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Deployment of an AWAC off the east coast of St Vincent, 2018-2019

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This report is part of the NOC-led project "Climate Change Impact Assessment: Ocean Modelling and Monitoring for the Caribbean CME states", 2018-2019; under the Commonwealth Marine Economies (CME) Programme in the Caribbean.

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Summary

The eastern Caribbean islands encompass some of the most vulnerable coastlines in terms of sea level rise and exposure to tropical cyclones (hurricanes), waves and storm surges. The climate in the Caribbean is already changing and sea level rise impacts are being observed. Governments in the Caribbean islands, many of which may be regarded as Small Island Developing States, recognise that climate change and sea level rise are serious threats to the sustainable development and economic growth of their countries and urgent actions are required to increase climate resilience and make informed decisions about how to adapt to future climate change (Caribbean Marine Climate Change Report Card, 2017; IPCC, 2014). Although the level of vulnerability will vary from island to island, it is expected that practically all SIDS will be adversely affected by sea level rise. Islands typically have a windward coast, which is exposed to coastal erosion by storm and swell waves from the Atlantic Ocean, but there are limited *in situ* data on wave conditions in the nearshore zone.

In this report, we present results from deployment of a wave and current meter deployment over two 2-month periods off the east coast of the island of Saint Vincent (the main island of the state of Saint Vincent and Grenadines).

The work presented here is a contribution to a wide range of ongoing activities under the Commonwealth Marine Economies (CME) Programme in the Caribbean, falling within the NOC-led project “Climate Change Impact Assessment: Ocean Modelling and Monitoring for the Caribbean CME states”, 2018-2020.

1 Introduction

1.1 Background, aim and objectives of the study

The work presented here is a contribution to the wide range of ongoing activities under the Commonwealth Marine Economies (CME) Programme in the Caribbean, task 2 **"Monitoring and Risk Assessment to Increase Climate Change Resilience"** under work package 2.4 *"*Ocean Modelling and Monitoring for Caribbean SIDS*"*.

The aim of Work Package 2.4 is to provide tools for monitoring and modelling of coastal processes for Small Island Developing States (SIDS) in the Caribbean, with the main focus on Saint Vincent and Grenadines.

This work package contributes to the development of a strategy for decision-making about coastal management and climate adaptation in the coastal zone, facilitating integrated coastal zone management including planning of development of coastal infrastructure for the islands.

While this study is focused on acquisition of *in situ* data for Saint Vincent and the Grenadines, the methodology is transferable to other SIDS and can be applied generally in other nearshore locations. The instrument used (the Nortek AWAC) has been deployed in many locations worldwide. The deployment method used here is specific to small-boat deployment in a micro-tidal region.

Specific objectives are:

- To contribute to the capacity-building for coastal studies in Caribbean Islands (specifically SVG) for applications in coastal management, by providing a wave and current gauge and training local personnel to deploy it and interpret the data
- To acquire *in situ* data on water level, currents and waves in the nearshore zone off the east coast of Saint Vincent, where coastal erosion/retreat is being observed, and archive the data with the British Oceanographic Data Centre (BODC), for future access.

1.2 Study Area – Saint Vincent and the Grenadines

Saint Vincent and the Grenadines (hereafter referred to as SVG) is an island state that forms part of the Windward Islands in the southern part of the eastern Caribbean Sea (part of the Lesser Antilles island arc). Located at about 13^0 15' N and 61^0 15' W, it is neighboured by St Lucia to the North, Barbados to the East and Grenada to the South (Figure 1). The state covers a total land area of approximately 150.3 square miles (388 sq. km.) and a larger marine area including a shallow coastal shelf encompassing an area of approximately 690 square miles. The capital, Kingstown, is located on the largest island of Saint Vincent (commonly referred to as the mainland).

The Grenadines archipelago covers a total land area of 16.5 sq. miles (44 sq. km), and stretches a distance of 45 miles to the southwest of Saint Vincent toward Grenada. The land area of the Northern Grenadines (belonging to SVG) covers 9 sq. miles, and the Southern Grenadines (part of Grenada) 7.5 sq. miles.

The majority of infrastructure and settlements in SVG, like most SIDS, are located on, or near, the coast, including government, health, commercial and transportation facilities. High-density tourism development on the coast is particularly vulnerable to coastal erosion, inundation and climate change, including sea level rise (SLR). Coastal development also tend to increase the degradation of coastal and marine biodiversity, thereby reducing resilience to climate change impacts such as SLR, enhancing the impact of waves and storm surges.

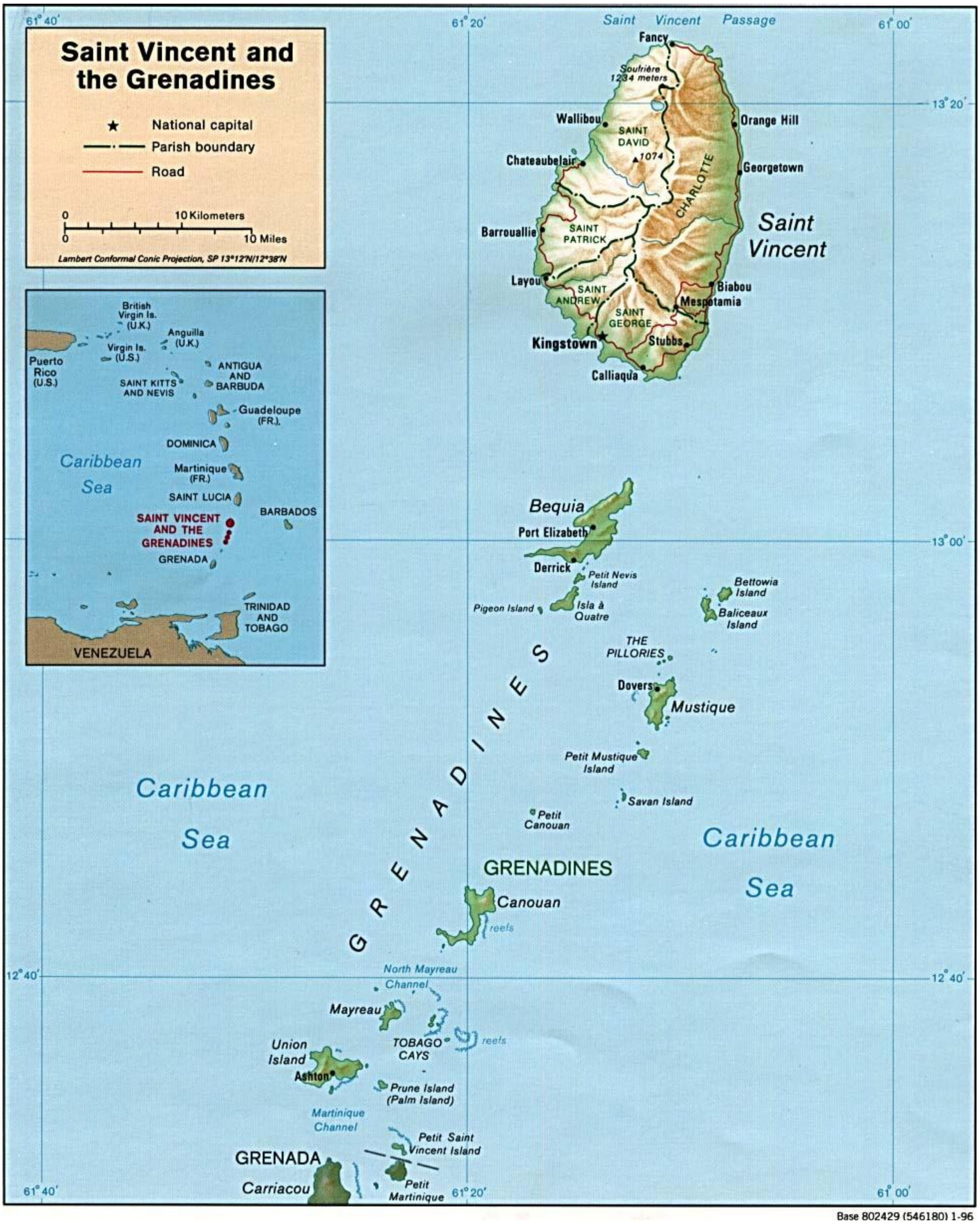

Figure 1: Location of St. Vincent and the Grenadines

In common with many Small Island Developing States (SIDS) globally, the coastal areas of SVG are experiencing erosion arising from a variety of causes, including hurricanes, sea level rise, reef damage and human activity. An understanding of wave processes and energy along the island's coastline and in surrounding waters, combined with geographical knowledge of natural and man-made features and human activity within coastal areas, can aid the assessment of current and future risk of damage and inundation from storm surges, waves and SLR.

Beaches, reefs, seagrass beds and mangroves are particularly vulnerable to sea level rise, more intense storms surges and changes in waves. In the small islands of the Grenadines, protecting fisheries is important for maintaining healthy populations of herbivores and hence the resilience of coral reefs, as well as for safeguarding the sustainability of artisanal fisheries.

The main island of Saint Vincent is a steep volcanic island, in contrast to the coral atolls of the Grenadines, with black volcanic sand beaches around most of the coast (except for some of the southern coast, where white coral sand is found). There is a shortage of low-lying land for development of industry, coastal infrastructure (roads and airport) and settlement.

The east coast (windward coast) is exposed to swell and storm waves from the North Atlantic. There is evidence of coastal erosion/retreat of the east coast. Anecdotal evidence of sea level rise exists in recent years. Within this project we held a stakeholder consultation and training workshop in which information on coastal hazards was collected (National Oceanography Centre (2018, 2019). The information was collated into a GIS layer (Lichtman, 2018).

Examples of vulnerable coastlines in Saint Vincent include:

1) Argyle International Airport on the SE of the Windward (east) coast
2) The Windward Highway
3) Settlements including Georgetown on the Windward coast
4) Port of Kingstown (SW coast)
5) Marine Protected Areas –SW coast, where main tourist resorts are located
6) West coast settlements like Layou, where SLR is already being experienced, and setback of buildings has been introduced and a seawall constructed.

A separate study of flood risk to the Argyle International Airport has been carried out (Phillips et al., 2019). The most urgent need for wave data appears to be for the east coast, especially near Georgetown, so this was the location selected for the present study. An airborne LiDAR bathymetric survey was performed on behalf of the UK Hydrographic Office as part of the wider CME Programme. The steep topography in the nearshore zone of Saint Vincent means that there is only a narrow coastal strip of data around Saint Vincent. Figure

1.3 Oceanographic description of the study area

The Caribbean Sea is a deep ocean basin, adjacent to the North Atlantic Ocean. It extends from Mexico and Central America in the west and south west, to the Lesser Antilles island arc in the east; and from the north coast of South America to the south to the Greater Antilles islands, including Cuba, Hispaniola, Puerto Rico, Jamaica, and the Cayman Islands to the north.

At the eastern side of the Caribbean basin, there are two basins: the Venezuelan Basin and, farther east, the Grenada Basin. A north-south ridge, running between the Virgin Islands and the north coast of Venezuela, separates these two basins. On the outside of the island arc, to the south, the Tobago Basin separates the Grenadine islands from Barbados, whilst to the north and west the deepest, part of the Atlantic Ocean occurs in the Puerto Rico Trench.

The general circulation of the- currents on the western side of the North Atlantic is to the north and west, in the south, and towards the north and east in the north, as part of the clockwise circulation around the sub-tropical gyre, including the- following currents:

the Florida Current flows north, alongside the coast of Florida; the Gulf Stream and the North Atlantic Current, to the north, flow NE towards Europe; the North and South Equatorial Currents flow westward. The Antilles Current is a highly variable surface ocean current of warm water that flows northerly past the Lesser Antilles island chain that separates the Caribbean Sea and the Atlantic Ocean. The current results from the flow of the Atlantic North Equatorial Current. The South Equatorial Current is also known by other names e.g. the Guiana Current that extends from the North Brazil Current along the coast of South America.

Tides in the eastern Caribbean are small, micro-tidal in fact, with an amphidrome of the principal semi-diurnal tide in Puerto Rico, thus there is a notable diurnal inequality in the region.

In general, there is a lack of *in situ* oceanographic data in SIDS. There are some regional wave buoys (see https://www.ndbc.noaa.gov/, select Caribbean Sea). A tide gauge was installed at Calliaqua Coast Guard station (in 2016) as part of the tsunami warning network for the Caribbean (https://www.weather.gov/ctwp/; http://www.ioc-tsunami.org/). Williams et al. (2019) describe a new automated data access and quality control system developed for the present project. Apart from that, occasional oceanographic data have been acquired for engineering works, including an AWAC deployed by Coastal Dynamics Ltd of Trinidad and Tobago off Spring Gardens.

The UK Hydrographic Organisation, also as part of the Commonwealth Marine Economies Programme, has collected some LiDAR bathymetry data around the area of St Vincent and the Grenadines.

In order to acquire some *in situ* wave data to understand the wave climate in Saint Vincent, in combination with a wave model and to validate and force the XBeach model (Roelvink et al., 2009) we decided to purchase and deploy a wave and current gauge, which would be donated to SVG for future studies.

2 Purchase of a wave gauge for St Vincent and Grenadines

The Nortek AWAC (Acoustic Wave and Current) meter was chosen as the most versatile instrument available, to be deployed in the nearshore zone. This instrument measures water levels, waves and current profiles through the water column and can be easily deployed, with diver assistance, from a small boat. Alternatively, a buoy and rope can be used, on a diver-less recovery system (e.g. as described in a deployment in Chesapeake Bay, USA by Puckette and Gray (2008).

A 1-MHz AWAC-AST (with acoustic surface tracking option) was purchased, in May 2018, and was delivered to the Coast Guard base at Calliaqua in Saint Vincent, for storage and safekeeping. The instrument includes a pressure sensor (suitable for 0-50m water depth), a compass and tilt sensor, 9 MB of memory on motherboard (M8) and the acoustic surface tracking firmware. It was delivered in a storage case, together with a battery case, 2 alkaline battery packs (540Wh, 13.5V, non-rechargeable) and the necessary cables, together with a 4GB SD card and data logger. (Note that new batteries must be purchased for any further deployments.)

A copy of the STORM software for downloading a visualising the water level, current and wave data was also purchased from Nortek for SVG. Various manuals and other documentation can be downloaded from the Nortek website, e.g. https://www.nortekgroup.com/products/awac-1-mhz

Figure 2: Close up photos of Saint Vincent AWAC

3 AWAC deployment

The plan was for the AWAC to be deployed in the nearshore zone off the east coast of Saint Vincent, just south of Georgetown. A location off Black Point was selected, in about 10m water depth. In Figure 3, the extent of LiDAR coverage in this region is shown, along with the location of beach profiles being measured at intervals.

Two deployments, each of two months' duration were planned. The first deployment was during the hurricane (summer, wet) season, was from 26 July-10 October 2018. The second deployment was in the contrasting winter (dry season), when the NE Trade winds are stronger but there are normally no tropical cyclones.

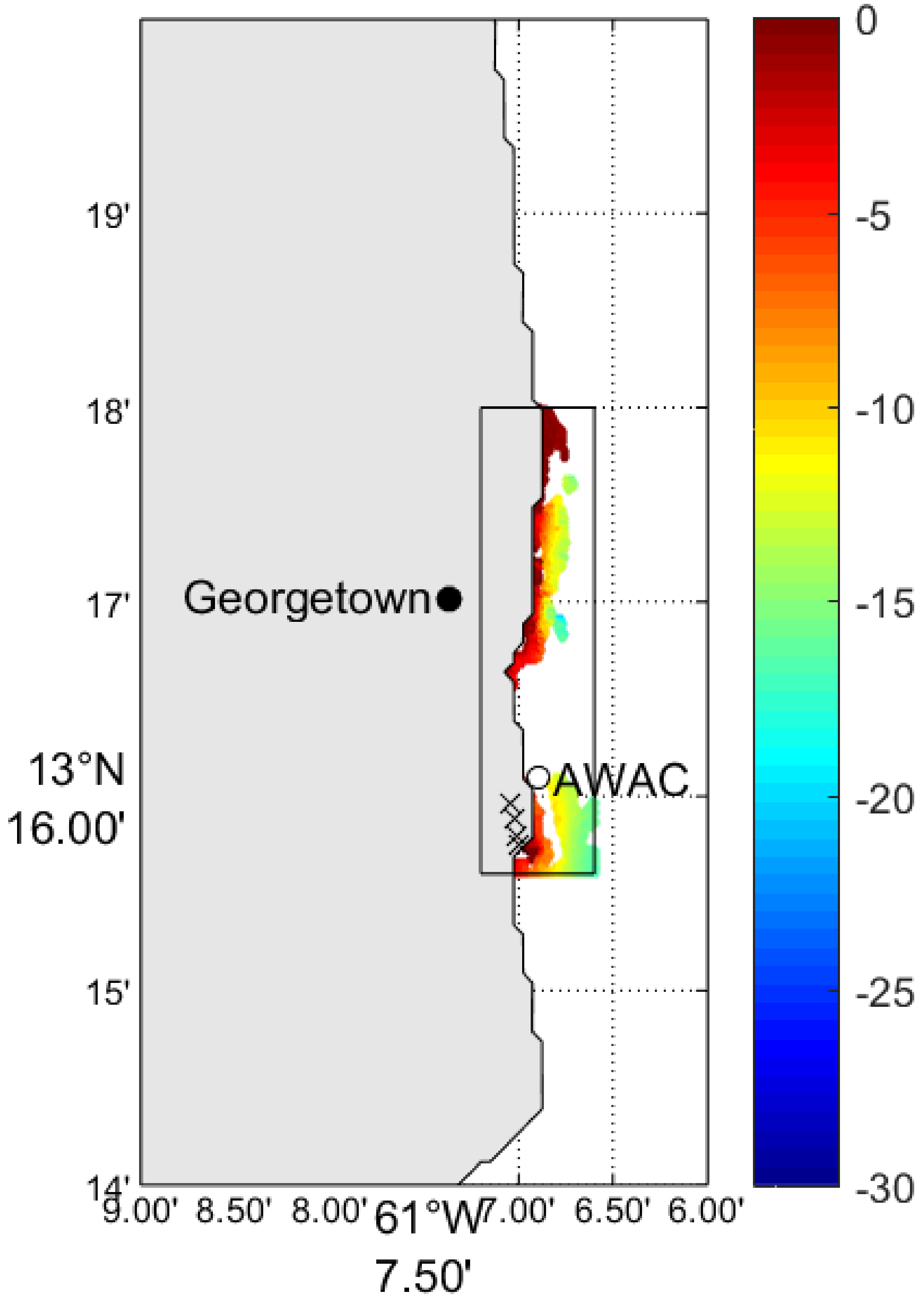

Figure 3: East coast around Georgetown showing LiDAR extent (colour-shaded). The crosses show start points of beach profiles at Black Point recreation centre. Colour shading is depth below local chart datum (0.5m below MSL at Owia Bay)

Coastal Dynamics Ltd (CDL), a coastal consultancy company from Trinidad and Tobago, were contracted to carry out the setup and deployment of the AWAC for 2 2-month periods. They also constructed and supplied a bottom-mounted mooring frame. A boat and divers were hired from Serenity Dive Shop in Calliaqua, Saint Vincent.

The CDL team consisted of:
Giles Williams – Coastal Scientist
Nikoli Forbes – Field Technician
Israel Jittan - Diver

AWAC setup:

The AWAC was removed from its shipping case and tested to ensure that it was functional. Online data collection was started and used to verify that the transducers were functional and collecting data. The battery canister was also prepared for the deployment. The two supplied O-rings were lightly coated with silicone grease and installed. The canister was sealed according to manufacturer specifications and the battery voltage was measured through the canister at 14.43V.

Following the installation of the AWAC into the mooring frame, the pressure offset was zeroed and a compass calibration was performed. A maximum error of one degree was noted after calibration. The instrument was set to local St. Vincent time (UTC – 4 hours).

Mounting Height of AWAC in frame: 0.5 m above bed.

Compass offset (magnetic declination): -15° (see http://www.geomag.nrcan.gc.ca/calc/mdcal-en.php)

The AWAC was programmed to measure water velocity in 26 0.5m bins starting approximately 0.4m above the instrument. The water velocity profile was recorded every 30 minutes and wave measurements were enabled. The AWAC collected 2048 ensembles of currents and pressure at 2 Hz, over a 17-minute period, once every hour, which are then processed to give integrated wave parameters. Concurrent with the water velocity and pressure measurements for wave data analysis, the AST also tracks the free surface.

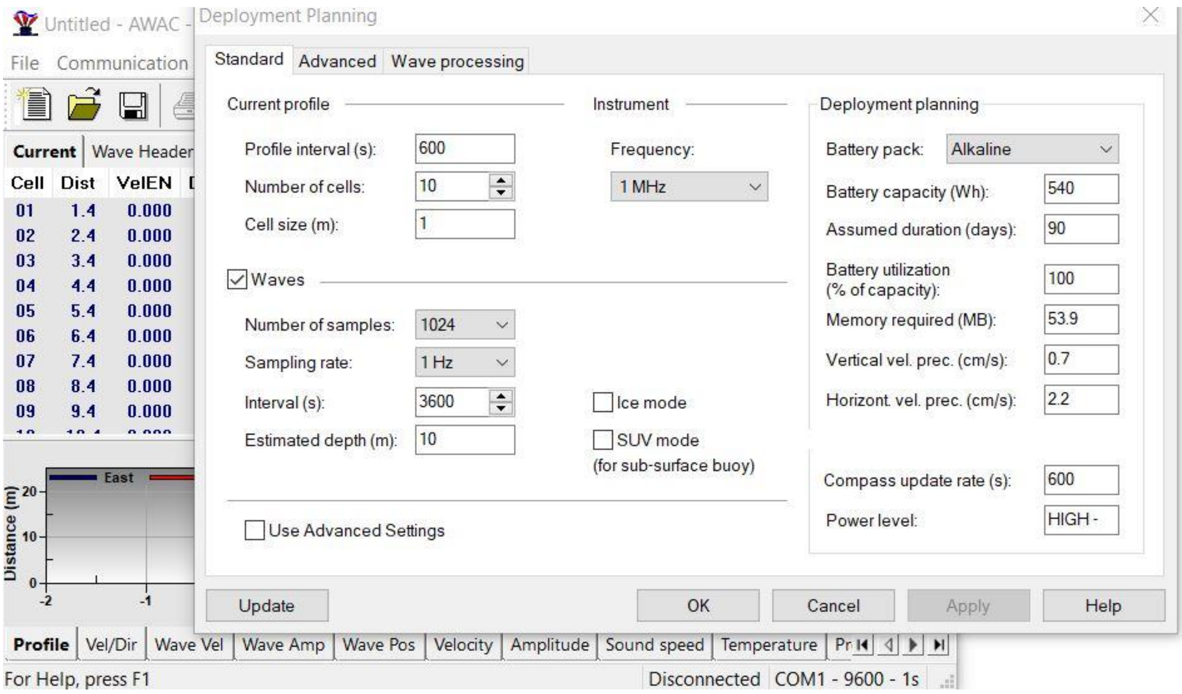

Figure 4: Screenshot of AWAC setup

3.1 July-October 2018

Deployment: 26 July 2018 at approximately 1100 hrs (local time).

Location: WGS84 UTM Zone 20N = 704235, 1467577 (13.2683 N, 61.1149 E), ~10m depth

The deployment went well, although the seas were quite rough, making conditions on the boat a little difficult. The proposed coordinate was too deep so it was moved closer to shore in ~10m depth. The seabed in the area was gently sloping as the divers confirmed. The seabed was hard-packed sand and flat, with a very strong wave surge at the seabed. Due to this, the divers placed a couple of extra concrete blocks on the frame to ensure it had enough weight to stay put.

Recovery: 10 October 2018 at 1230 hrs (local time)

75 days data acquired (N.B. The battery was estimated to run out by 20 October 2018 - 86 days' duration).

Figure 5: The recovery team with instrument and frame 10 Oct 2018

On recovery, the divers found that the mooring frame was half buried by sand and gravel, which made it a little tricky to get out from the seabed, but it was eventually successfully recovered (Figure 5). There was not much biofouling.

The frame and instrument were dismantled and cleaned before being put back into storage at the Coast Guard base.

The Storm software package can be used to visualise the data. Some screenshots are shown below. The time series of water level, current and wave data are shown in Figures 6 and 7.

Figure 6 shows the pressure and temperature profile in the upper panel. The next panel shows the orientation (heading, pitch and roll), which indicates a slight settling event; probably due to arrival of some long swell waves. The bottom panel shows a 'heat map' of current profiles through time. The panel to the right also shows a selected current profile.

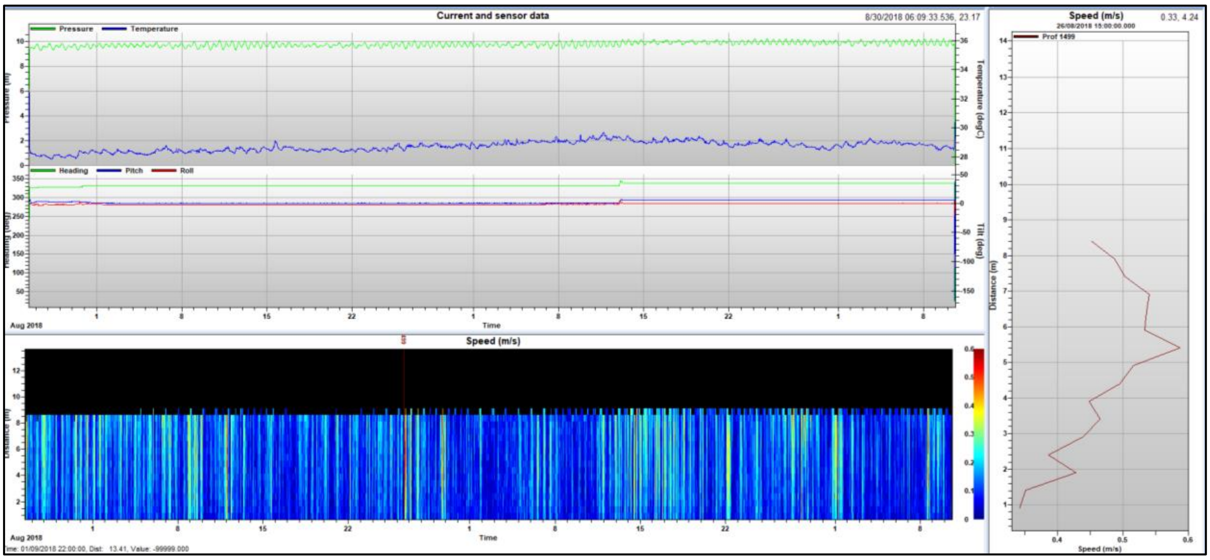

Figure 6: Processed current data from STORM software

Both the bottom pressure recorder and the AST record the water level. The mean water level over the deployment is 9.8m above the instrument. Combined with the mounting being 0.5 m about the bed this gives a mean depth of 10.3 m. A small tidal signal can also be seen with a maximum spring tidal range of about 0.8m.

Figure 7 shows the processed wave data. In Figure 7a, the uppermost panel shows the time series of wave height, showing three variables: the significant wave height, H_{m0} (sometimes equated to the highest 1/3 of waves); the top 10% wave height, H_{10}; and the maximum wave height during the wave burst, H_{max}. The upper middle panel shows wave period: peak wave period, T_p, mean wave period, T_{m02}; and the zero-up-crossing wave period, T_z (the latter two definitions are almost equivalent). The third of the three upper panels shows wave directional parameters (using the wave 'from' direction): peak wave direction, *DirTp*; mean wave direction, *MeanDir*; and the wave spreading parameter, *SpTp*. The bottom-most panel is a 'heat map' showing the wave frequency spectrum through time. In Figure 7b, the lower left panel is a snapshot of the wave frequency spectrum at 11:03 on 29 September, with the lower right panel being the frequency-direction spectrum for the same time.

The instrument recorded the passage of a couple of tropical storms, which passed north of the island during the deployment period. These were T/S Isaac on 13 September and T/S Kirk on 27 September (https://www.nhc.noaa.gov/data/tcr/). From the motion data it can be seen that the mooring frame shifted by a few degrees (pitch, roll, heading) within the first week, this may have been due to the frame settling and getting buried a bit as the waves were high during that period and the divers recalled significant surge felt at the seabed during deployment. The next shift probably happened during the first storm, which may have buried it further (this may have been good, in that it was secure enough to record the next storm that passed closer to the island). The instrument tilts are less than 10° (when using the AST) so the Storm software mapped the cells to a vertical profile using the pitch and roll data collected by the on-board attitude sensors.

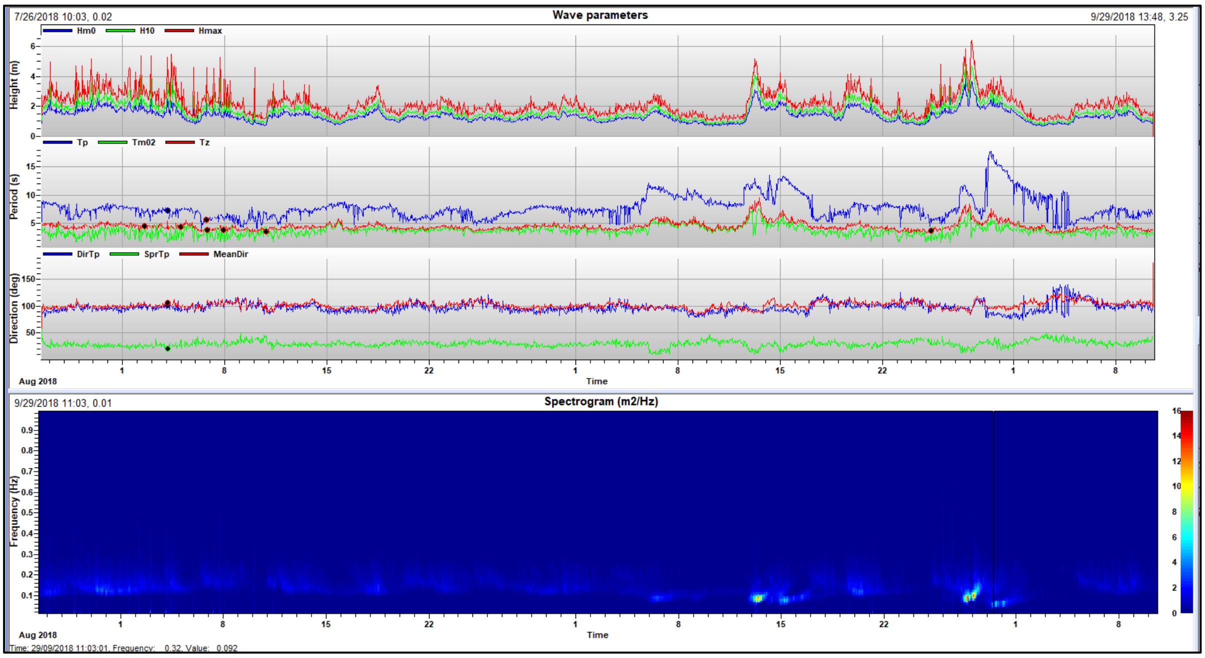

Figure 7a: Processed wave data from STORM software

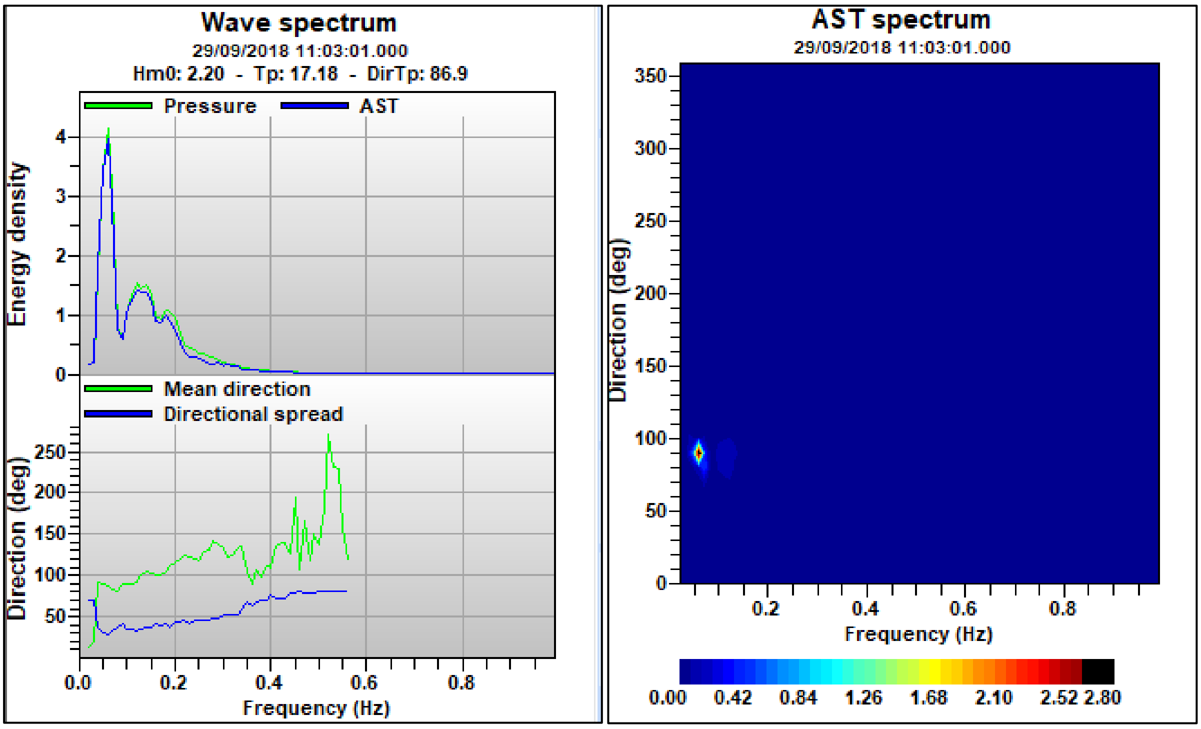

Figure 7b: Processed wave data from STORM software

A few of the instantaneous data points have error flags, the number is <4% of the 1,825 hours of data, so overall the data are of good quality. The significant wave height exceeds 3m for 13 hourly bursts in 3 events on 13 September, 27th September and 28th September, corresponding to tropical storms Isaac and Kirk as mentioned above, with peak wave period 11-13 s, from 90-100 degrees (magnetic). The maximum peak wave period exceeds 17s, which is very long period swell occurring on 29th September, when the wave height is lower, around 2 m, coming from about 088 degrees (magnetic). This is seen to be a combination of a narrow long-period swell peak with some wind sea (Figure 7b). Note that the magnetic declination is -15 degrees so the recorded directions should be reduced by this amount. Thus the shorter waves are coming from almost due east (~80 deg T), while the very long waves are coming from slightly further north (~70 deg T).

3.2 January-March 2019

The second deployment and recovery used the same settings and location. Figure 8 shows the dive boat used for the deployment.

Deployment: 15 January 2019 at approximately 11:00 hrs (local time)

Figure 8: AWAC in frame on dive boat, prior to deployment 15 January 2019

Recovery: 20 March 2019 at 11:45 hrs (local time)

The recovery was straightforward, but somewhat more biofouling was observed (Figure 9).

Figure 9: AWAC in frame after recovery, showing the amount of bio-fouling

Processed current and wave data are shown in Figures 10 and 11, similarly to the first deployment.

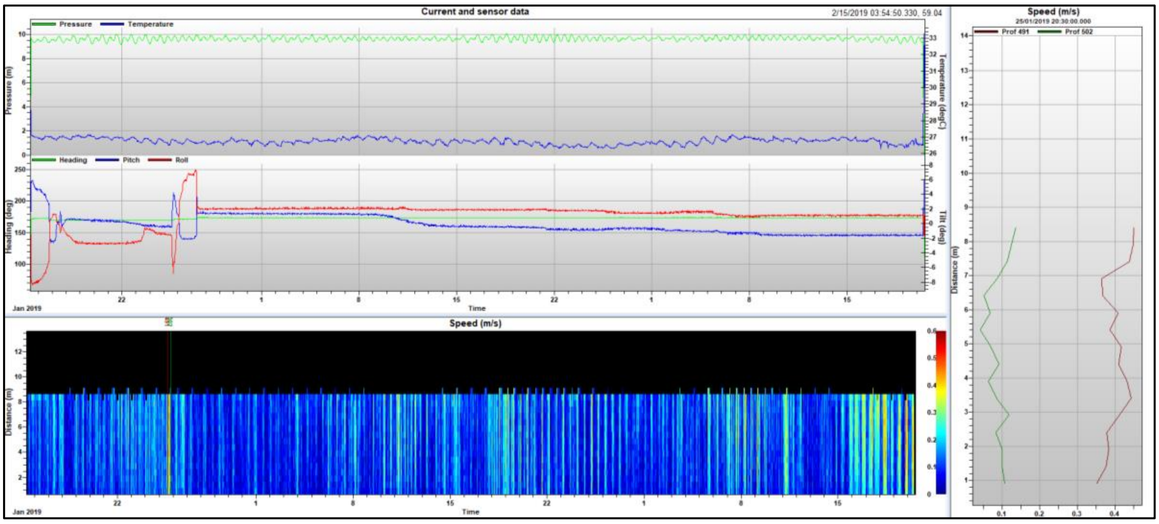

Figure 10: Processed current data from STORM software

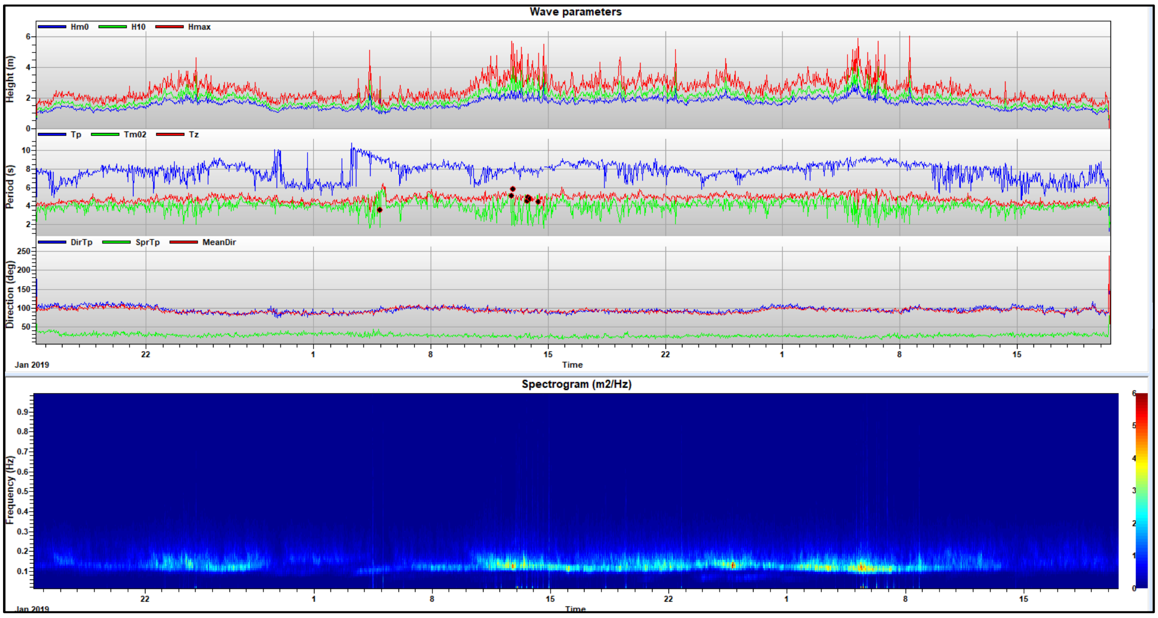

Figure 11a: Processed wave data from STORM software

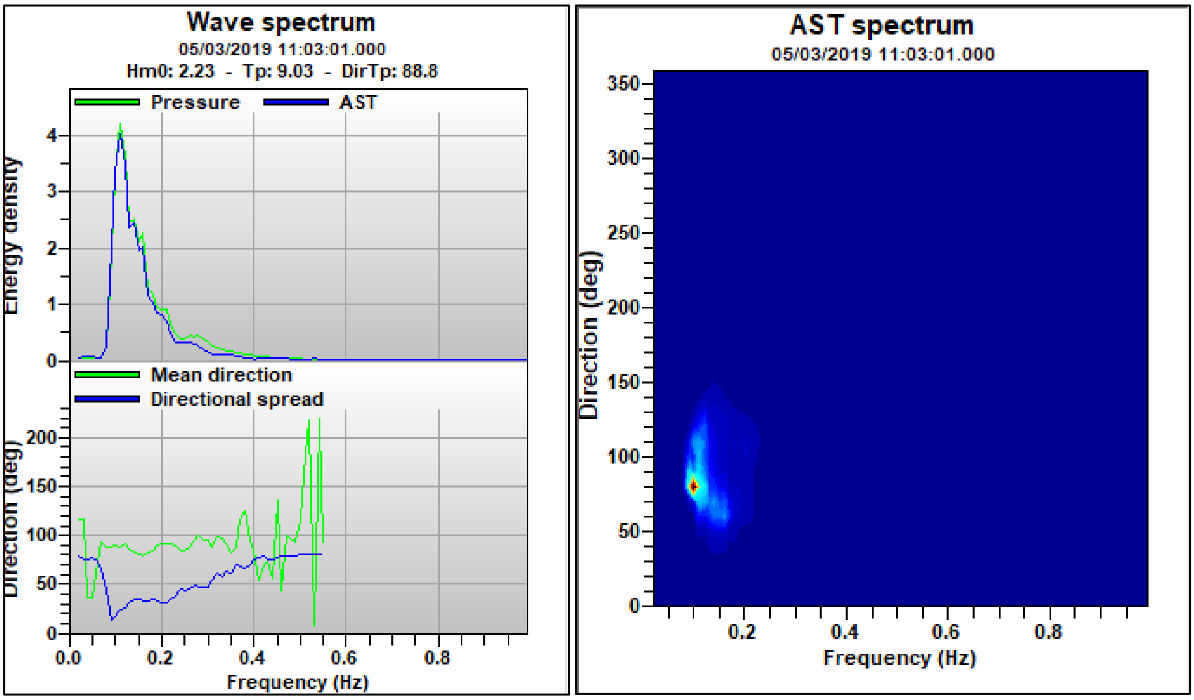

Figure 11b: Processed wave data from STORM software

For the second deployment, the waves were lower, not exceeding 3 m and the peak period did not exceed 12 s.

4 BODC data archival

As part of the CME programme, we have produced a prototype web portal to visualise and provide access to some of the programme's outputs.

The web portal has been created as a subsection of the Permanent Service for Mean Sea Level (PSMSL) website: https://psmsl.org, and is located at https://psmsl.org/cme. See also https://projects.noc.ac.uk/cme-programme/.

The AWAC data from both deployments have been deposited with the British Oceanographic Data Centre (BODC) for long-term archiving and availability. A digital object identifier (DOI) has been issued for each deployment in order to publish the data and make them easily available to other interested users.

1. For the July-October 2018 deployment, the DOI is

https://www.bodc.ac.uk/data/published_data_library/catalogue/10.5285/8e0a28de-a47f-6e3b-e053-6c86abc07dcf/

The following abstract is provided:

This dataset consists of wave, current and water level data, from a Nortek AWAC profiler at a depth of approximately 10 m, off the east (windward) coast of St. Vincent in the Windward Islands of the Lesser Antilles. Data were processed using Nortek Storm software. This deployment took place between July to October 2018, in the wet/hurricane season and recorded the passage of two tropical storms north of St. Vincent.

2. The DOI for 2nd deployment has been published as follows:

https://www.bodc.ac.uk/data/published_data_library/catalogue/10.5285/9386e626-d402-3934-e053-6c86abc06ccd/

with abstract:

This dataset consists of wave, current and water level data, from a Nortek AWAC profiler at a depth of approximately 10 m, off the east (windward) coast of St. Vincent in the Windward Islands of the Lesser Antilles. Data were processed using Nortek Storm software. This deployment took place between January and March 2019, in the dry season.

The Data can also be downloaded here:

https://www.bodc.ac.uk/data/bodc_database/nodb/data_collection/6901/

Acknowledgements

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