27 February 2023

Digital Elevation Model training in the Caribbean: Evaluation of potential impact for Caribe-EWS Member States

This document is a supplement to the "Digital Elevation Model Development Training Workshop" proposal prepared by the U. S. National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information (NCEI) on 28 June 2022.
At the ICG/CARIBE-EWS Officers meeting on 02 February 2023, the Technical Secretary of the ICG/CARIBE-EWS, Mr. Bernardo Aliaga, requested an evaluation of potential ICG/CARIBE-EWS Member States for participation in proposed Digital Elevation Model (DEM) training. This evaluation would help determine potential Member States with known data to take advantage of a proposed DEM training.

To perform the requested cursory evaluation, the proposal's authors reviewed data from the following:

- 23rd Meeting of The Meso American – Caribbean Sea Hydrographic Commission (MACHC21) national reports
- MACHC data audit (https://www.iho-machc.org/documents/meip/Reference%20Documents/Data%20Audit%20Layout%20By%20Country.pdf)
- Caribbean GeoPortal (https://caribgeoportal.maps.arcgis.com/home/index.html)
- Caribbean Marine Atlas (https://www.caribbeanmarineatlas.net/)
- Caribbean Community Climate Change Centre (https://www.caribbeanclimate.bz/)
- General Bathymetric Chart of the Oceans (GEBCO; https://www.gebco.net/data_and_products/gridded_bathymetry_data/)

Based on the review of the aforementioned data portals, reports, etc., the authors identified the Member States most likely to have data available to build a DEM suitable for tsunami inundation mapping purposes. Consultation with an expert in tsunami inundation modeling confirmed that 10-meter DEM is preferred; however, a 30-meter DEM would be considered the acceptable minimum.

As of February 2023, the following Member States would benefit from this DEM development training, based on known bathymetric and topographic data:

- Aruba
- Bahamas
- Cayman Islands (United Kingdom)
- Colombia
- Curaçao
- Dominica
- Grenada
- Guyana
- Haiti
- Jamaica
- Mexico

- Panama
- Sint Maarten
- Trinidad and Tobago
- Guadeloupe, Martinique, Saint-Martin, Saint-Barthélemy (France)
- Bonaire, Saba, Sint Eustatius (Netherlands)

This recommendation illustrates the knowledge of existing data, not data availability and should not be used to exclude participation by non-listed Member States. As outlined in the original proposal, training participants must provide adequate digital data for their Member State as well as meeting the minimum technical proficiency requirements. If participants are unable to provide adequate digital data for their Member State, a sample set of data will be provided in advance of the workshop. This sample set will be representative of a U.S. territory and not of a participant's Member State.

DIGITAL ELEVATION MODEL DEVELOPMENT TRAINING WORKSHOP

Prepared by the U. S. National Oceanic and Atmospheric Administration (NOAA), National Centers for Environmental Information (NCEI) in support of international hazard mitigation

June 28, 2022

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PROPOSAL SUMMARY

The National Centers for Environmental Information (NCEI) of the U.S. National Oceanic and Atmospheric Administration (NOAA) proposes to lead an international digital elevation model (DEM) development instructional workshop for invited participants. The need for improved capabilities in the area of collecting, processing, analyzing, and modeling elevation data (topographic and bathymetric) has been well documented by UNESCO/IOC.

NOAA is the lead U.S. agency responsible for tsunami detection, forecast, warning, and mitigation capabilities. NOAA's Tsunami Mission is to provide reliable tsunami warning and promote community resilience. It operates the U.S. Tsunami Warning System, organizes the National Tsunami Hazard Mitigation Program (NTHMP), conducts a tsunami research program, provides access to tsunami observational data and products, and provides technical assistance and training to the global tsunami warning system. As the primary tsunami operational and research agency, NOAA retains scientific and technical expertise in most areas related to tsunami hazard.

NOAA's National Centers for Environmental Information provides scientific data management of and serves as the primary archive for global historic tsunami data, including tsunami source events and run-ups, bottom pressure recorder data from Deep-Ocean Assessment and Reporting of Tsunamis (DART) buoys, coastal water level data, deep-ocean and near-shore bathymetry data, and the DEMs developed from these data. NCEI also hosts the World Data Service for Geophysics and operates the International Hydrographic Organization's Data Center for Digital Bathymetry (IHO DCDB). The World Data System (WDS) is an Interdisciplinary Body of the International Science Council (ISC; formerly ICSU). The mission of the World Data System is to support the ISC's vision by promoting long-term stewardship of, and universal and equitable access to, quality-assured scientific data and data services, products, and information across all disciplines in the Natural and Social Sciences, and the Humanities. WDS aims to facilitate scientific research under the ISC umbrella by coordinating and supporting trusted scientific data services for the provision, use, and preservation of relevant datasets, while strengthening their links with the research community.

NCEI develops high-resolution DEMs for select U.S. coastal regions to support tsunami forecasting and modeling efforts at the NOAA Center for Tsunami Research at PMEL (ngdc.noaa.gov/mgg/coastal/coastal.html). The DEMs are used in U.S. tsunami forecast systems that incorporate a numerical model that simulates tsunami generation, propagation, and inundation. Moreover, NCEI has developed numerous DEMs in the Caribbean and Pacific for non-U.S. coastal areas to support programs led by the United Nations Development Programme (UNDP) and the Office of U.S. Foreign Disaster Assistance (OFDA), an organizational unit within the United States Agency for International Development (USAID). NCEI has led two international instructional workshops on the methodology and process of DEM development. This proposal builds on and extends these previous successful training sessions.

CONTENTS

1 INTRODUCTION

The National Centers for Environmental Information (NCEI) of the U.S. National Oceanic and Atmospheric Administration (NOAA) proposes to coordinate and lead the DEM development training for participants from international communities. Building on previous training conducted by NCEI and hosted by Ocean Networks Canada (ONC), NCEI will provide a five-day workshop on developing coastal digital elevation models (DEMs) which could precede training on inundation modeling.

The field of tsunami hazard mitigation encompasses a multitude of issues from understanding and predicting tsunami behavior to establishing warning systems and preparing for, responding to and recovering from tsunamis as they occur around the world. The importance and complexity of tsunami hazard mitigation issues require properly trained professionals ready to face the challenges posed by the threat of tsunami events.

Since tsunamis are strongly affected by variations in coastal relief, a carefully constructed DEM of the coastal zone is critical to modeling and forecasting tsunami inundation. DEMs are a required input to inundation models which are a critical component in the development of inundation maps and, ultimately, evacuation maps. DEMs are detailed representations of coastal relief that are constructed from near-shore seafloor depth and land elevation data. Non-trivial issues such as different vertical and horizontal datums and file formats, data age and quality, sparse data coverage and availability, and data evaluation contribute to the challenges faced in developing high-quality coastal inundation DEMs.

2 PROJECT NEED

The specific requirements, deliverables, and timelines set forth in this proposal are in direct response to statements made in the UNESCO/IOC documents referenced herein to enhance the capabilities of Member States of the Intergovernmental Coordination Group for Pacific Tsunami Warning System (ICG/PTWS) and the Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (ICG/CARIBE EWS) to address the risk of tsunami impact. In summary, the main recommendations outline the need to pay more attention to practical components of inundation mapping, including preparing appropriate bathymetry/topography data for tsunami inundation modeling. NCEI proposes to fill this need by preparing and delivering a repeatable curriculum for training on the development of coastal inundation DEMs.

As stated in the Preparing for Community Tsunami Evacuations: From Inundation to Evacuation Maps, Response Plans, and Exercises SUPPLEMENT MANUAL (draft, UNESCO/IOC, 2019): “There are two essential data/information needed before any tsunami modeling is conducted: tsunamigenic earthquake sources and a high-resolution DEM. Establishing these two takes significant time and effort and should be planned well ahead of time.” The importance of DEM development is further emphasized in the ICG/CARIBE-EWS Working Group 2

report Evaluation Of The Needs For Generating Tsunami Evacuation And Inundation Maps For ICG/CARIBE-EWS Member States (UNESCO/IOC, 2016) which states the following: "WG2 re-urges Member States to make an effort to have their bathymetric data ready in digital form with a standard quality, format and resolution so that tsunami modeling can be performed during a training workshop or a group of experts visit." However, the capacity for the development of DEMs is lacking in many of PTWS and CARIBE-EWS Member States. The Workshop on Tsunami modeling & Mitigation 2014 report (UNESCO/IOC, 2015) stated the following: "It is often the case that countries lack the appropriate resources, expertise or skilled personnel to obtain bathymetric data." As such, it is clear that DEMs are a critical component of the development of tsunami inundation models and maps to determine the hazard and that expertise in the region is lacking. A DEM development workshop would address the gaps in DEM expertise and products globally, and particularly in the Caribbean region.

NCEI is uniquely qualified to offer this training, as it currently develops high-resolution DEMs for U.S. coastal regions supporting NOAA tsunami forecasting and modeling (ngdc.noaa.gov/mgg/coastal/coastal.html). Moreover, NCEI has developed numerous DEMs in the Caribbean and Pacific for non-U.S. coastal areas to support programs led by the United Nations Development Programme (UNDP) and the Office of U.S. Foreign Disaster Assistance (OFDA), an organizational unit within the United States Agency for International Development (USAID). The DEMs are used in a variety of tsunami models to simulate tsunami generation, propagation, and inundation.

NCEI has developed a training workshop with a curriculum that gives tsunami professionals the tools and knowledge required to develop and update DEMs used in tsunami modeling and in planning tsunami-resilient communities. This overview program consists of topical sessions taught by experts in the field of DEM development. Upon the successful completion of the proposed training workshop, participants could incorporate the methodologies learned during the DEM workshop into their inundation modeling, thus meeting tsunami preparedness recommendations for their nation. A recent workshop was established for a specific partner (ONC) and their needs, however, the curriculum serves as a foundation for a general DEM development workshop. This proposal aims to leverage on the existing DEM workshop materials and experience and develop the materials into a workshop more encompassing of the broader international community's needs.

3 METHODOLOGY

3.1 Coordination and preparation

NCEI will prepare and contribute an overview presentation on DEM development to the host organization. NCEI will use this opportunity to relay the technical and physical layout needs for the workshop and to solicit feedback from host agency and potential participants. This initial presentation will also serve to make managers and professionals aware of the proposed training, enabling NCEI to refine the curriculum, and to coordinate with participants on workshop requirements. NOAA has a number of groups with expertise in coordinating international workshops between NOAA and UNESCO/IOC, such as the International Tsunami Information

Center and the Caribbean Tsunami Warning Program. NCEI would encourage their participation in logistical and coordination roles.

3.2 Tsunami inundation DEM development course

NCEI will develop a five-day DEM development training workshop. The workshop will offer participants and attendees the opportunity to learn how to process and evaluate coastal topographic, bathymetric, and shoreline data, and to develop individual coastal relief models for use in regional tsunami inundation studies (Section 9). Participants will learn methods for checking data quality, changing horizontal and vertical datums and converting between different data formats. Attendees will participate in hands-on exercises to learn to evaluate and edit data and to develop the DEMs using gridding algorithms and GIS software. They will evaluate the completed DEMs using various manual and automated techniques and generate detailed documentation reports describing each step carried out in the DEM development process.

3.3 Participant requirements

To ensure the highest level of participation and success of the workshop, attendees should be carefully selected by the host organization. The total number of participants should not exceed 12 participants. Potential participants will submit a letter of support and CV to the host organization. Final selection of participants will be determined by organization(s) hosting, coordinating, and/or funding the workshop and NCEI DEM team and must meet the following minimum requirements:

- Bring digital, GIS-ready topographic, bathymetric and coastline data sets and nautical charting data to support a DEM development project for an area of interest within their Member State. *
- Bring a laptop with provided DEM specific software installed and functional.
- Have a basic understanding of horizontal and vertical datums specific to participants' Member State. In particular, tidal datums and relationship to land based datums.
- Have a basic understanding of tsunami inundation modeling needs as required for/by their Member State.
- Have a background in geography, geology, geomorphology, geophysics or hydrography.
- Have a working fluency in English.
- Receive a nomination by an ICG Tsunami National Contact.

Experience with the command line, and working in a Linux environment are strongly recommended.

*If participants are unable to provide adequate digital data for their Member State, a sample set of data will be provided in advance of the workshop. This sample set will be representative of a U.S. territory and not of a participant’s Member State.

3.4 Hardware requirements

Participants must provide their own computer workspace. No computers will be provided by either host facility/organization or NCEI DEM instructors.

Minimum Hardware requirements for laptop:

- 2G RAM
- 20G Hard Disk Space
- Minimum of 2Ghz processor speed, faster is preferable

3.5 Software requirements

Successful completion of the workshop requires that each participant have the following software installed and functional:

- A GIS software package such as ESRI ArcGIS v. 10.x (esri.com) or QGIS (qgis.org).
- NCEI DEM development custom software package (github.com/ciresdem).
- Linux OS (to run DEM software and for data processing).

NCEI will provide access and basic written installation instructions prior to the workshop for the DEM customized software package for Windows or Linux OS (currently NCEI is unable to provide assistance for Mac users). NCEI will have very limited ability to troubleshoot the installation of the software at the workshop so installation and verification of functional workspace is vital for a successful and productive experience.

3.6 Pre-workshop participant recommendations and requirements

To maximize the time spent at the workshop on the DEM development methodology, NCEI would request that participants have basic GIS skills, familiarity using command line and navigating file structures in a Linux environment. To assist in this, NCEI will recommend and in some cases require online tutorials and reading materials in preparation for the DEM workshop. A preliminary list is included below:

- QGIS tutorials and tips - there are many, here are some options
    - qgistutorials.com/en/
    - qgis.org/en/site/forusers/trainingmaterial/index.html
    - GAIA Resources - youtu.be/Fag9Yn65Qy0
- ESRI tutorials and tips - esri.com/training/
- Linux shortcuts and commands - unixguide.net/linux/linuxshortcuts.shtml
- Nano - text editor for Linux - nano-editor.org/docs.php
- A tutorial on Datums - vdatum.noaa.gov/docs/datums.html

4 PERSONNEL

Two instructors are required to prepare, coordinate, and conduct the five-day DEM development course. The following have been identified by NCEI as qualified instructors.

Dr. Christopher Amante

Dr. Christopher Amante is a Geospatial Research Scientist collaborating with NOAA National Centers for Environmental Information (NCEI) through the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder. Dr. Amante is developing integrated bathymetric-topographic digital elevation models (DEMs) to support the Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act. His research interests include quantifying the uncertainty in coastal DEMs, and incorporating that uncertainty and uncertainty in sea-level rise projections and storm surge models in probabilistic, future flood risk assessments. Dr. Amante's professional web map, UncertainSeas.com, highlights his methods for modeling future flood risk for the southern tip of Staten Island, NYC.

Dr. Amante earned his B.A. from the College of the Holy Cross in Environmental Studies with a minor in Physics. Chris previously worked at NCEI through CIRES as a graduate research assistant, during which time he received his M.A. in Geography from the University of Colorado Boulder. He received his Ph.D. in Geography from the University of Colorado Boulder in 2018.

Kelly Carignan

Ms. Kelly Carignan is employed by the Cooperative Institute for Research in Environmental Sciences (CIRES), a National Oceanic and Atmospheric Administration and University of Colorado, Boulder (CU) joint research institute. She manages the development of coastal digital elevation models in support of tsunami inundation modeling and forecasting efforts at the NOAA Center for Tsunami Research and the National Tsunami Hazard Mitigation Program (NTHMP). Ms. Carignan obtained a B.A. in Geography from the University of Colorado Boulder.

Elliot Lim

Mr. Elliot Lim is employed by the Cooperative Institute for Research in Environmental Sciences (CIRES), a National Oceanic and Atmospheric Administration and University of Colorado, Boulder (CU) joint research institute. He is developing integrated bathymetric-topographic digital elevation models (DEMs) to support the Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act. Mr. Lim is also currently working with NCEI's U.S. Extended Continental Shelf (ECS) Project as a GIS specialist and bathymetric data analyst. Mr. Lim obtained a B.A. in Geography from the University of Colorado Boulder.

Matthew Love

Mr. Matthew Love is employed by the Cooperative Institute for Research in Environmental Sciences (CIRES), a National Oceanic and Atmospheric Administration and University of Colorado, Boulder (CU) joint research institute. He is developing integrated bathymetric-topographic digital elevation models (DEMs) to support the Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act. He also leads and manages the

DEM group custom software development. Mr. Love obtained a B.A. in Geography from San Francisco State University, California.

Dr. Michael MacFerrin

Dr. MacFerrin is employed by the Cooperative Institute for Research in Environmental Sciences (CIRES), a National Oceanic and Atmospheric Administration and University of Colorado, Boulder (CU) joint research institute. Dr. MacFerrin is currently developing new methodologies to automate, improve, and validate topo-bathy DEM generation for the ETOPO update in 2022 and other NOAA DEM projects using open-source AI models and other tools. His doctoral dissertation work focused on developing new algorithms to detect, monitor, and predict surface-mass-balance feedbacks on the Greenland ice sheet using remotely-sensed airborne data. His post-doctoral work has spanned a number of topics including historical high-resolution production of DEMs from archival collections of Navy airborne photography over coastal Antarctica. Dr. MacFerrin has a computational background (BSE & MS in Computer Science & Engineering) and a PhD in Physical Geography from the University of Colorado, Boulder.

5 EVALUATION

In order to determine the effectiveness of the workshop and to improve future trainings, feedback for the inundation DEM development course will be collected via a survey form from all participants immediately following the training.

6 BUDGET

Total funding required to cover salaries, travel, and materials for two scientists to prepare, coordinate and conduct a five-day DEM development workshop is $54,272. Table 1 breaks down the costs related to NCEI staff to cover salaries, travel, and materials for two scientists to prepare, coordinate and conduct a five-day DEM development workshop. Workshop development and adaptation is expected to take three weeks for two scientists to execute. This will include the development/adaptation of participant materials, software packages and datasets. Any future workshops will have significantly reduced development time. Both budgets are calculated with the assumption that the host country will provide local transport and workshop facilities for all participants and instructors for the duration of the workshop. This includes time for instructors, who will arrive before the start of the workshop, to handle logistical issues such as hardware and software set-up. Participant travel is estimated in Table 2 with the assumption that the host country will have two participants which will not require air travel. Participant's budgets and travel cannot be managed or coordinated by NCEI due to internal limitations, thus funding agencies or similar must receive funds and coordinate.

Table 1: Budget workshop development and delivery

Task	*Cost*
Workshop development and coordination (3 weeks of two persons' time)	$18,000

Workshop delivery (5 days of 2 persons' time)	$6,000
Air travel (flights, 2 people) and Per Diem (based on San Jose UN DSA $231) 7 days, $231/day	$5,500
Total	**$29,500**

Table 2: Participant budget (based on 10 participants that require travel), to be managed by host/funding agency (non-NCEI)

Task	*Cost*
Air travel ($900 per person, 10 participants)	$9,000
Per Diem (based on San Jose UN DSA $231) 6 days, $231/day and 12 participants	$16,632
Total	**$25,632**

7 DELIVERABLES

- Development/adaptation and delivery of a 5-day DEM regional workshop which provides participants with the technical expertise to develop a DEM.
- Rescope existing workshop materials to refer to non-specific datasets.
- Develop region appropriate presentation.
- Rewrite material to apply to regional datums and general DEM parameters.
- Prepare alternative workshop practice dataset.
- Prepare DEM software package for use in an open source Virtual Machine based on Fedora.
- Participant workbook and instruction material.
- Participant access and basic installation instructions for NCEI's custom DEM development software package.
- A survey of workshop strengths and weaknesses.
- Post-workshop report from the instructors to the host organization with recommendations to improve future workshops.

8 REFERENCES

UNESCO-IOC. (2015). Workshop on Tsunami Modeling and Mitigation. ICG/CARIBE-EWS Working Group 2: Tsunami Hazard Assessment. Cartagena de Indias, Colombia.

UNESCO-IOC. (2016). ICG/CARIBE-EWS Working Group 2: Evaluation of The Needs for Generating Tsunami Evacuation and Inundation Maps for ICG/CARIBE-EWS Member States.

UNESCO-IOC. (2019) Preparing for Community Tsunami Evacuations: From Inundation to Evacuation Maps, Response Plans, and Exercises SUPPLEMENT MANUAL draft

9 DRAFT AGENDA

Digital Elevation Model Development Training Workshop

Training Goals:

Attendees will learn how to process and evaluate coastal topographic and bathymetric data, and will develop individual coastal relief models for use in regional tsunami inundation studies.

- Process bathymetric, topographic and shoreline data with select GIS software.
- Evaluate and edit data.
- Develop coastal digital elevation models (DEMs) using gridding algorithms.
- Evaluate DEMs.
- Document DEM development.
- Gain a broad understanding of DEM accuracy and uncertainty.
- Learn what is required from the DEM to produce community inundation maps.

One day before workshop:

- Set up and test hardware and software (computers, projectors, internet…).
- Organize workspace and materials.
- Review logistics with training hosts.

Day 1: Introduction and Data Assessment

- Introduction and workshop goals.
- Overview of workshop agenda.
- Data types and formats
- Data categories: topographic, bathymetric, coastline and tidal and geodetic datum information.
- Data types: LiDAR, multibeam, beach profiles, hydrographic surveys, satellite imagery, etc.
- Data formats: raster grids, point data, ESRI shape files and coverages, etc.
- Horizontal and vertical datums
- Horizontal: geographic (WGS84), UTM zones.
- Vertical: geodetic, tidal.
- Establishing relationships between vertical datums.

- DEM planning: DEM extents and model requirements

Day 2: Data Processing and Conversions

- Introduction/review of data processing and conversion methods using GIS software and command line tools.
- Data coverage and cataloging existing data
- Example: identifying relationships between vertical datums.
- Example: processing data with a GIS (change horizontal and vertical datums, data formats).

Day 3: Data Evaluation and Editing

- Intra-dataset consistency and identification of anomalous data values.
- Development of a high-resolution coastline at a specific vertical datum.
- Identifying and interpreting inconsistencies due to:
- Anthropogenic change
- Geomorphologic change
- Differences in data resolution
- Incorrect metadata
- Data improperly processed
- Using satellite imagery and nautical charts to assist in resolving data inconsistencies.

Day 4: DEM Development and Assessment

- Generating DEM using various gridding algorithms:
- Advantages and limitations of gridding algorithms
- Evaluating DEM
- Determining horizontal and vertical accuracy
- Identifying gridding anomalies using slope maps and three-dimensional images
- Comparison with source data files
- Comparison with tidal station data, topographic elevation and geodetic monument data, and/or control points

Day 5: DEM Assessment (cont.), Documentation, and Workshop Wrap-up

- Overview of Integrating DEM into tsunami modeling software
- DEM cell registration and nested DEMs
- Documenting DEM development.
- Metadata
- DEM development report
- Benefits and requirements for open data access. Example: Data Trust
- Workshop wrap-up and evaluations