	*Lunch* .....*Puerto Rico 1*

General Session II: Identify existing stations with high quality GPS data that could be made freely and openly available to the geodetic community and identify locations for new COCONet geodetic/atmospheric infrastructure.

Chairs: Mike Jackson, Glen Mattioli, Richie Robertson, Hector Mora-Paez

Session IIA: Existing Geodetic Infrastructure, Chair, Glen Mattioli - (Co-Chairs: A. Borsa, S. Olds)

Session IIA Objective: This session will identify 60 (50 + 10 spare) stations with high quality GPS data that could be made freely and openly available to the geodetic community.

1:00pm – 1:15pm	Coco/Nazca – Caribbean boundary ..... P. La Femina
1:15pm – 1:30pm	South American - Caribbean boundary..... H. Mora-Paez
1:30pm – 1:45pm	N. American – Caribbean boundary Lesser Antilles focus .....J.B. de Chabalier
1:45pm – 2:00pm	N. American – Caribbean Boundary Cayman, Hispañola, Puerto Rico focus ....G. Wang
2:00pm - 3:00pm	Discussion
3:00pm – 3:15pm	*Break*.....*Puerto Rico 1*

Session IIB: Station siting for new locations, Chair, Mike Jackson – (Co-Chairs: K. Feaux, J. Normandeau)

Session IIB Objective: This session will identify 60 (50 + 10 spare) new stations locations with a high probability of land-use access, data communications, and security.

3:15pm – 3:30pm	Coco/Nazca – Caribbean boundary ..... M. Protti
3:30pm – 3:45pm	South American - Caribbean boundary..... O. Perez
3:45pm – 4:00pm	N. American – Caribbean boundary Lesser Antilles focus ..... R. Robertson
4:00pm – 4:15pm	N. American – Caribbean Boundary Cayman, Hispañola, Puerto Rico focus .... E. Calais
4:15pm – 4:30pm	Change control process .....Jackson
4:30pm - 5:30pm	Discussion
5:30pm – 6:30pm	Poster Session..... Ballroom Foyer
6:30pm – 8:00pm	*Dinner* .....*Fountain Terrace (weather back up Caribeno Room)*
8:00pm – 10:00pm	Evening Sessions Infrastructure brainstorming session (K. Feaux/B. Friesen) ..... San Juan 1 LiDAR Group Initiative discussion (C. Prentice/C. Crosby)..... Puerto Rico 3

Introduction
The basics of LiDAR
Applications of LiDAR to active fault studies
Examples of recent, large-scale, open LiDAR acquisitions
Open data access and capacity building
Discussion
(CLI steering committee: C. Prentice, C. Crosby, E. Calais, P. Mann, D. Phillips, C. Meertens, K. Frankel, R. Haugerud, R. Arrowsmith)

Friday, 4 February - Day 2 – Ballroom – Puerto Rico 3

General Session III: Capacity Building, Open Data and Training
Chairs: David Carlson and Raj Pandya
Objective: Develop a capacity building plan that articulates the activities that might build on COCONet infrastructure on the topics of International and in-country scientific capacity building and data sharing, international education partnerships, and risk mitigation.

7:00am - 8:00am	Breakfast ..... Puerto Rico 1
8:00am – 8:10am	Introduction: Making Geoscience Relevant to Development ..... E. Calais
8:10 am – 8:30am	Echoes of a Disaster: Seismic Risk and Lessons from Haiti ..... S. Hough
8:30am – 8:50am	Needs and Opportunities: The Caribbean Tsunami Warning System .... von Hillebrandt
8:50am – 9:10am	COCONet and the Caribbean surveying community..... ... A. Holsteinson
9:10am - 9:30am	International Partnerships for Shared Capacity: An IRIS perspective ..... O. Cabello
9:30am – 9:40am	Funding opportunities for international capacity building ..... J. Robin
9:40am – 9:45am	Charge to Breakout sessions ..... Pandya/Carlson
9:45am – 10:00am	*Coffee break*.....*Puerto Rico 1*
10:00am – 11:15 pm	Breakout Sessions International scientific and technical capacity building (V Cronin, Cabello)San Juan 1 The next generation: international education partnerships (Haase, Olds, Pandya). The practitioners: connecting hazards to risk (J. Weaver, D Carlson) Puerto Rico 3
11:15am – 12:00pm	Reports from Breakout Sessions ..... Puerto Rico 3
12:00pm – 1:00pm	*Lunch break*.....*Puerto Rico 1*

General Session IV: Science: Siting & Capacity Building Plans – Working Groups
Chairs: Meghan Miller, Tim Dixon, Bob Wang
Objective: Written contributions to workshop report

1:00pm – 1:20pm	Summary of progress and charge to writing breakouts by Organizing Committee ... . Puerto Rico 3
1:20pm – 2:50pm	Writing Breakout Sessions Refinements to science plan (Calais, Braun) ..... San Juan 1 COCONet siting plan and change control process (Mattioli, Jackson) Puerto Rico 3 Capacity building opportunities in the Caribbean (Dixon, Carlson).....San Juan 2
2:50pm – 3:05pm	Reports from Breakout Sessions ..... Puerto Rico 3
3:05pm – 4:00pm	Wrap-up session ..... Puerto Rico 3
4:00pm – 6:00pm	Poster Session ..... Ballroom Foyer
Evening	On Own
6:00pm – 9:00pm	MAW Working Group Chairs meeting (closed)..Dinner in Ponce and Rincon Room

Saturday, 5 February – Day 3 – San Juan I

Participants: Organizing Committee
Objective: Complete draft of workshop report

9:00am Writing Session .....COCONet Organizing Committee

III. Science questions from the initial COCONet proposal

The COCONet proposal to NSF established a set of science priorities that were expanded on during the Puerto Rico workshop. The proposal can be found at: http://www.unavco.org/pubs_reports/proposals/proposals.html.

The central questions put forth in the initial science plan included:

Solid Earth Science

Questions: What are the kinematics of the Caribbean domain? How rigid is the Caribbean plate? What Caribbean reference frame is appropriate for tectonic studies?

Questions: How is stress released at convergent plate boundaries? What controls interplate coupling? How does interseismic plate coupling change along strike

Questions: What controls strain partitioning at convergent margins? How is stress transferred across plate boundaries?

Question: How can we better understand and assess hazards in the Caribbean and Central American regions?

Atmospheric Science

Question: What are the physical mechanisms for the coupling between sea surface temperatures and atmospheric water vapor, and is this coupling confined to the atmospheric boundary layer or does it extend into the free troposphere?

Question: What is the impact of continuous estimates of PW on hurricane intensity forecasts?

Question: Can forecasts of severe precipitation that is not related to hurricanes be improved in the region?

IV. Attendees

Abrego, Antonio
Panama Canal Authority
Research Engineer
Building 721
West Corozal
Panama 0819-00007
507-276-1989
aabrego@cableonda.net

Adams, David
Universidade do Estado do Amazonas
Research Professor
CESTU/UEA
Manaus, Amazonas Brazil 69050-010
55 92 9178-2030
dave.k.adams@gmail.com

Anderson, Steven
University of Northern Colorado
Director, Mathematics and Science Teaching Institute and Professor of Earth Sciences
MAST Institute
Greeley, Co USA 80639
970-351-2973
steven.anderson@unco.edu

Antuna, Juan Carlos
GOAC, INSMET
Senior Researcher
Carretera Nuevitas Km 7½
Camaguey, Camaguey Cuba 70100
53-32-262397
anadelia@caonao.cu

Audemard, Franck
Venezuelan Foundation for Seismological Research
Researcher
Final Prolongacion Calle Mara, Quinta Funvisis, El Llanito
Caracas, Venezuela 1073
58-(0)212- 2575153 ext 234
faudemard@funvisis.gob.ve

Belizaire, Dwinel
ONEV-MDE (HAITI)
Professeur
14 Trinite Vivy Mitchell
Petion Ville, Port au Prince, Haiti
509 3696 5332
bdwynn1@gmail.com

Bennett, Rick
University of Arizona
Associate Professor
1040 E 4th Street
Tucson, AZ USA 85721-0077
520-621-2324
rab@geo.arizona.edu

Bilham, Roger
CIRES
Professor
2200 Colorado Ave
Boulder, CO USA 80309-0399
303-492-6189
bilham@colorado.edu

Bohnenstiehl, Kyle
UNAVCO/PBO
Permitting Manager
6350 Nautilus Dr
Boulder, CO USA 80301
720-320-7501
kyleb@unavco.org

Borsa, Adrian
UNAVCO
Data Products Manager
6350 Nautilus Drive
Boulder, CO USA 80301
303-807-1248
borsa@unavco.org

Braun, John
COSMIC/UCAR
Project Scientist
P.O. Box 3000
Boulder, CO USA 80307
303-497-8018
braunj@ucar.edu

Brown, Lyndon
Earthquake Unit, University of the West Indies, Mona
Research Fellow
Earthquake Unit, Faculty of Pure and Applied Sciences,
University of the West indies, Mona,
Kingston 7 Jamaica
876-927-2586
lyndon.brown@uwimona.edu.jm

Cabello, Olga
IRIS Consortium
Director of International Development Seismology
1200 New York Ave, Suite 800
Washington, DC USA 20005
202-682-2220 ext 121
olga.cabello@iris.edu

Cabral-Cano, Enrique
Instituto de Geofisica, UNAM
Research Scientist
Instituto de Geofisica
Mexico, DF Mexico 04510
52-55-5622-4204
ecabral@geofisica.unam.mx

Calais, Eric
Purdue University
Science Advisor, UNDP Haiti
550 Stadium Mall Drive
West Lafayette, IN USA 47907
765-409-5134
ecalais@purdue.edu

Carlson, David
UNAVCO
Education Outreach Director
6350 Nautilus Dr
Boulder, CO USA 80301
720-412-5256
carlson@unavco.org

Chaves Sibaja, Esteban
OVSICORI
Estudiante
Universidad Nacional
Heredia, Costa Rica 2346-3000
50683644789
echfisica@gmail.com

Chen, Shuyi
RSMAS/University of Miami
Professor
4600 Rickenbacker Causeway
Miami, Florida USA 33149
305-421-4048
schen@rsmas.miami.edu

Chiao, Sen
Florida Institute of Technology
Associate Professor
150 W. University Blvd
Melbourne, FL USA 32901-8222
321-674-8008
schiao@fit.edu

Clouard, Valerie
Obs. Volc. Sismo. Martinique (OVSM/IPGP)
Associate Professor
Morne des Cadets, Fonds Saint Denis
Saint Pierre, FWI Martinique 97250
+596 596 78 41 44
clouard@ipgp.fr

Colon-Pagan, Ian
Georgia Institute of Technology
PhD Student
311 Ferst Dr.
Atlanta, Georgia USA 30332-0340
787-341-9444
ian_colon@yahoo.com

Cronin, Vincent
Baylor University
Professor
26 Timber Ridge Trail
Lorena, Texas USA 76655
(254) 710-2174
Vince_Cronin@baylor.edu

Crosby, Christopher
San Diego Supercomputer Center, UCSD
Project Manager
9500 Gilman Dr. MC 0505
La Jolla, CA USA 92093
858-822-5458
ccrosby@sdsc.edu

Daniel, Georges Emmanuel
SEMANAH (Service Maritime et de Navigation d'Haiti
Consultant en Communication
Local (LNBTP) 27, Rue Toussaint Louverture/Delmas 33
Delmas/Port-au-Prince, Ouest Haiti
509-3856-7505
gedaniel@hotmail.com

de-Chabalier, Jean-Bernard
IPGP - Guadeloupe Observatory
Doctor
Le Houëlmont
Gourbeyre, French West Indies
Guadeloupe 97113
+590 590 99 11 38
dechabal@ipgp.fr

DeWeaver, Eric
National Science Foundation
Program Director
4201 Wilson Blvd
Arlington, VA USA 22203
703-292-8527
edeweave@nsf.gov

Dixon, Tim
University of South Florida
Professor
4202 E. Fowler Ave, SCA528
Tampa, FL USA 33620
813-974-0152
thd@usf.edu

Douglas, Michael
National Severe Storms Laboratory/NOAA
Meteorologist
120 David L. Boren Blvd
Norman, OK USA 73072
405-325-6098
Michael.Douglas@noaa.gov

Feaux, Karl
UNAVCO
GPS Operations Manager - PBO
6350 Nautilus Drive
Boulder, CO USA 80301
720-320-7532
feaux@unavco.org

Fernandes, Rui
SEGAL
Assistant Professor
Departamento Informática, R. Marques d'Avila e Bolama
Covilhã, Portugal 3200-337
+351 919999300
rmanuel@di.ubi.pt

Figueroa, Carlos Enrique
Instituto Geografico Nacional - Centro Nacional de Registros
Gerente de Geodesia
43 Av. Nte. y 1ra C. Pte. # 2310
San Salvador, El Salvador 0101
503-22618831
cfigueroa@cnr.gob.sv

Fountain, David
NSF
Program Director
4201 Wilson Blvd.
Arlington, VA USA 22230
703-292-4751
dfountai@nsf.gov

Frankel, Kurt
Georgia Institute of Technology
Assistant Professor
School of EAS - 311 Ferst Drive
Atlanta, Georgia USA 30332-0340
404-894-4008
kfrankel@gatech.edu

Friesen, Barrett
UNAVCO
Regional Engineer
6350 Nautilus Dr
Boulder, CO USA 80301
303-775-3527
friesen@unavco.org

Fuller, Carlos
Caribbean Community Climate Change Centre
Deputy Director
Lawrence Nicholas Building, Ring Road, PO Box 563
Belmopan, Belize 99999
501-822-1104
cfuller@btl.net

Garcia, Oswaldo
San Francisco State University
Professor
224 Bradford Street
San Francisco, California USA 94110
415-310-6745
ogarcia@sfsu.edu

Girigori, Pedzi
Meteorological service of the Netherlands Antilles and Aruba
Researcher/ Meteorologist
Kaya Apache 12
Rust en Vrede, Curacao
00599 98393364
pedzi.girigori@meteo.an or
pvjgirigori@yahoo.com

Guzman-Speziale, Marco
Centro de Geociencias, UNAM
Research Scientist
Blvd. Juriquilla 3001
Queretaro, Queretaro Mexico 76230
+52 442 238 1104
marco@geociencias.unam.mx

Haase, Jennifer
Purdue University
Assistant Professor
550 Stadium Mall Dr
West Lafayette, IN 47906
765-494-8677
jhaase@purdue.edu

Hernandez-Ramirez, Francisco
University of Puerto Rico at Mayaguez
Undergraduate Student
Calle Ilan-Ilan
Mayaguez, Puerto Rico USA 00681
787-805-5881
fjhernandez89@gmail.com

Higgins, Machel
Seismic Research Centre, UWI
Research Fellow
St. Augustine Trinidad and Tobago
1-868-662-4659
machelhiggins@uwiseismic.com

Holsteinson, Alexander
Universidad Autonoma de Santo Domingo
Geomatics Professor
Wenceslao Alvarez 62 Apt 3b, Zona Universitaria
Santo Domingo, DN Dominican Republic 10103
809-686-3215
aholsteinson@geomatica.biz

Huerfano, Victor
Puerto Rico Seismic Network
PhD
Call Box 9000
Mayaguez, PR USA 00680
787-833-8433
victor@prsn.uprm.edu

Jackson, Michael
UNAVCO
Director Plate Boundary Observatory
6350 Nautilus Drive
Boulder, CO USA 80301
303-888-0718
Jackson@unavco.org

Jeffress, Gary
Texas A&M University-Corpus Christi
Professor
6300 Ocean Dr.
Corpus Christi, TX USA 78412-5868
361-825-2720
gary.jeffress@tamucc.edu

Jiang, Yan
University of Miami
PhD Student
4600 Rickenbacker Causeway,
RSMAS, MGG
Miami, FL USA 33129
305-421-4928
yjiang@rsmas.miami.edu

Joseph, Joel
CNIGS
Employe du CNIGS
26 bis, rue jasmin, delmas 65
Delmas, Port-au-Prince Haiti 509
509 37 11 19 68
arjoey@hotmail.com

Kelz, Russell
National Science Foundation
Program Director
4201 Wilson Blvd
Arlington, VA USA 22230
703-292-4747
rkelz@nsf.gov

Kontar, Yev
University of Illinois at Urbana-Champaign
Sr. Scientist/Head
615 East Peabody Drive
Champaign, Illinois USA 61820-6964
217-265-5438
kontar@illinois.edu

Kursinski, Rob
University of Arizona
Associate Professor
1118 E 4th St
Tucson, AZ USA 85721
520 260-8404
kursinski@atmo.arizona.edu

LaFemina, Peter
The Pennsylvania State University
Assistant Professor
406 Deike Bldg
University Park, PA USA 16802
814-865-7326
pcl11@psu.edu

Laforest, Ronald J B L
SEMANAH
Membre du Cabinet Technique au SEMANAH
47, Delmas 12
Delmas/Port-au-Prince, Ouest Haiti
(509) 3806-8109
laforest2008@hotmail.com

López, Alberto
UPRM
Assist. Professor
#723 Qtas. de Santa Maria
Mayaguez, PR USA 00680
847-217-3828
alberto.lopez3@upr.edu

Mann, Paul
Univ of Texas at Austin
Inst for Geophysics
Senior Research Scientist
10100 Burnet Road, Pickle Res Campus, Bldg 196
Austin, Texas USA 78758
512-471-0452
paulm@ig.utexas.edu

Martinez-Torres, Fernando
University of Puerto Rico at Mayagüez
Student-Undergraduate
Mayaguez, PR USA 00681
787-519-7314
fernan.martinez.2@gmail.com

Mattioli, Glen
University of Texas at Arlington
Professor
Department of Earth & Environmental Sciences Box 19049
Arlington, TX USA 76019-0049
817-272-2987
gmattioli@uta.edu

McNamara, Daniel
USGS ASL NEIC
Research Geophysicist
1711 Illinois St.
Golden, CO USA 80401
303-273-8550
mcnamara@usgs.gov

Meertens, Charles
UNAVCO
Director, UNAVCO Facility
6350 Nautilus Dr.
Boulder, CO USA 80301
303-381-7465
meertens@unavco.org

Metayer, Gerard
SEMANAH (Service Maritime et de Navigation d'Haiti
Charge de Tsunami Pour Haiti
Local (LNBTP) 27, Rue Toussaint Louverture/Delmas 33
Port-au-Prince, Ouest Haiti
(509) 3713-5936
gerard_metayer@yahoo.fr

Meza, Oscar Andres
Instituto Geografico de Honduras
Gerente de Geodesia
Barrio La Bolsa
Tegucigalpa, Francisco Morazan Honduras 504
99 66 14 67 or 224 12 87
omeza1257@hotmail.com

Mildor, Saint Louis
Bureau of Mines and Energy (BME)
Technical Director
11 Rue Jacques1er entre Delmas 31 et Delmas 33
Port-au-Prince, HAITI (W.I)
HT6231
(509) 3407 7223 or 3722 8778
saintmildor1953@yahoo.fr

Miller, Meghan
UNAVCO
President
6350 Nautilus Drive
Boulder, CO USA 80301
303-381-7514

Mora, Mauricio
Universidad de Costa Rica
Head of Seismology, Volcanology and Geophysics Exploration Section
mmorarsn@gmail.com

Mora-Paez, Hector
INGEOMINAS - Colombian Institute of Geology and Mining
GEORED Project, Coordinator
Diagonal 53 # 34-53
Bogota, D. C. Colombia 17-0001
571-220-0052
hmora@ingeominas.gov.co or hmora.igm@gmail.com

Munoz, Ernesto
New Mexico Consortium
Research Scientist
4200 West Jemez Road, Suite 301
Los Alamos, New Mexico USA 87544
505-412-4192
emunoz@newmexicoconsortium.org

Murray, Corliss
Lands and Surveys Department
Land Surveyor
P.O Box 2800
Kingstown, St Vincent
784-530-4154
corliss_m@hotmail.com

Newman, Andrew
Georgia Institute of Technology
Assistant Professor
311 Ferst Drive
Atlanta, GA USA 30332
404-894-3976
anewman@gatech.edu

Nigam, Sumant
University of Maryland
Professor of Atmospheric & Oceanic Science
3419 Computer & Space Sci. Bldg.,
University of Maryland
College Park, MD USA 20742-2425
1-301-405-5381
nigam@atmos.umd.edu

Nixon, Orson
Bahamas Department of Meteorology
Meteorological Officer I
P. O. Box N8330, Crawford Street
Nassau, New Providence Bahamas
242-356-3734
omnixon@gmail.com

Normandeau, Jim
UNAVCO
Project manager
6350 nautilus dr
Boulder, Co USA 80303
303-381-7475
Normandeau@unavco.org

Odbert, Henry
Montserrat Volcano Observatory/ Seismic Research Centre
Research Fellow
Montserrat Volcano Observatory
Flemmings, Montserrat WI
+16644915647
henry@mvo.ms

Olds, Shelley
UNAVCO
Education Specialist
6350 Nautilus Dr
Boulder, CO USA 80301
303-381-7496
olds@unavco.org

Oliva, Paola
Universidad Nacional Autonoma de Honduras(UNAH)/Instituto de Ciencias de la Tierra(IHCIT)
Estudiante
Col. Altos de Miraflores sur.
Tegucigalpa, Francisco Morazan
Honduras 11101
(504)32197143
paulacecil8@gmail.com

Ollivierre, Adolphus
Lands and Surveys Department Saint Vincent and The Grenadines
Chief Surveyor
Richmond Hill
Kingstown, St. Vincent and the Grenadines
784-456-1310 or 784-433-8834
ajimpt@gmail.com

Pandya, Raj
UCAR
Director, Community Building Program
P.O. Box 3000
Boulder, CO USA 80307
303-497-2650
pandya@ucar.edu

Perez, Omar J.
Simon Bolivar University
Professor of Earth Sciences
Urb. El Placer, Baruta
Caracas, Miranda Venezuela 1080A
00584166256426
ojperez@usb.ve

Phillips, David
UNAVCO
Project Manager
6350 Nautilus Dr
Boulder, CO USA 80301
303-381-7471
philliops@unavco.org

Plattner, Christina
University of Miami, Rosenstiel School of Marine and Atmospheric Sciences
Postdoctoral Associate
4600 Rickenbacker Causeway
Miami, FL USA 33149
305-421-4690
cplattner@rsmas.miami.edu

Polanco Rivera, Eugenio
Instituto Sismológico, Universidad Autónoma de Santo Domingo
Director, Investigador
Dr. Brenes No. 3, Don Bosco
Santo Domingo, D.N., Distrito Nacional República Dominicana
10201
809-687-5349 or 809-501-3715 cell
eugenio_polanco_rivera@msn.com

Prentice, Carol
US Geological Survey
Research geologist
345 Middlefield Rd ms 977
Menlo Park, CA USA 94025
650-329-5690
cprentice@usgs.gov

Protti, Marino
OVSICORI-Universidad Nacional
Seismologist
Aparatdo 1718-3000
Heredia Costa Rica 3000
(506) 8822-9993
marino.protti@gmail.com

Pujols, Rafael
ISU/UASD
Chief Seismic Instrumentation Engineer
Ciudad Universitaria, Apartado Postal 1355
Santp Domingo, D. N.
Dominican Republic 10105
809-485-8879
rafaelpujols@hotmail.com

Pulliam, Jay
Baylor University
Professor, Department of Geology
26 Timber Ridge Trail
Lorena, Texas USA 76655
512-809-5144
Jay_Pulliam@baylor.edu

Ramirez, Arlenys
University of Puerto Rico at Mayaguez
Student
Via 31 4AN-10
Carolina, Puerto Rico 00983
787-605-4900
arlenys.ramirez@upr.edu

Ramirez Hernandez, Jose Roberto
Recinto Universitario de Mayaguez
Estudiante
URB Bellas Lomas 636 Manuel Ramon
Mayaguez, Puerto Rico USA 00682
787-554-7883
ramirez.joseroberto@gmail.com

Rivera, Felix O.
University of Puerto Rico-Mayaguez
Student
Calle San Jose 100 west
Aibonito, PR USA 00705
787-486-1871
felix.rivera12@upr.edu

Rivera Rivera, Garymar Dé
Department of Disaster Management - Government of British Virgin Islands
Technical Planning Officer
3 Wailing Road, MacNamara
Road Town, Tortola British Virgin Islands VG 1110
284-468-4200
grivera@gov.vg

Robertson, Richie
Director, Seismic Research Centre
The University of the West Indies
St. Augustine Trinidad
868-662-4659 (Office)
868-461-8328 (Cell)
richie.robertson@gmail.com

Rockwell, Thomas
San Diego State University
Professor
Geological Sciences, MS 1020, San Diego State University
San Diego, California USA 92182
619-594-4441
trockwell@geology.sdsu.edu

Rodriguez Maradiaga, Manuel
Instituto Hondureño de Ciencias de la Tierra/UNAH
Professor
3 Caminos, 5 Calle, 2 Ave., 3556
Tegucigalpa, FM Honduras 11101
504-3204-2158
marerola@intelnet.net.gt

Rodriguez-Martinez, Mario
Universidad Nacional Autonoma de Mexico Campus Juriquilla, Centro de Geociencias
Research Fellow
Blvd Juriquilla 3001
Juriquilla, Queretaro, Mexico 76230
(+52) (55) 5623-4104
mariorm@geociencias.unam.mx

Rosado, Keren
Florida Institute of Technology
Student
578 Terrace Spring
Orlando, Florida USA 32828
407-621-1676
krosado2008@my.fit.edu

Rousseau, Lenine Christian
Université d'État d'Haïti
Professseur de Sciences Géographiques
2 Rue Citadelle
Port-au-Prince, ouest Haiti 5117
509-36875901
lcrousseau@gmail.com

Sauveur, Renaldo
Centre National de L'Information Geo-spatiale (CNIGS)
Employe du CNIGS
26 bis, rue jasmin, delmas 65
Delmas, Port-au-Prince Haiti 509
509-37015751
rsauveur@cnigs.ht

Shrestha, Ramesh
University of Houston
Professor
130 E Tupelo Green Cir.
The Woodlands, Texas USA 77389
832-842-8882
rlshrestha@uh.edu

Simon, Donald
Antigua & Barbuda Meteorological Service
Information Systems Manager
V.C. Bird International Airport
St. Johns, Antigua & Barbuda
268-764-2143
don_acs@yahoo.com

Soto-Cordero, Lillian
Puerto Rico Seismic Network, University of Puerto Rico at Mayaguez
Chief Geophysical Data Analyst
Call Box 9000
Mayaguez, PR USA 00681-9000
787-833-8433
lillian@prsn.uprm.edu

Teran, Angel
Servicio Meteorlogico Nacional
PhD
Av. Ovservatorio No. 192
Distrito Federal, Mexico 11860
(5255)26364646
angel.teran@conagua.gob.mx

Valdes, Carlos
UNAM
Director, Red Sismica Nacional, Instituto de Geofisica
carlosv@ollin.igeofcu.unam.mx

von Hillebrandt-Andrade, Christa
NOAA NWS Caribbean Tsunami Warning Program
Manager
Residencia 2A, 259 Blvd. Alfonso Valdés
Mayaguez, PR USA 00680
787-249-8307
christa.vonh@noaa.gov

Wang, Guoquan
University of Puerto Rico
Assistant Professor
PO Box 9000, UPRM-Geology
Mayaguez, Puerto Rico USA 00681
787-833-8433
guoquan.wang@upr.edu

Watts, Robert
Seismic Research Centre, University of West Indies
Research Fellow
St. Augustine, Port of Spain Trinidad & Tobago
868-662-4659
robwatts@uwiseismic.com

Wdowinski, Shimon
University of Miami
Research Associate Professor
4600 Rickenbacker Causeway
Miami, FL USA 33149
305-421-4730
shimonw@rsmas.miami.edu

Weaver, Jean
U.S. Geological Survey
Chief, Latin America Programs
US Geological Survey, MS 917
Reston, VA USA 20192
703-648-6012
jweaver@usgs.gov

Weber, John
Grand Valley State University
Professor of Geology, PhD
1 Campus Drive
Allendale, MI USA 49401
616-331-3191
weberj@gvsu.edu

Whitcomb, James
National Science Foundation
Section Head, Deep Earth Processes
4201 Wilson Blvd. 785
Arlington, VA USA 22230
703-292-4725
jwhitcom@nsf.gov

Woodward, Robert
IRIS
Director of USArray
1200 New York Ave., NW
Washington, District of Columbia USA 20005
202-682-2220
woodward@iris.edu
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V. Existing Geodetic Networks operating in the Caribbean region and Central America

- ACP (Autoridad del Canal de Panama)
- CORS (Continuously Operating Reference Stations)
- FUNVISIS (La Fundación Venezolana de Investigaciones Sismológicas)
- GEORED (Geodesia: Red de Estudios de Deformación), run by INGEOMINAS, Colombia
- GGN (Global Geodetic Network)
- IGN (Instituto Geografico y del Catastro Nacional de El Salvador)
- IGVSB (Instituto Geografico de Venezuela Simon Bolivar)
- MVO/SRC-IPGP (Monserrat Volcano Observatory)
- OVISCORI-UNA (Observatorio Vulcanologico y Sismologico de Costa Rica de la Universidad Nacional)
- OVSG/IPGP (Observatoire Volcanologique et Sismologique de Guadeloupe)
- OVSM/IPGP (Observatoire Volcanologique et Sismologique de Martinique)
- SRC-UWI* (University of the West Indies Seismological Research Center)
- PBO (Plate Boundary Observatory)
- UNAM (Universidad Nacional Autonoma de Mexico)
- VINET (Puerto Rico and U.S. Virgin Islands Real-Time High-Rate GPS Network)

*Note that the SRC runs the Eastern Caribbean Seismograph Network

Meteorological networks and/or operators

- BDM (Bahamas Department of Meteorology)
- CARIBE-EWS (Tsunami and Other Coastal Hazards Warning System for the Caribbean and Adjacent Regions)
- CCCCC (Caribbean Community Climate Change Centre), Belize
- MDC (Meteorological Department Curacao)

Other US based Networks

- Purdue University (USA)
- University of Puerto Rico Mayaguez
- UCAR (USA)
- NOAA (USA)
- USGS (USA)

These networks have been identified during the course of the COCONet planning. We welcome identification of additional networks (contact: Jackson@unavco.org).

VI. Abstracts & White Papers

- David Adams, Universidad do Estado do Amazonas
  GNSS Precipitable Water Vapor and Characteristics of Tropical Deep Convection
- Steve Anderson, University of Northern Colorado
  The Use of COCONet to Support Ground-based and Airborne LIDAR Assessment of Glassy and Vesicular Lava Textures on Caribbean Volcanoes
- Steve Anderson, University of Northern Colorado
  The NCAR Global Climate Change Research Experience for Teachers Institute: A potential model for COCONet broader impacts
- Rick Bennett, University of Arizona
  COCONet White Paper for CGPS sites in Panama
- Sen Chiao, Florida Institute of Technology
  Quantifying the Impact of 0600 UTC and 1800 UTC Assimilated Upper Air Observations and COCONet Measurements in the Western Atlantic and Caribbean during the Hurricane seasons of 2011 and 2012
- Vince Cronin, Baylor University
  Some thoughts about the challenges of E&O for COCONet
- Chris Crosby, UCSD
  Towards a Caribbean Airborne Topography LiDAR Initiative
- Peter Dare, FRICS, University of New Brunswick
  Monitoring the Montserrat Volcano by GPS
- Jean-Bernard de Chabalier, IPGP
  Continuous GPS measurements in Guadeloupe and Martinique (FWI): Implications for the seismotectonics of the Lesser Antilles
- Carlos Enrique Figueroa, National Center of Registries, National Geographic Institute, Management of Geodesy
  Planning for the possible establishment of new GPS stations of continuous operation in El Salvador, Central America
- Jennifer Haase, Purdue University
  Observing Onshore Penetration of Sea Breeze using GPS IWV: a Student Run Research Project in Puerto Rico
- Victor Huerfano, Puerto Rico Seismic Network
  Seismic and Tsunami Monitoring in the Caribbean
- Yev Kontar, University of Illinous, Urbana-Champaign
  Haiti Earthquake Aftermath: Urgent Action Needed to Improve Scientific Communication in the Caribbean Region
- Yev Kontar, University of Illinous, Urbana-Champaign
  Addressing Caribbean Geophysical Hazards through the Continuously Operating Caribbean GPS Observational Network (COCONet) and International Ocean Drilling Program (IODP)
- Paul Mann, University of Texas, Austin
  Rotations of GPS vectors near subducting buoyant highs: How are they expressed geologically?
- Daniel McNamara, USGS, ASL, NEIC
  Site Characteristics of USGS Global Seismographic Network Stations in the Caribbean Region
- Ernesto Munoz, New Mexico Consortium
  Variability and remote influences of Intra-Americas moisture fluxes and impacts on precipitation

VI. Abstracts & White Papers

- Sumant Nigram, Department of Atmospheric and Oceanic Science, University of Maryland, College Park
  The Caribbean Low-Level Atmospheric Circulation and Regional Hydrometeorology: Resolved by the COCONet GPS Network?
- Eugenio Polanco Rivera, Universidad Autonoma de Santo Domingo
  Justification of a Permanent GPS Station Network in the Dominican Republic
- Ramesh Shrestha, NCALM
  Research-quality LiDAR and High-resolution Topographic and Bathymetric Observationsin Support of COCONet
- Lillian Soto-Cordero, UPRM
  Improvement on Puerto Rico Seismic Network Capabilities for Monitoring Seismic and Aseismic Deformation in Southeastern Puerto Rico
- Andy Newman, Georgia Institute of Technology
  Interseismic Megathrust Coupling near Nicoya, Costa Rica Between 1994 and 2010
- Omar Perez, Simon Bolivar University
  Ways to Improve the COCOnet GPS Array Along the Caribbean/South-America Plate Boundary
- Richie Robertson, Seismic Research Centre
  Perspectives on the COCONet Project.
- Guoquan Wang, UPRM
  Introduction to the Puerto Rico and Virgin Islands High-Rate GPS Network
- Robert Watts, Seismic Research Centre, University of West Indies, St. Augustine, Trinidad and Tobago
  Inception, Deployment, Processing and Initial Results of a cGPS Network Across the Lesser Antilles Arc: Implications for Caribbean Plate Geodesy and Volcano Monitoring
- Shimon Wdowinski, University of Miami
  Addressing the vertical component in COCONet
- John Weber, Grand Valley State
  Caribbean-South American plate tectonics and Trinidad/Tobago neotectonics from GPS