

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

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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 $M_w=7.0$ 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/meteorological 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 tsunamis, 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.

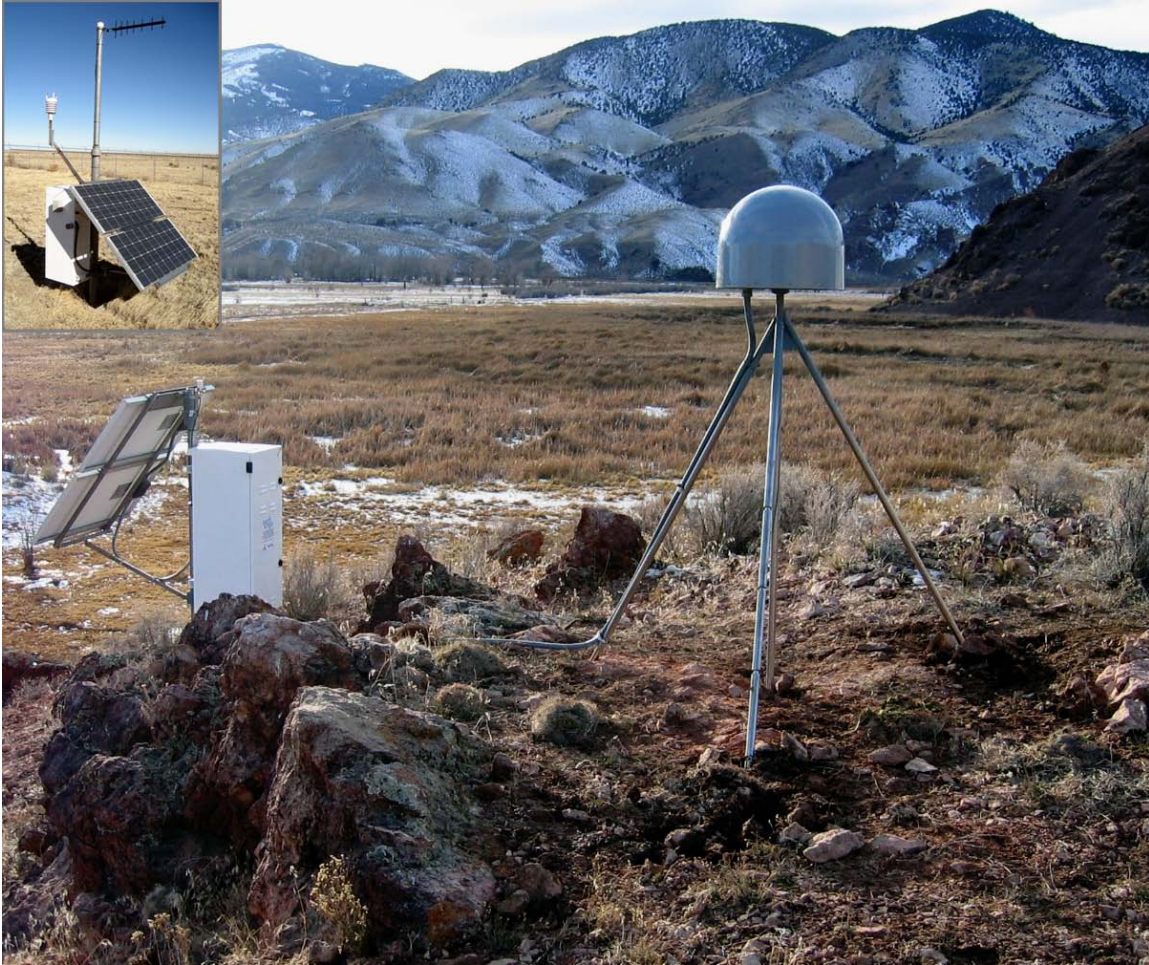


Figure 1. PBO station P009 near Marysvale, Utah. This station combines a short drilled-braced monument with a radome housing the geodetic antenna (right) and the receiver and data communications enclosure and solar panels (left). A similar monument style will be utilized on COCONet where competent bedrock 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.

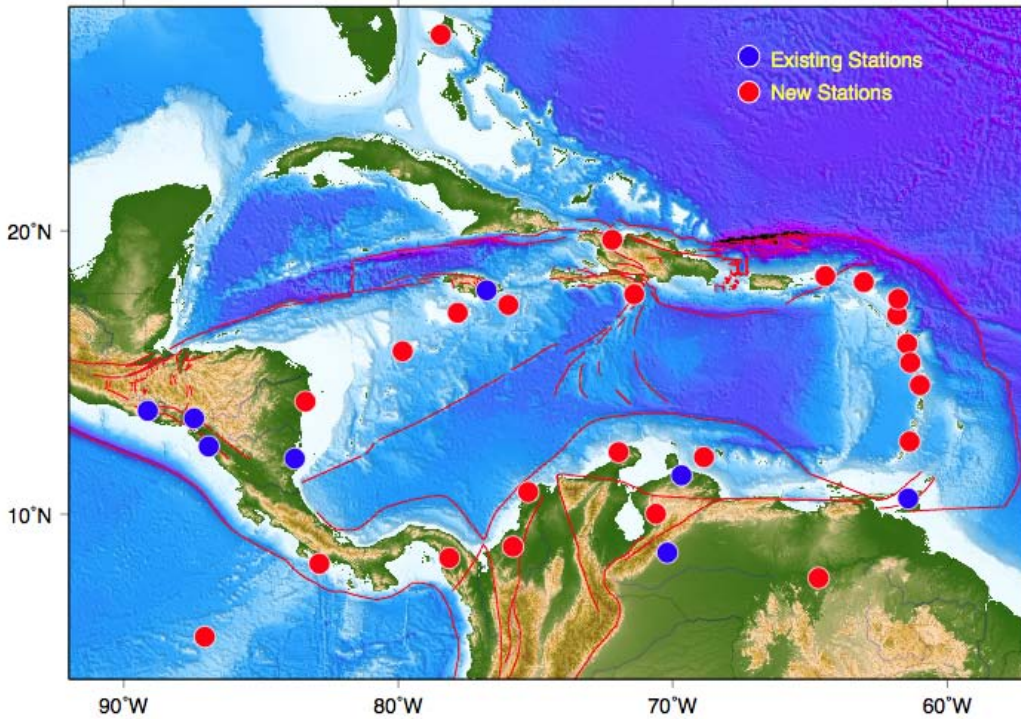


Figure 2. Proposed phase one for COCONet site installations. This revised plan shows the locations for new (red) installations and existing (blue) stations suitable for upgrade or inclusion in the first stage of network installations. The siting plan was developed during workshop working group discussions 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
Guadeloupe	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 (CEPRENAC). 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 – 8:00am	Breakfast	Puerto Rico 1
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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 Chabaliér
1:45pm – 2:00pm	N. American – Caribbean Boundary Cayman, Hispaniola, Puerto Rico focusG. 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, Hispaniola, 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) The next generation: international education partnerships (Haase, Olds, Pandya). The practitioners: connecting hazards to risk (J. Weaver, D Carlson)	San Juan 1 Puerto Rico 3 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 Puerto Rico 3 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 SessionCOCONet 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?

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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)
- IGVS (Instituto Geografico de Venezuela Simon Bolivar)
- MVO/SRC-IPGP (Montserrat 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 IWW: 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 Illinois, Urbana-Champaign
Haiti Earthquake Aftermath: Urgent Action Needed to Improve Scientific Communication in the Caribbean Region
- Yev Kontar, University of Illinois, 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 Observations in 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