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# Guidance Note on the Application of Coastal Monitoring for Small Island Developing States

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# Summary

Small Island Developing States (SIDS) are a diverse group of 51 countries and territories vulnerable to human-induced climate change, due to factors including their small size, large exclusive economic zones and limited resources. They generally have insufficient critical mass in scientific research and technical capability to carry out coastal monitoring campaigns from scratch and limited access to data. This guidance report will go some way to addressing these issues by providing information on monitoring methods and signposting data sources.

Coastal monitoring, the collection, analysis and storage of information about coastal processes and the response of the coastline, provides information on how the coast changes over time, after storm events and due to the effects of human intervention. Accurate and repeatable observational data is essential to informed decision making, particularly in light of climate change, the impacts of which are already being felt.

In this report, we review the need for monitoring and the development of appropriate strategies, which include good baseline data and long-term repeatable data collection at appropriate timescales. We identify some of the methods for collection of in situ data, such as tide gauges and topographic survey, and highlight where resources in terms of data and equipment are currently available. We then go on to explore the range of remote sensing methods available from satellites to smart phone photography. Both in situ and remotely sensed data are important as inputs into models, which in turn feed in to visualisations for decision-making. We review the availability of a wide range of datasets, including details of how to access satellite data and links to international and regional data banks. The report concludes with information on the use of Geographical Information Systems (GIS) and good practice in managing data.

# 1. Introduction

This report presents some recommendations for acquisition of coastal observations for Small Island Developing States (SIDS), a distinctive group of 51 countries and territories recognised at the United Nations Conference on Environment and Development (UNCED), or Earth Summit, held in Brazil in 1992 (Bush, 2018). Such small nations generally do not have sufficient critical mass in scientific research and technical capability to carry out coastal monitoring campaigns from scratch (GIZ, 2017). We review the availability of various datasets from remote sensing and in situ observations which are available from work done by the National Oceanography Centre (NOC) and other international organisations. We then provide some basic guidance on using existing tide gauge data and short deployments of instruments which can be easily deployed from small boats. Access to data and local monitoring can give a certain amount of independence from the use of external consultants and a level of expertise which allows the use of such data for policy development, increasing the maritime economy, coastal management and climate change resilience planning.

The need to improve baseline monitoring for SIDS was identified as a priority action at the third international conference on SIDS, held in Samoa in 2014 (Bush, 2018). The methodologies described are applicable to SIDS globally, but examples given in this document are focused on the Caribbean region, and St. Vincent and the Grenadines (SVG) in particular.

## What is Coastal Monitoring?

The coast provides important amenity, habitat and defense against the sea. Its management must be balanced between management of flood and erosion risks and environmental considerations. Disaster resilience is particularly important to SIDS in a region where the geography means countries are particularly vulnerable to natural hazards (Environmental Solutions Ltd, 2007). Monitoring data is essential to achieving sustainable development and can be used to inform strategic plans, determine intervention thresholds, influence the design and timing of engineering works and inform environmental protection and management. Characterizing and monitoring of coastal and marine areas is also important in attracting funding for climate change adaptation programmes (Bush, 2018). In formulating ecosystem based action plans, for example, it is necessary to have detailed and accurate mapping of ecosystems in order to recommended appropriate adaptation actions.

Coastal monitoring is the collection, analysis and storage of information about coastal processes and the response of the coastline to these processes (Environment Agency, 2010). Things that can be monitored include physical factors, such as waves, tides, sea level, wind and currents and responding systems such as beaches, the seabed, cliffs structures and ecosystems (e.g. mangroves and seagrasses). Monitoring provides quantitative information that can be used to identify changes, rates of change and trends in the evolution of key variables, required to make management decisions. The monitoring of forcing factors and system response should together advance understanding of causal links and, through the use of modelling (Wolf et al., 2020) allow for better projection of future outcomes.

Monitoring provides information on how the coast changes over time, after storm events and due to the effects of human intervention. Accurate and repeatable data is essential to informed decision making, which often relies on historic or baseline data as well as up-to-date information (Brooks et al., 2018). This is particularly true when trying to understand and plan for the effects of climate change and sea level rise, where long-term monitoring is essential (Environment Agency, 2010; Mott MacDonald, 2017).

Data management is an essential aspect of monitoring, particularly when data is collected by several different actors, over long periods and using different methodologies (see Appendix 1).
The types of coastal and marine data which are useful to collect for coastal monitoring include (but are not restricted to):

- Beach profiles and topographic data
- Bathymetric data
- Wave and current measurements
- Tides and sea level
- Coastline change
- Habitat mapping

Data collection may be through in situ methods, such as topographic survey, using traditional methods, or wave measurements from a buoy, or through remote sensing, which can be from satellite, airborne, water or land based platforms.

# 2. Developing a monitoring strategy

“Systematic, frequent and broad-scale monitoring of coastal drivers (forcing) and shoreline response is a fundamental task in planning for long-term coastal change” (Nicholls et al., 2013)

Good coastal monitoring enables an evidence-based approach to decision making, by providing a long-term story of coastal evolution on which future decisions can be based. The ability of agencies to plan and manage resources is limited by a lack of monitoring data (Caribsave, 2012). To ensure that monitoring meets the needs, it is advisable to develop a monitoring strategy (Brooks et al., 2018), by:

- Identifying the monitoring objectives;
- Selecting the parameters to be investigated;
- Identifying the methods to be used in measuring these parameters;
- Establishing timing and frequency of monitoring campaigns;
- Establishing a timescale over which the monitoring exercise will be reviewed (providing the opportunity to modify the methodology or stop the monitoring);
- Identifying appropriate thresholds of change.

In cases where there has been no previous data collection, or where the purpose of monitoring or the methodology has changed, it is advisable to carry out a baseline survey against which future data can be compared. The physical conditions of a site, cost and the availability of previous data may dictate the monitoring methods and equipment suitable for a particular location (Table 1). For example if a location is inaccessible or dangerous, remote sensing methods are likely to be more suitable than in situ measurement. In order to conserve resources, it may be advisable to focus monitoring effort on locations that are most vulnerable, where there is greatest risk or where the most significant changes are occurring.

The selection of parameters to be investigated is dependent on the monitoring objectives. In order to better understand coastal erosion and vulnerability, consideration should be given to changes in the topography and morphology; sediment distribution and transport; hydrodynamics (sea level, currents and waves); and coastal habitats and vegetation (which may offer natural protection). Appropriate quantified thresholds levels, which would trigger remedial action, should be established. This can be difficult if natural variability is wide and if it is difficult to attribute cause.

The timing and frequency of monitoring campaigns should be decided according to local coastal risks. This risk should be assessed with consideration of (CCO, 2019a):

- Exposure to wave attack
- Coastal flood risk
- Geomorphology/defence type
- Management policy
- Assets at risk

Suggested frequency of monitoring campaigns under a cost-optimised, risk-based approach is outlined in Table 2. More intensive monitoring may be desirable at higher risk sites.

Table 1: Table of parameters and example alternative monitoring methods

| **Parameter** | **Methods** | |
|---|---|---|
| | **Remote Sensing** | **In situ** |
| **Hydrodynamics** | | |
| Sea level | Satellite Altimetry | Tide gauge |
| Waves | X-Band Radar | AWAC |
| | SAR Satellite | |
| Currents | X-Band Radar | AWAC |
| | SAR Satellite | |
| **Topography/Morphology** | | |
| Beach profile | LiDAR | Topographic survey by a range of methods including "SANDWATCH" and GPS |
| Topographic survey | Optical Satellite | GPS |
| | X-Band Radar | |
| | LiDAR | |
| | Aerial Photography/Photogrammetry | |
| Bathymetry | LiDAR | |
| | X-Band Radar | |
| | Optical Satellite | |
| **Habitat** | Aerial Photography | |
| | Optical Satellite | |
| | Autonomous Marine Vehicle (AMV) | |
| **Water quality** | | |
| Suspended sediment | Optical Satellite | Secchi disc |
| | Aerial Photography | |
| Chla | Optical Satellite | Water sampling |
| | Aerial Photography | |

Table 2: Outline of monitoring programme elements (recommendations from the Regional Monitoring Programme for England, CCO, 2019a)

| **Activity** | **Coverage** | **Frequency** |
|---|---|---|
| Beach profiles (topographic survey) | All sites, but with variable spacing on risk basis at accessible locations. High density surveys at beach management sites.<br>Dune toe surveys should be undertaken in high risk areas (Esteves et al., 2009) | Biannual at high risk/high exposure locations<br>Annual for all other risk types |
| Baseline topographic survey | All Sites | Annual for high risk sites otherwise every 5 years |
| Post-storm surveys | At accessible sites | Average one per year<br>Emergency/incident response |
| Bathymetry | Use swath (multi-beam) bathymetry for 100% seafloor coverage, with single beam over shallow banks | 5 years<br>Additional isolated annual surveys to support beach management schemes |
| Hydrodynamics (Wave and Tidal measurement) | Wave and tide measurements at targeted nearshore locations associated with scheme development, beach management and high risk sites.<br>Site-specific current monitoring to support sediment transport studies. | Continuous |
| Lidar | Typically 1 m resolution is sufficient.<br>Particularly effective for: soft, rapidly eroding cliffs; wetland areas; dune systems; and where beach access is difficult. | 5 years<br>Targeted areas such as sand dunes and soft cliffs may be surveyed in intermediate years.<br>In locations with rapid erosion biannual LiDAR and aerial photography may replace topographic survey |
| Aerial photography /photogrammetry | Whole coastline to Mean Low Water Springs | 5 years<br>This may be increased for areas of rapid erosion |
| Terrestrial ecological mapping (Using aerial photography and near-infrared images which can be captured simultaneously) | Baseline survey to map extent of dynamic priority habitats based on aerial photography interpretation | 5 years |

### Using Remote sensing data and in situ data together

The monitoring programme outlined in Table 2, recommends a mix of in situ (e.g. topographic survey) and remote sensing (e.g. LiDAR and aerial photography) techniques. Decisions on which techniques should be used will depend on a range of factors, including cost, availability of equipment, availability of expertise, accessibility of locations etc. In addition, other methods such as the use of X-band radar or satellite imagery may be used to monitor, amongst others, bathymetry and coastline change. Satellite imagery can also be very useful in habitat mapping, so long as it is used in conjunction with in situ measurements to verify the data.

## 3. In Situ Data

How to collect in situ data for:

- Sea level and tides (Tide Gauge)
- Wave and current measurements (AWAC)
- Coastline change (Beach profiles and topographic data)

### Sea Level: Tide Gauge

A tide gauge is a device for measuring the change in sea level relative to a datum (a reference point of known height). Early self-recording tide gauges used mechanical floats and stilling wells, modern gauges tend to use either acoustic or radar technology. Radar tide gauges are composed of a sensor positioned several metres above the water surface and use either a pulse or wave reflected off the water to obtain a measurement of water level (Woodworth and Smith, 2003). Common methods of sea level measurement are described in Table 3. Comprehensive information can be found in the Manual on Sea Level on Measurement and Interpretation Volume IV produced by the IOC (2006), with an update focused on Radar Gauges (IOC, 2016).

Table 3: Commonly used methods of sea level measurement

| **Category** | **Type** | **Wave averaging** | **Accuracy** | **Advantage** | **Disadvantage** |
|---|---|---|---|---|---|
| **Surface following** | Tide pole | By eye | 0.02-0.10m | Inexpensive,<br>Easy to make | Effort, workforce |
| | Float | Stilling well | 0.01-0.05m | Robust | Needs vertical structure, high maintenance |
| **Fixed sensors** | Acoustic reflection | Multiple samples | 0.005-0.01m | Robust, low cost, low maintenance | Needs vertical structure |
| | Radar reflection | | | | |
| | Pressure | Hydrodynamics and multiple samples | 0.01m | No vertical structure is needed | Density and wave corrections, high maintenance |
| **Remote** | Satellite | Empirical adjustment | 0.01m | Systematic global coverage | Expensive, specialist use only, multiple corrections, misses local storms, does not sample near the coast |

Tide gauges are important for sea level hazard warning (tsunamis and storm surges), tidal predictions, and determining long-term trends. These data are critical for coastal activities including safe navigation, engineering work (such as the installation of new infrastructure) and habitat management. Water level data from tide gauges can be important boundary information for models and long-term data gives information on how sea level is responding locally to climate change.

A tide gauge was installed at the Calliaqua Coast Guard Station in SVG in 2013 and data from this station and others in the region (Figure 1) are publicly available via the Intergovernmental Oceanographic Commission (IOC) Sea Level Monitoring Facility (http://www.ioc-sealevelmonitoring.org/). Details on how to process these data are available through a NOC report (Williams et al., 2019).

It is imperative that equipment, such as tide gauges, are maintained effectively so that complete records are available for use. There are many tide gauges worldwide for which research quality data for sea level studies is not available. In some cases, although high-frequency data is available for download from the IOC, manual quality control has not been completed as it is too labour intensive (Williams et al., 2019). As part of the CME Programme, the NOC has developed a system in Matlab for automatic quality control of tide gauge data, details and full instructions are available through the NOC report *Development of an Automatic Tide Gauge Processing System* (Williams et al., 2019) and through PSMSL website (https://psmsl.org/cme/index.php).

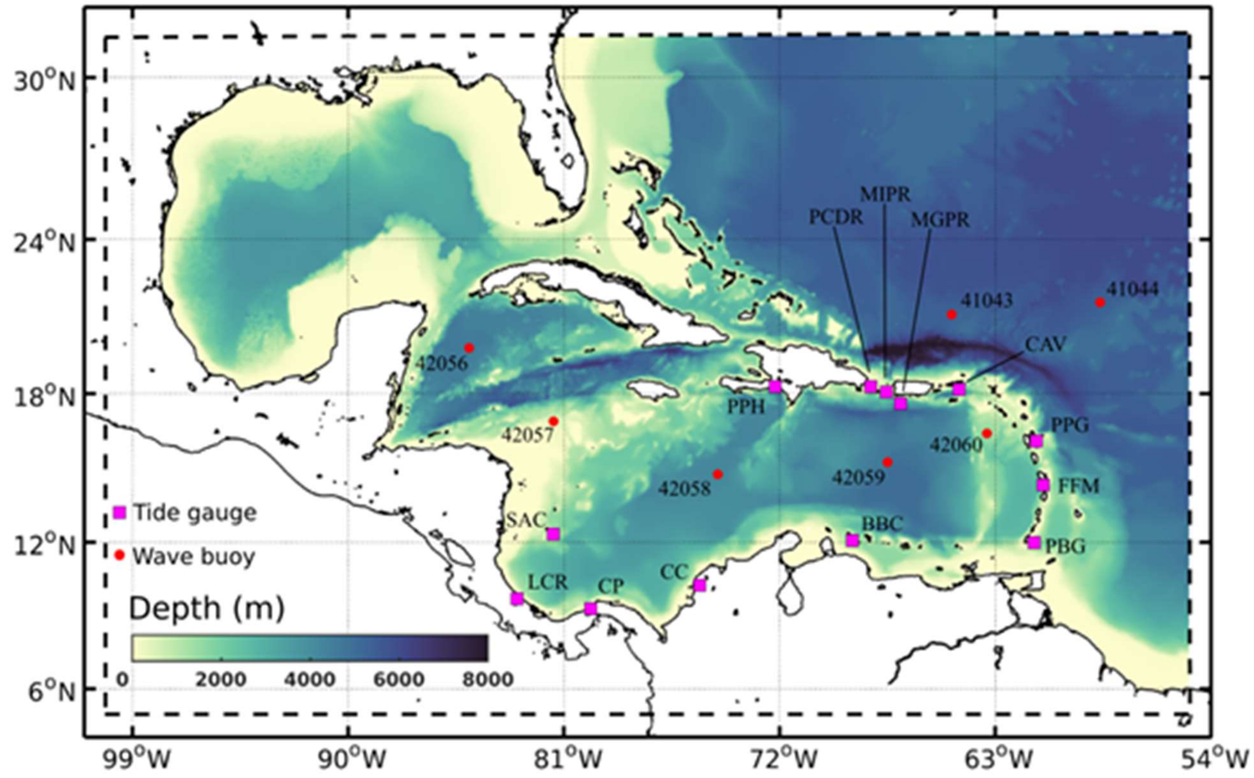

Figure 1: Map of the Caribbean Sea, showing bathymetry and locations of 13 tide gauges and seven wave buoys. Tables 4 and 5 give the locations of the tide gauges and wave buoys respectively (Jevrejeva, et al., 2020)

Table 4: Locations of the 13 Caribbean tide gauge stations identified in Figure 1 (Jevrejeva, et al., 2020)

| **Site** | **Name** | **Country** | **Longitude** | **Latitude** |
|---|---|---|---|---|
| SAC | San Andrés | Colombia | 81.701 W | 12.569 N |
| LCR | Limon | Costa Rica | 83.020 W | 9.989 N |
| CP | Cristobal | Panama | 79.915 W | 9.355 N |
| CC | Cartagena | Colombia | 75.537 W | 10.391 N |
| BBC | Bullen Bay | Curaçao | 69.020 W | 12.187 N |
| PBG | Prickly Bay | Grenada | 61.765 W | 12.005 N |
| FFM | Fort-de-France | Martinique | 61.063 W | 14.602 N |
| PPG | Pointe à Pitre | Guadeloupe | 61.531 W | 16.224 N |
| CAV | Charlotte-Amalie | US Virgin Islands | 64.92 W | 18.335 N |
| MGPR | Magueyes Island | Puerto Rico | 67.046 W | 17.970 N |
| MIPR | Mona Island | Puerto Rico | 67.938 W | 18.09 N |
| PCDR | Punta Cana | Dominican Republic | 68.376 W | 18.505 N |
| PPH | Port-au-Prince | Haiti | 72.380 W | 18.534 N |

Table 5: Location of seven wave buoys (Figure 1), and time period for which data is available (Jevrejeva, et al., 2020) Data available from the National Data Buoy Centre (https://www.ndbc.noaa.gov/)

| **Buoy** | **Longitude** | **Latitude** | **time period** |
|---|---|---|---|
| 41043 | 64.830 W | 21.124 N | 2007 - 2016 |
| 41044 | 58.630 W | 21.582 N | 2009 - 2016 |
| 42056 | 84.946 W | 19.812 N | 2005 - 2016 |
| 42057 | 81.422 W | 16.908 N | 2005 – 2016 (missing 2007) |
| 42058 | 74.560 W | 14.775 N | 2005 – 2016 (missing 2010) |
| 42059 | 67.483 W | 15.252 N | 2007 – 2016 |
| 42060 | 63.354 W | 16.413 N | 2009 - 2016 |

## Wave and current measurements: AWAC (Acoustic Wave and Current) Profiler

SIDS globally experience erosion arising from a variety of causes, including hurricanes (or tropical cyclones), sea level rise, reef damage and human activity. An understanding of wave processes and energy along coastlines and in surrounding waters, combined with geographical knowledge of natural and human-made features and human activity within coastal areas, aids assessment of current and future risk of damage and inundation from storm surges, waves and SLR. In situ wave data are important in the development of coastal management and climate adaptation strategies for decision-making and planning of development of coastal infrastructure for islands, however, there is a limited amount of in situ wave data available in nearshore locations (Wolf et al., 2019).

The Nortek AWAC (Acoustic Wave and Current) profiler, http://www.nortek.no/en/products/wave-systems/awac, is a versatile instrument for deployment in the nearshore zone. It 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). The instrument includes a compass, a tilt sensor and 9MB of data storage. It has an optional Acoustic Surface Tracking (AST) firmware that can echo range the surface of the water and contains an improved pressure sensor with an absolute accuracy of 0.1%. It can be delivered with backup batteries, protected cables, shore side interface units and online software. The AWAC software is used to configure the instrument for deployment, retrieve the data and convert all raw data files to ASCII. The battery life allows approximately 80 continuous days of data acquisition. STORM software is used for downloading and visualising the water level, current (Figure 2) and wave (Figure 3) data, various manuals and other documentation can be downloaded from the Nortek website, e.g. https://www.nortekgroup.com/products/awac-1-mhz.

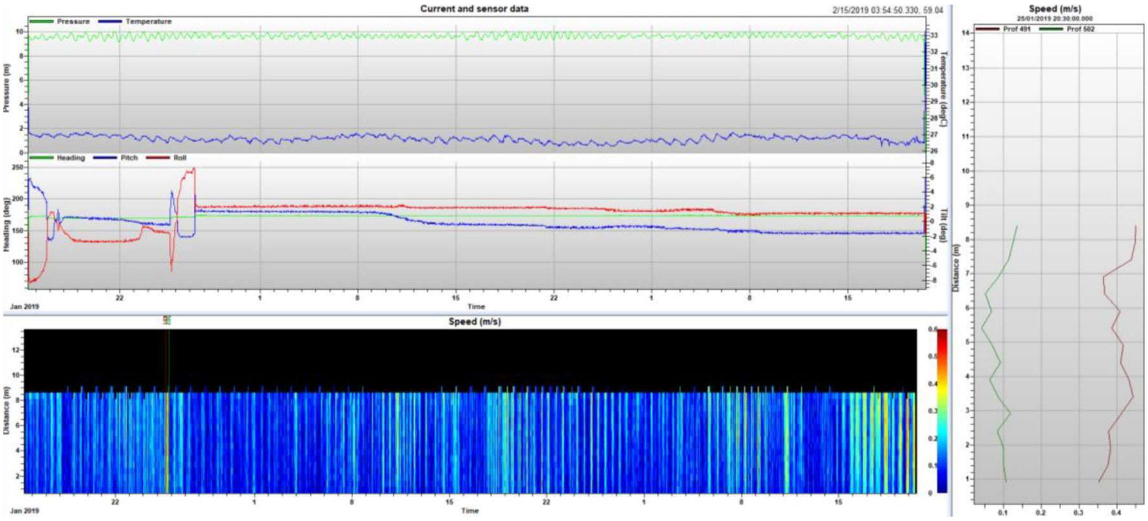

Figure 2: Processed current data from STORM software (Wolf et al., 2019)

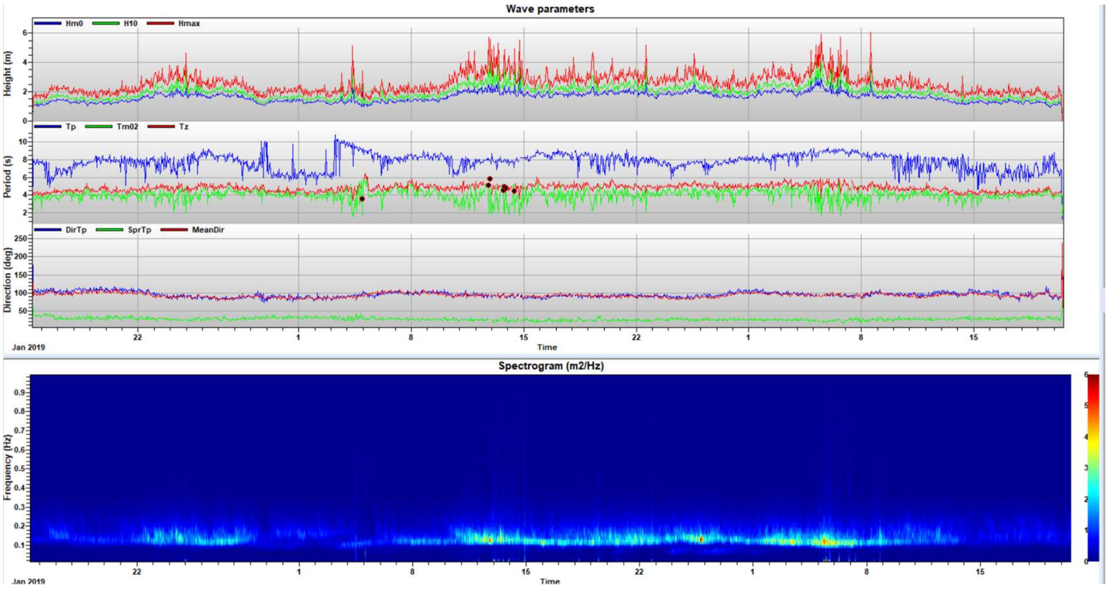

Figure 3: Processed wave data from STORM software (Wolf et al., 2019)

A 1-MHz AWAC-AST (with acoustic surface tracking option) was purchased, in May 2018, and delivered to the Coast Guard base at Calliaqua in Saint Vincent and the Grenadines, for storage and safekeeping (Figure 4). Details of set up and deployment of this instrument can be found in Wolf et al. (2019). Data from deployments during July to October 2018 and January to March 2019 is available from the web portal created as part of the CME programme as a subsection of the Permanent Service for Mean Sea Level (PSMSL) located at https://psmsl.org/cme. It can also be downloaded here: https://www.bodc.ac.uk/data/bodc_database/nodb/data_collection/6901/. Data are published under the Open Government Licence data access policy http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/.

AWAC data can be used as input boundary data for local storm impact and shoreline evolution models such as XBeach, SWAN and COVE as described in (Wolf et al., 2020).

Figure 4: The recovery team with instrument and frame 10 Oct 2018 (Wolf et al., 2019)

## Coastline change (Beach profiles and topographic data)

Beach profile surveys comprise a selection of survey transects, perpendicular to the coastline, usually from the back of the beach or dune to Mean Low Water Spring. These can be used to establish the beach response to storm events; understand the impact of interventions (such as sea walls, groynes, etc.); or seasonal and long-term volume changes, including areas vulnerable to erosion. Surveys are usually carried out using GPS, by levelling or using a total station. Any survey must be referenced to a fixed point, so that it individual surveys are repeatable and comparable to each other. Profile surveys can be complimented with shore parallel surveys, along the high water mark.

Beach profile survey measures the slope of the beach and has traditionally been carried out by the simple Emery (1961) method, which uses two wooden rods of equal length to measure the change in height by eye at intervals equal to the length of the rods. In SVG the SANDWATCH method as described by Cambers and Diamond (2010) is currently used for beach monitoring (Prime et al., 2019). This is a simple method which requires little, low cost equipment. They are measured from a reference mark, which may be a painted square on a tree or building, but would ideally be a survey marker capable of withstanding hurricanes. Profiles are taken perpendicular to the shoreline from the marker to the offshore step, using ranging poles (marking each break in the slope) and an Abney level to measure the slope angel and a tape to measure the ground distance between the poles (Cambers and Diamond, 2010). It is suggested that beach profiles are measured at three monthly intervals or more frequently if time allows.

More modern methodologies use RTK-GPS (Figure 5) to achieve a more accurate result. The use of RTK-GPS is also quicker and it is therefore possible to collect many more data points. RTK-GPS surveys of five locations in SVG were carried out by the CARIBSAVE project to collect beach profiles in order to understand how the coastline might respond to rising sea levels (CARIBSAVE, 2012).

These surveys can be complimented with remote sensing data, such as fixed aspect or aerial photography (from a drone or plane) and by satellite imagery. It is also possible to carry out surveys using remote sensing methods such as LiDAR or X-Band Radar as described in section 4.

Figure 5: SVG National Park, River and Beach Authority and Ministry of Physical Planning staff visit to NOC, with a site visit to Crosby Beach north of Liverpool (UK) to join the WireWall project (CCO, 2019b) in a pre-high water beach survey

# 4. Remote Sensing

Remote sensing has been defined as:

"The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation" (Lillesand and Keifer, 1994).

It therefore encompasses the use of a wide range of platforms including satellite, airborne (aircraft or Unmanned Aerial Vehicles (UAVs or Drones)), fixed platform (e.g. X-band radar, LiDAR, photography, video, etc.) and autonomous marine vehicles, which can all accommodate a range of instruments useful in marine and coastal monitoring. Data acquisition from aerial sources, X-band radar and autonomous vehicles (AVs) will generally need to be planned and collected on an individual mission basis (in much the same way as in situ data collection), although some of these (e.g. X-band radar) can be left in situ to collect data over several months. Long-term fixed land based instruments, such as cameras, can collect information continuously over long periods of time, enabling analysis of rapid changes. Satellite data is collected remotely by satellites, which constantly orbit the earth, such as the European Space Agency (ESA) Sentinel satellites and the United States Geological Survey (USGS)/National Aeronautics and Space Administration (NASA) programme, Landsat. Data from Sentinel and Landsat is freely available for users to download and interpret, whilst other satellite data sets may need to be paid for. Whilst data collected from different platforms may be of a similar type, e.g. LiDAR from an aircraft or fixed platform, the platform affects spatial and temporal resolution and cost.

Remotely sensed data has advantages in that it can enable data to be collected from areas that are difficult or dangerous to access. It usually enables data collection from a larger area than would be achievable with in situ data collection; it may allow data to be collected more frequently with less effort and at lower cost, (this is particularly true of satellite data, but also of "citizen science" data collection via mobile phone images).

## Satellite data

Satellite remote sensing can deliver a range of measurements of key ocean parameters relevant to ocean and climate science. These include sea level, surface winds, sea surface temperature (SST), Chl*a*, suspended sediment, habitat mapping, bathymetry, surface currents, waves, salinity, precipitation, etc. Satellite remote sensing has several advantages over in situ data collection or other remote sensing methods, in that it delivers global coverage, with frequent revisits at various spatial and temporal scales. The object of interest is undisturbed during data collection and a single image may be used to examine a wide range of parameters. There is also a growing time-series, which in some cases spans several decades (such as that available from Landsat, Figure 16), enabling the investigator to go back in time and examine changes over extended periods. However, satellite remote sensing should not be oversold. Some ground truthing is usually required to verify results and the resolution achieved will be lower than that achieved with other remote sensing and in situ methods. There is also the issue of cloud cover, which obscures the Earth's surface from optical satellite sensors, reducing data availability. Here we focus on satellite instruments using electromagnetic radiation reflected, scattered and emitted at the ocean surface at visible, infrared and microwave wavelengths. This encompasses two types of satellite sensor, passive or optical (Figure 6, such as Landsat or Sentinel-2) and active radar (Figure 8, such as Sentinel-1 and the Jason series). A single satellite can carry a range of instruments, both passive and active, for example, Sentinel-3 carries four main instruments, two passive and two active. Guides to the range of instruments available for different aspects of Earth Observation (EO) through the Sentinel missions can be found at https://sentinel.esa.int/web/sentinel/missions.

Satellite data is available from a range of sources, some of which are described in Section 6.

The NOC is currently working with the Caribbean Regional Oceanscape Project (CROP) and Caribbean Oceans and Aquaculture Sustainability FaciliTy (COAST) in the Caribbean through a European Space Agency funded project Earth Observation for Sustainable Development (EO4SD) Marine and Coastal Resources (http://eo4sd-marine.eu/). The project is developing a portfolio of EO-derived products and services designed to provide information required for the management of coastal and marine environments and for planning and implementing Blue Economy initiatives to support sustainable economic development for coastal regions and island states (EO4SD, 2019).

## Passive/optical sensors

Passive or optical sensors receive and measure the energy reflected or re-emitted (thermal infrared wavelengths) by the Earth's surface and atmosphere using the sun as the energy source (Figure 6). These sensors are used to collect data in the visible and infrared parts of the electromagnetic spectrum and can only be used when the energy source is available, which for reflected energy requires the sun to be illuminating the Earth. Passive sensors, such as Sentinel-3's Ocean and Land Colour Instrument (OLCI) and Sea and Land Surface Temperature Instrument (SLSTR), can be used for parameters such as sea surface temperature (SST) and Chlorophyll *a* concentrations. Others satellites such as Sentinel-2 (Figure 7), which carries a single payload Multi-Spectral Instrument (MSI), can be used for parameters such as suspended sediment concentration. In clear, shallow water, Sentinel-2 MSI can be used for bathymetric mapping; estimation of seagrass area and density; and estimation of extent and health of coral reef systems. They can also be used to map the position of the coast and to look at the extent and health of coastal habitats, such as mangroves.

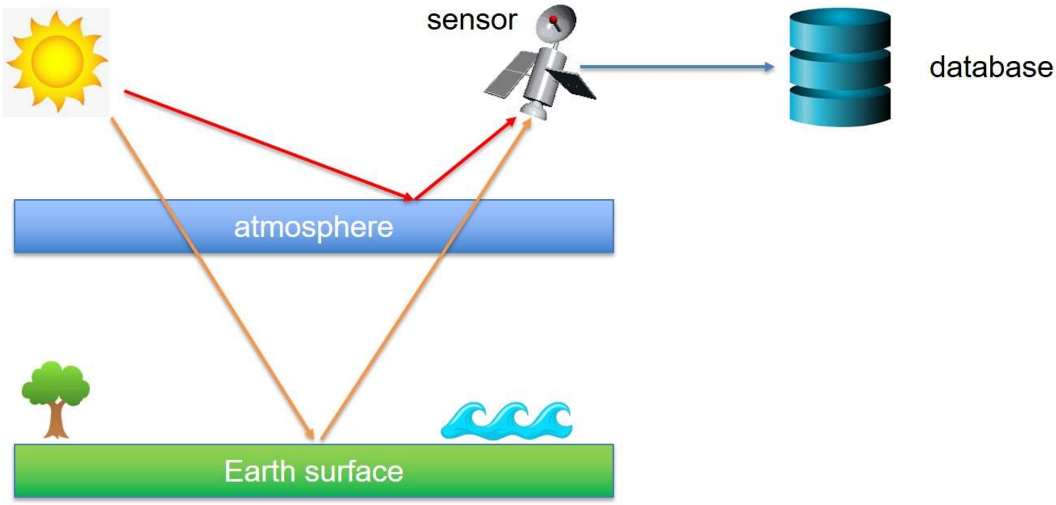

Figure 6: Schematic of passive/optical satellite data acquisition

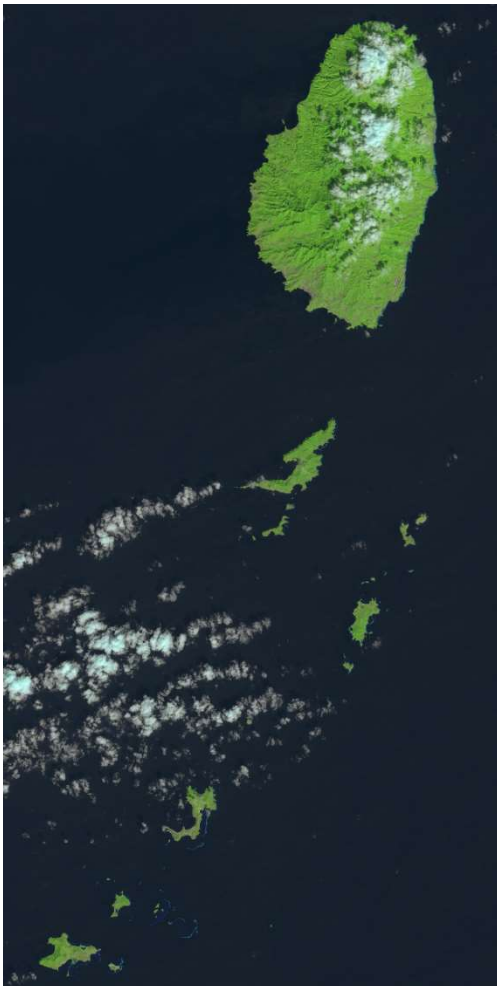

Figure 7: Sentinel-2B image of SVG acquired on 19 January 2020

## Active sensors

Active satellite sensors provide their own source of illumination and do not rely on the sun's energy. The sensor emits radiation, directed towards the target under investigation and measures the signal refracted, reflected or scattered by the Earth's surface and atmosphere (Figure 8). The most common type of active sensor is radar operating in the microwave and radio wavelengths. Active sensors can obtain measurements at any time, because they are not reliant on solar energy and the signals pass through clouds (NASA, 2020). They are used to measure parameters such as sea level, significant wave height and surface ocean currents.

Sea level is measured using an altimeter (a type of radar instrument) which detects the distance to the sea surface by measuring the time taken for a radar pulse to travel from the satellite antenna to the surface and back to the satellite receiver (ESA, 2018). This information has been used to understand the regional variation in changing sea levels at a global scale (Figure 9), but can also be used locally to understand trends and annual and seasonal variability (C-RISe, 2019).

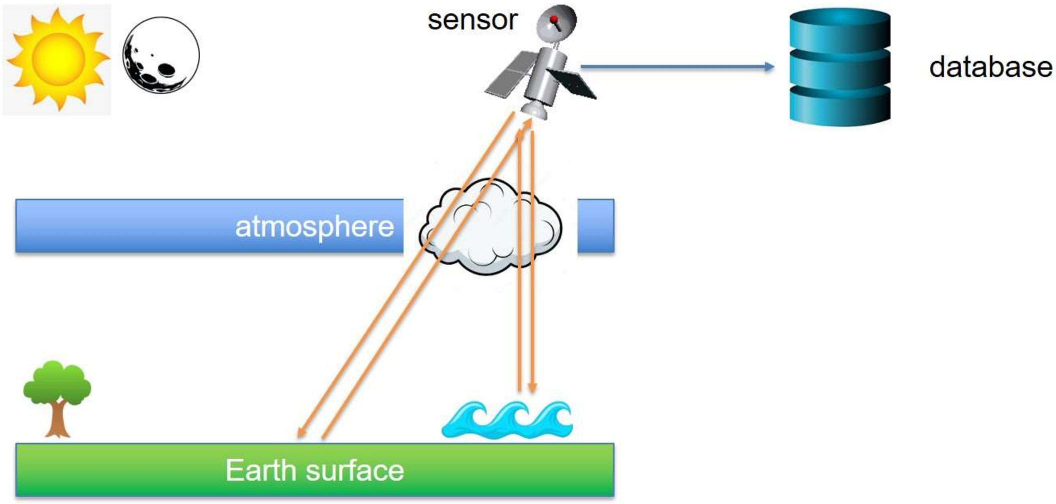

Figure 8: Schematic of active satellite data acquisition

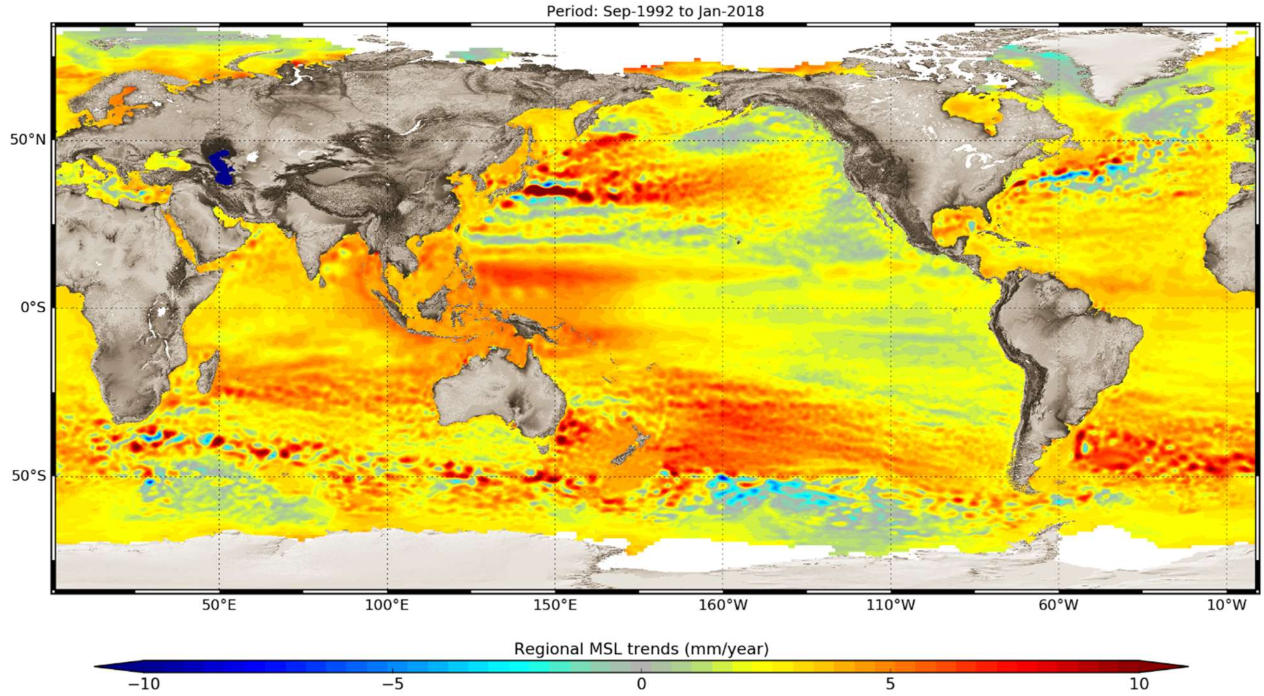

Figure 9: Map based on measurements from satellite altimeters showing regional sea level trends © CNES/LEGOS/CLS/EU Copernicus Marine Service/contains modified Copernicus Sentinel data (2018)

## Water quality

Water quality, important for fisheries and aquaculture, tourism and pollution monitoring, may be assessed remotely through a range of indicators including, sea surface temperature (SST), Chl*a* concentration and suspended sediment.

SST is an indicator for productivity and pollution, as well as climate change. It is also important for hurricane development, so understanding this parameter assists in the forecasting of a storm's path and understanding if intensification will occur ahead of landfall (NASA, 2007). Satellite technology has improved our ability to measure SST, by providing frequent global coverage (Figure 10), however satellites only provide information within the top few millimetres of the ocean surface. To understand the temperature at greater depth measurements can be made in situ from ships or buoys and by Argo floats, which obtain temperature and salinity profiles in the oceans up to depths of 2000m and transmit the data via satellite when they return to the surface (BODC, 2020).

SST is measured by satellite microwave radiometers and thermal infrared radiometers. Thermal infrared SST measurements have a long heritage and good resolution and accuracy, but they can be obscured by clouds and require atmospheric correction. Microwave SST measurements are relatively insensitive to atmospheric effects and clouds are mostly transparent, but they are sensitive to surface roughness and precipitation and provide poorer accuracy and resolution (Maurer, 2002).

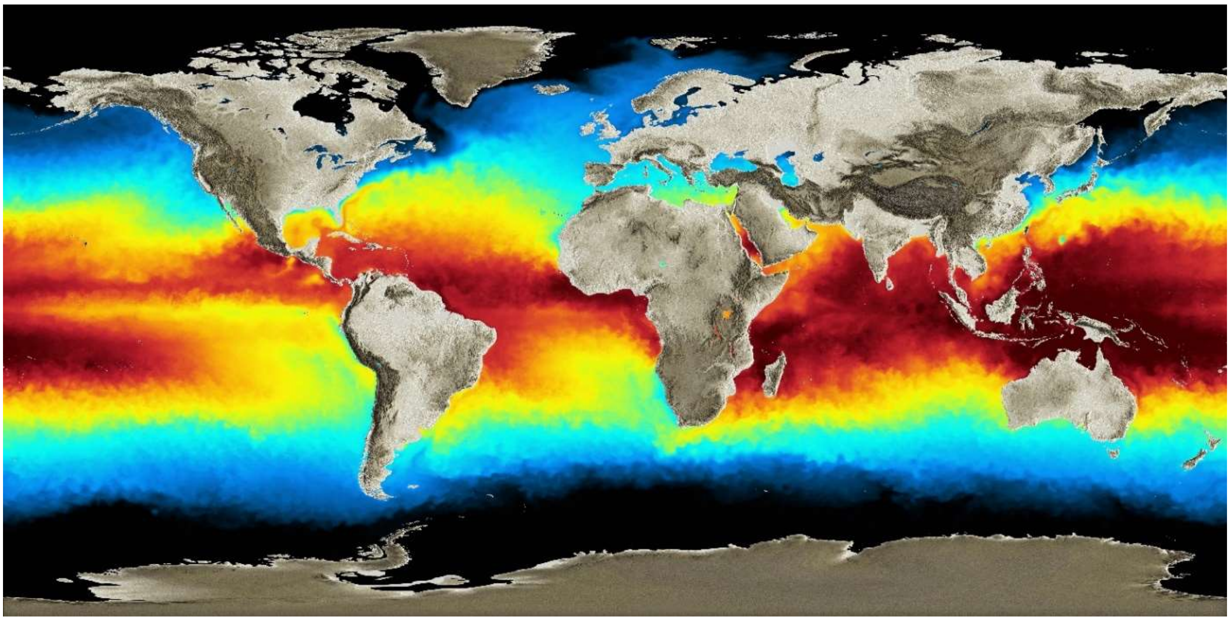

Figure 10: Sea surface temperature from ESA's European Remote Sensing (ERS) Satellites measured using an infrared radiometer © ESA

Chlorophyll-a is a proxy measure for plankton productivity, high concentrations indicate high nutrient content and possible eutrophication of coastal water. Chlorophyll-a concentration is estimated using the visible bands of the electromagnetic spectrum from sensors such as Sentinel-3's OLCI. To retrieve chlorophyll-a estimations close to the coast, Landsat-8 and Sentinel-2 give higher resolution data than other, freely available data (Poddar, et al., 2019).

Optical satellite data from Landsat or Sentinel-2 platforms captures the variability in water clarity over a wide area, to show how it changes over spatial and temporal scales (Luis et al., 2019). Local validation of radiative transfer algorithms is necessary in coastal locations, where the optical constituents (phytoplankton, detritus, CDOM and sediment) vary widely. A methodology developed by Lee et al. (2016), for use with Landsat-8 images, was recently validated for coastal areas of the North East USA (Luis et al., 2019), demonstrating how this could be used for other locations, including the Caribbean.

## Coastline change

Coastlines are likely to be exposed to increasing hazards, due to sea level rise, increasing wave energy and wind speeds, and understanding their current position and change over time is vital to managers and policy makers. It may also be beneficial to understand changes in shoreline position following storm events or due to developments which can affect sediment supply. It is possible to extract information on shoreline position using freely available satellite data from Landsat and Sentenil-2, in a similar way to measuring coastal position using aerial photography. Vos et al. (2019) describe a methodology for using an open source Python software toolkit to obtain a time series of shoreline position of sandy coastlines which can be applied worldwide. This enables mapping to sub-pixel accuracy, i.e. to higher resolution than the 10m available from Sentinel-2 or 30m from Landsat, and correction for position of the tide. Whilst the use of satellite remote sensing for shoreline detection is still a developing research area, it does provide 30-years of freely available historical data which can deliver information on long-term variability and inter-annual changes in shoreline position.

### Tools for processing satellite data

There is a wide range of software available for the processing of satellite data, several of which are open source. ESA has the Sentinel Toolbox (https://sentinel.esa.int/web/sentinel/toolboxes) for the processing of Sentinel-1, 2 and 3 data. There is also a plugin available for QGIS, the semi-automatic classification plugin, which enables direct download of imagery from Sentinel, Landsat, ASTER and MODIS.
Bilko (https://www.learn-eo.org/software.php) was first developed for UNESCO in 1987 to provide free image processing capability for educational use, it continues to be updated and supports data from a wide range of satellites including ERS, Jason and Sentinel-2. The software includes a range of lessons, images and worksheets in ocean and coastal oceanography and in coastal management applications of remote sensing.

## LiDAR

LiDAR (Light Detection and Ranging) is a remote sensing instrument used to collect topographic or bathymetric data over broad areas from an aircraft. It is a well established tool for obtaining data spanning large coastal extents (Sallenger, 2003). Airborne LiDAR enables the collection of data at a high spatial density over much larger areas than terrestrial methods, such as GPS survey, and at higher resolution than satellite data.

LiDAR uses light in the form of a pulsed laser to measure variable distances from the sensor to the Earth surface. The instrument also includes a GPS receiver and scanner. For topographic survey a near-infrared laser is used, whilst for bathymetric survey water-penetrating greenlight can capture seafloor and riverbed elevations. The output is a three-dimensional point cloud which can be used to generate digital elevation models (DEMs), canopy models and contours.
A LiDAR bathymetric survey was carried out in 2016 by the UK Hydrographic Office for SVG and Grenada as part of the CME Programme. This gave a DEM of the coastal zone at a 2 m resolution, up to a depth of 40 m which will be used to inform future projects and economic planning. These data were also used as input data for a LISFLOOD-FP model of St. Vincent’s Argyle International Airport (Philips et al., 2019, Figure 11) and an XBeach model of Black Point Beach, Georgetown, St. Vincent (Prime et al., 2019).

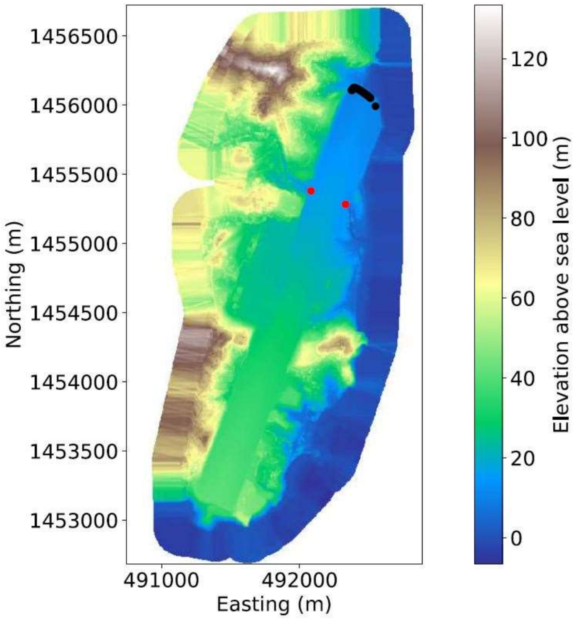

Figure 11: Applied DEM for modelling propagation of floodwater onto the runway at Argyle International Airport, St. Vincent. Derived from UK Hydrographic Office LiDAR survey with a spatial resolution of 5 m (Phillips et al., 2019)

# Fixed aspect remote sensing

## X-band radar

Shore-based X-band marine radar techniques are an excellent tool for monitoring the dynamic nearshore area, particularly where tides, weather and access make routine survey logistically challenging. Intertidal areas are often under-surveyed, with trends in sedimentation, local hydrodynamics and patterns of seasonal change only anecdotally understood (Bird et al., 2017a). X-band radar allows the estimation of wave parameters; near-surface current direction and magnitude; sub-tidal bathymetry to depths of 30-50 m (Figure 11); and intertidal topography (Figure 12). Results compare favourably with airborne LiDAR in that the radar system is able to derive the major topographical features and are generally within ±20 cm of LiDAR results (Bird et al., 2017a). X-band radar is much cheaper than either manual survey or repeated LiDAR survey. Although X-band radar achieves lower accuracy for bathymetry than traditional multi-beam survey, high temporal coverage and low cost, make it more suitable for long-term monitoring at sites where a cost-effective means of quantifying large scale bathymetric change is required (Atkinson et al., 2018). Although X-band radar has been used as an oceanographic tool for several decades, its popularity has recently increased due to advances in computing power, data storage, video digitisation and new data processing algorithms. Wave inversion techniques were developed in the late 20th century, following the discovery by researchers in the 1980s that radar imaging of ocean waves could be used to infer water depths and near surface currents.

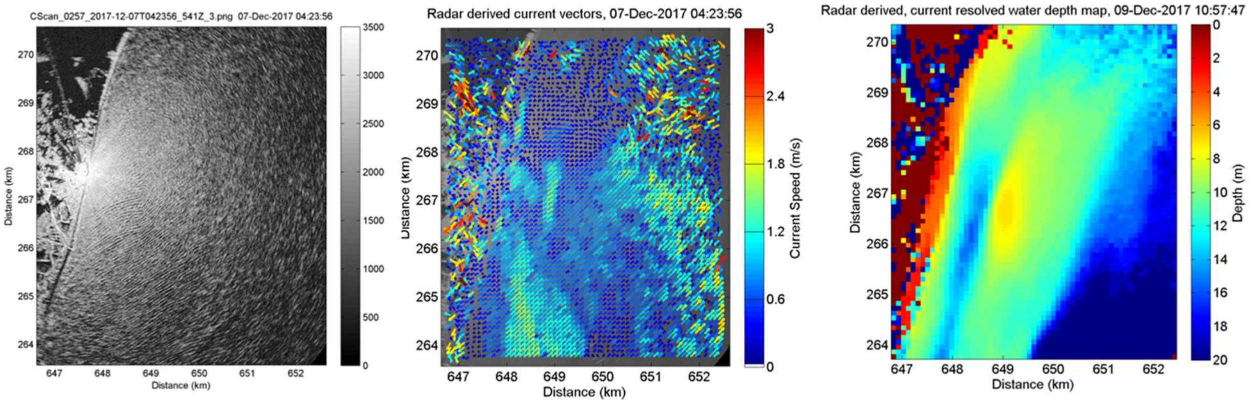

Figure 11: Raw data; radar derived vector currents; and bathymetry from wave inversion from data collected at Minsmere, UK.

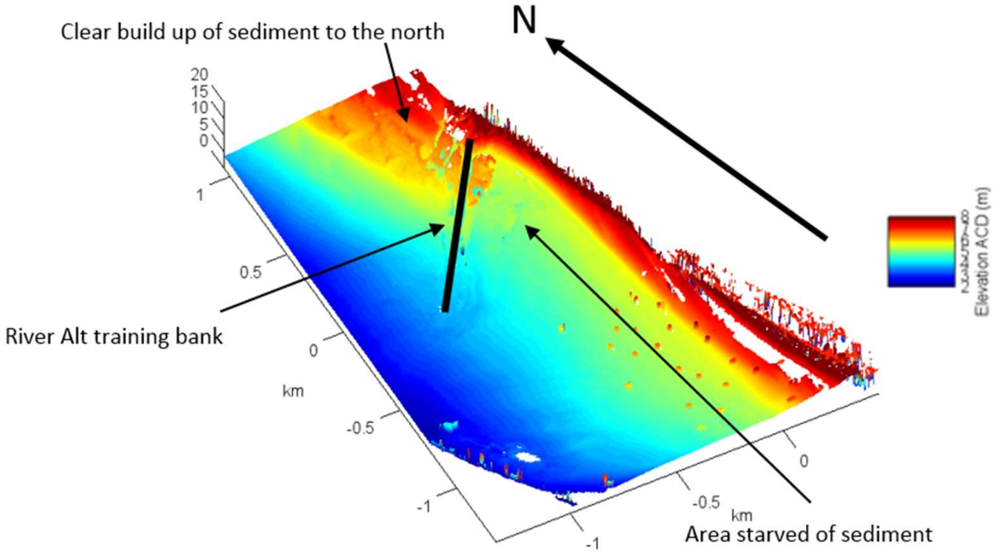

Figure 12: Intertidal elevation analysis December 2016 at Crosby, UK (Image provided by Marlan Maritime Technologies Ltd)

Marlan Marine Technologies Ltd (https://marlan-tech.co.uk/synoptic/) in collaboration with the National Oceanography Centre, UK, have developed a rapidly deployable radar survey platform (Figure 13), which incorporates X-band radar, video and other sensor technologies, to enable long-term, cost effective monitoring of coastal areas. The fixed remote sensing platform enables regular automated repeat-surveys with a high temporal resolution. Radar can give volumetric information on sediment movement (Bird et al., 2017b, Figure 12) and broad-scale information on beach system health as well as near-real-time current directions (Figure 11) and magnitudes over a 4 km radius. It provides better understanding of sediment migration, and trends of erosion and accretion to inform better planning and decision making for maintenance operations, nearshore dredging and coastal defence construction. Marlan Maratime Technologies Ltd and University of Liverpool are planning a deployment of the radar platform in St. Vincent to survey the coastline near Argyle International Airport during 2020.

Figure 13: Radar survey platform (Marlan Maritime Technologies Ltd)

## Photography and video

Fixed aspect photography is remote sensing in that it acquires information without being in contact with the subject. This can be a very useful way of collecting monitoring data from the public (citizen science) and may be particularly effective in locations where there are likely to be a large number of visitors/tourists taking pictures.

Shorelines can change over a range of time periods through process causing erosion and accretion, these changes may happen quickly during a storm or over the long-term, due to wave climate or sea level rise for example. There is generally limited observation data available to enable understanding of the magnitude and rate of response and this introduces an element of uncertainty into management plans. Photographs could be used to compliment beach profile surveys in understanding the evolution of the coastline. CoastSnap is a way of delivering frequent and long-term beach monitoring at low cost through the use of "citizen science".

The CoastSnap methodology was developed in Australia and tested on open coast sandy beaches, north of Sydney (Harley et al., 2019). It involves the installation of a stainless steel camera cradle and signage allowing (Figure 14) the public to take photographs from fixed locations and giving instructions on how to submit the images to a central database via email or through popular social media platforms. CoastSnap has been initiated in nine countries including France, USA, Spain, UK and Mozambique (https://risingfromthedepths.com/blog/innovation-projects/coastsnap-1/). Submitted images are georectified, the shoreline edge is identified (based on the difference in the red and blue colour channels in the image) and a tidal correction is applied (depending on the state of the tide at the time the image was collected) (Harley et al., 2019). This method provides a time series of shoreline change and helps identify how the coastline is responding to seasonal changes and recovering from storms. The system not only has the potential for monitoring individual beaches, if widely installed, it may be possible to detect patterns of behavior across regions and ocean basins (Harley et al., 2019).

Figure 14: CoastSnap photo point at Stockton Beach, Australia (Michael Kinsela, https://www.environment.nsw.gov.au/research-and-publications/your-research/citizen-science/digital-projects/coastsnap)

## Autonomous Vehicles (AVs)

Autonomous Vehicles (AVs, which are unmanned and untethered) provide the ability to explore the oceans and collect data to increase our understanding of the oceans. AVs may be deployed at depth, Autonomous Underwater Vehicles (AUVs), or sit on the ocean surface, Autonomous Surface Vehicles (ASVs). Some of these can remain at sea, recording data for months at a time, transmitting data back to shore via satellites. There are a wide range AVs with a variety of functions, sensors and instruments. Details of several of these can be explored via the NOC website, https://www.noc.ac.uk/technology/technology-development. AVs are able to cover wide geographic areas, with high sampling rates and therefore enable countries to conduct marine scientific research within their extended economic zones.

### Containerised Autonomous Marine Environmental Laboratory (CAMEL) facility

The CME programme has funded the development and deployment of the Containerised Autonomous Marine Environmental Laboratory (CAMEL), which provides a complete autonomous survey and data collection solution. The facility consists of an ASV, a micro Remotely Operated Vehicle (ROV), a wave buoy and sound velocity profiler, as well as a weather station, fully featured mobile laboratory, control centre and a small inflatable boat with outboard motor. The CAMEL facility is fully containerised, in two ISO (International Organisation for Standardisation) containers, so that it can be shipped to any port and deployed from the quayside, beach or vessel (Figure 15).

The CAMEL ASV (C-Worker 4, Figure 16) is diesel powered, can operate continuously for 48 hours and has three exchangeable sensor payloads for hydrographic, geophysical or oceanographic data collection. The hydrographic payload consists of a high-resolution multibeam echo sounder and a speed of sound sensor for seabed mapping. The geophysical payload has a high-grade side scan sonar and sub-bottom profiler system which can image large areas of seafloor and classify features. The oceanographic payload includes an Acoustic Doppler Current Profiler (ADCP), a fluorometer, and conductivity/temperature/depth (CTD), pH, dissolved oxygen and partial $CO_2$ sensors. These can be used to collect data on a wide range of oceanographic parameters which may then be used for a variety of purposes including reef monitoring and the verification of satellite data. Subject to space and power needs, additional sensors can be added according to the purpose of the deployment.

The two CAMEL containers serve as workshop and operations room which houses the communications equipment for the ASV and provides a space in which to review and process the data.

Further information on CAMEL can be found via the NOC website http://projects.noc.ac.uk/cme-programme/projects/containerised-autonomous-marine-environmental-laboratory-camel.

Figure 15: The CAMEL containers

Figure 16: The CAMEL Autonomous Surface Vehicle (ASV), C-Worker-4

In 2019, as part of the CME programme, the CAMEL was deployed in Belize in collaboration with the Coastal Zone Management Authority and Institute (CZMAI), University of Belize, the Turneffe Atoll Sustainability Association (TASA) and the Belizean Port Authority. Extensive surveys included seafloor mapping, water quality testing and characterisation of marine habitats. Generated information will be included in the updated Belize Coastal Zone Management Plan, facilitating evidence-based decision-making (https://www.noc.ac.uk/news/nocs-portable-marine-science-lab-returns-belize).

# 5. In situ and remote sensing data as inputs to models

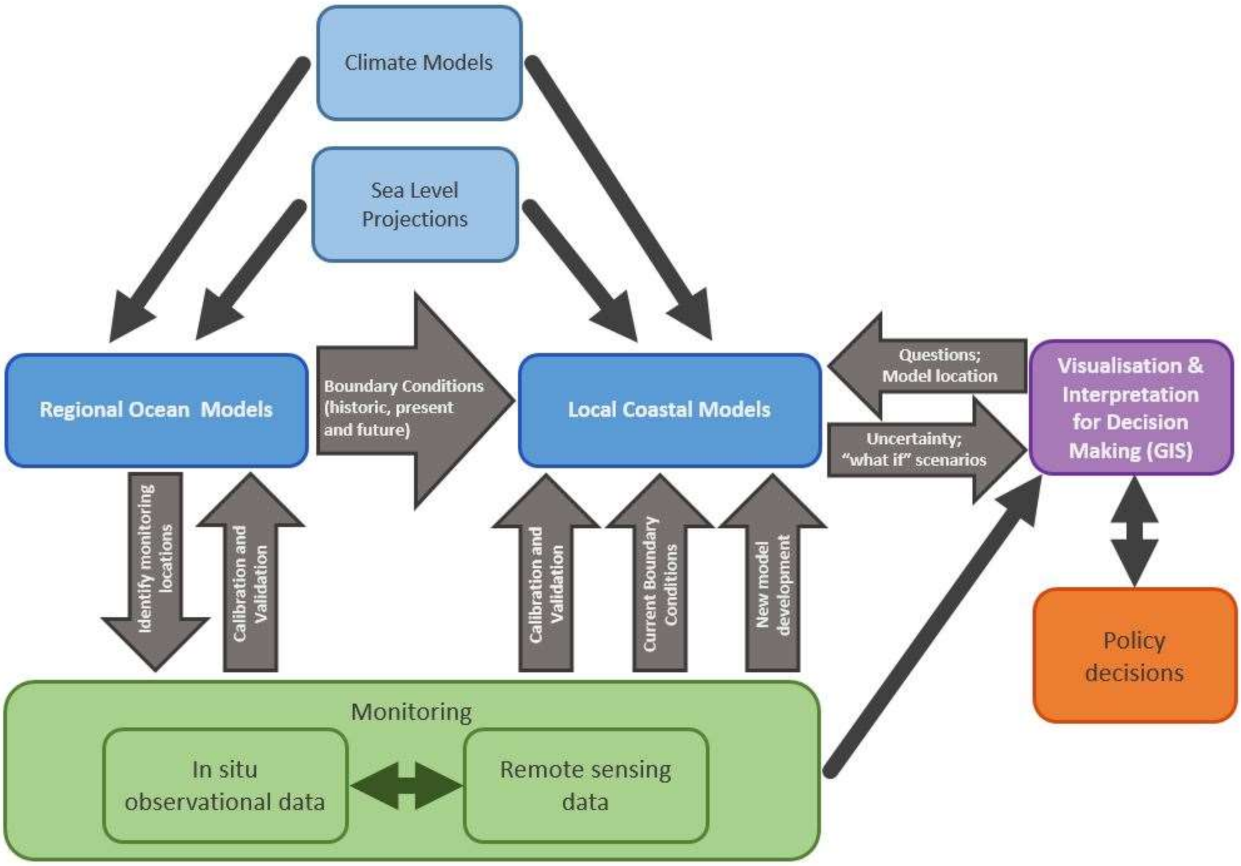

Figure 17: Different scales of model and their inter-relationship with monitoring

Pressures on coastlines from erosion and sea level rise demands that the response of natural and engineered coastal morphological systems to changing forcing factors is modelled and monitored over appropriate timescales (Bird et al., 2017b). Coastal managers and engineers often depend on model projections to understand possible shoreline responses.

Modelling and monitoring go hand in hand (Figure 17). Modelling is useful in mapping large areas, to identify where monitoring is required, and identify where to position instruments to collect detailed information. Models can also be used to map hazard and identify hotspots of risk to direct management activities and provide input to cost-benefit analysis to look at real options. However, whilst models provide (low-cost) information at large spatial (<global) and temporal (<climate) scales, in addition to providing forecast data and long-term projections, they require calibration and validation data collected through observational measurements (e.g. CCO, 2019b). Observations provide time series information that can be used as boundary condition forcing to hindcast events of interest. For example, nearshore topographic-bathymetric data are required to drive and validate coastal hydrodynamic and morphological models such as XBeach. Measurements are also necessary to develop the parameterisations used within models (e.g. Bluecoast, 2020). Uncertainty in model predictions can be quantified using observed information to improve our confidence when they are applied to project future conditions for management and planning purposes (e.g. ARCoES, 2020). Numerical studies can also be run to assess sensitivities within the coastal zone and explore what-if scenarios to develop strategic coastal management plans (Phillips et al., 2019). Further information on modelling is available in the companion to this report, *Guidance Note on the Application of Coastal Modelling for Small Island Developing States* (Wolf et al., 2020).

# 6. Available datasets

## Data types requested during the 2018 workshop

The National Oceanography Centre and University of Liverpool hosted a joint workshop in St. Vincent in March 2018, entitled *Monitoring and Modelling in the Coastal Zone*, during which data availability and accessibility was discussed. Attendees of the workshop identified the need for data on coastline change; sediment (linked to sand mining); and sea level; as well as Environmental Impact Assessment (EIA) data; and data in support of planning.

A wide range of data are available from a variety of sources, both international and regional, links to several of these are given below. Links to sources of satellite data are also identified separately, below.

## Sources of satellite data

The major public sources of satellite data are US Geological Survey (USGS) and the European Space Agency (ESA). USGS is responsible for Landsat and ESA operates the Sentinel satellites, however, both provide access to both satellite series via their websites.

Landsat is a joint NASA and USGS mission, which has been in continuous operation since 1972, providing the longest continuous space-based record of Earth (Figure 18). The current satellite, Landsat 8, began its operation in February 2013. It provides optical/passive images (visible, near infrared, short wave infrared, and thermal infrared) at 15 m to 100 m resolution (depending on the spectral frequency). It orbits the Earth every 99 minutes, giving it a 16-day repeat cycle, and captures 400 scenes per day. The next satellite, Landsat 9, has a target launch date of March 2021 and is expected to capture in excess of 700 scenes per day. All the data are freely available from the USGS archives through a range of websites, these are:

- LandsatLook Viewer, https://landlook.usgs.gov/viewer.html
- USGS GloVis: The Global Visualisation Viewer, https://glovis.usgs.gov/app
- USGS Earth Explorer, https://earthexplorer.usgs.gov/
- Free Web Enabled Landsat Data (WELD), http://globalmonitoring.sdstate.edu/projects/weld/

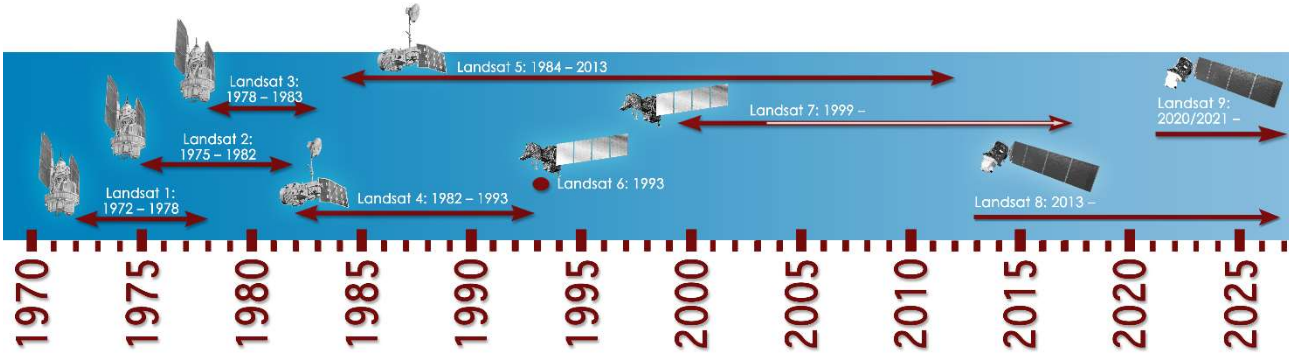

Figure 18: Timeline of the Landsat satellites (Source: https://landsat.gsfc.nasa.gov/a-landsat-timeline/)

The Sentinel programme, operated by ESA, replaces the current older EO missions, which have either reached or are nearing the end of their operational lifespan, to ensure data continuity.

Sentinel data is available through the Copernicus open access hub (https://scihub.copernicus.eu/dhus/#/home) and through the Copernicus Data and Information Access Service (DIAS) cloud environments, which include processing resources, tool and access to complimentary commercial data.

A range of satellite data sets are also available to view and manipulate through ESA's Ocean Virtual Laboratory, https://ovl.oceandatalab.com/ (Figure 19). This global web platform enables the synergistic investigation of satellite remote sensing data in context with in situ and model (atmospheric and oceanic) data by allowing the viewer to overlay different data layers simultaneously.

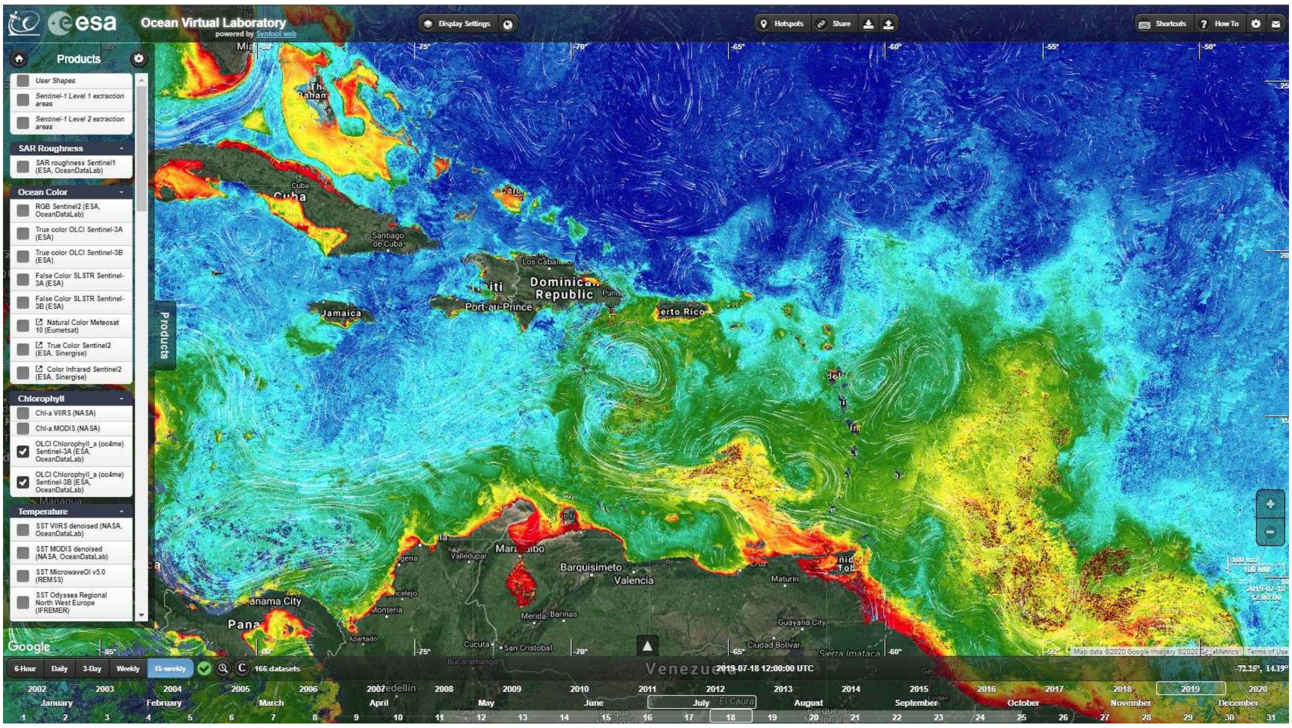

Figure 19: ESA Ocean Virtual Laboratory showing Chlorophyll *a* from Sentinel 3 and surface geostrophic currents (Globcurrent) in the Caribbean, July 2018

Google Earth Engine (https://earthengine.google.com/) is a platform for the visualisation and analysis of geospatial datasets. It hosts satellite imagery from Sentinel, MODIS and Landsat satellites as well as climate and geophysical data sets and a range of data products.

## International and Regional Data Banks

The IOC co-ordinates a network of data centres, National Oceanographic Data Centres (NODCs), providing resources for science, education, industry and the wider public. The International Oceanographic Data and Information Exchange (IODE) of the IOC was established in 1961 (IODE, 2020). Its purpose is to enhance marine research, exploitation and development by facilitating the exchange of oceanographic data and information between participating Member States and meeting the needs of users for data and information products. The majority of SIDS do not have NODCs, however, the IODE lists National experts in several locations, including SVG (https://www.iode.org/index.php?option=com_content&view=article&id=61&Itemid=100057).

The IODE website (https://www.iode.org/) hosts a wealth of information on ocean data resources including a “Catalogue of Sources” (https://catalogue.odis.org/), a searchable catalogue of ocean related data, information, products and services. It includes training material, guidance and software as well as links to data catalogues and many other information types.

A list of links to several global ocean data sources is presented in Table 6. A more comprehensive list, maintained and updated by the IODE, is available at https://www.iode.org/index.php?option=com_content&view=article&id=178&Itemid=141#global. A list specifically for sources for tide gauge data is given in Table 7.

There are several sources of coastal data available within the Caribbean, which have generally come about through projects operating across groups of SIDS. Some of these, such as CHARIM, have transferred responsibility for the site to Caribbean Disaster Emergency Management Agency (CDEMA) a regional inter-governmental agency. A list of some of these projects and sources of data is available in Table 8.

As part of the CME Programme in the Caribbean, the NOC has designed a coastal data hub with sea level information for stakeholder access in SVG, Grenada and St. Lucia (Jevrejeva et al., 2019). The prototype web portal has been created as a subsection of the Permanent Service for Mean Sea Level (PSMSL) website and is located at https://psmsl.org/cme.

Table 6: A selection of links to global data sources. A more comprehensive list is available through the IODE, https://www.iode.org/index.php?option=com_content&view=article&id=178&Itemid=141#global

| **Data/ Information Portals and Compilations** | **Description** | **Web Address** |
|---|---|---|
| Argo Floats | The broad-scale global array of temperature/salinity profiling floats, known as Argo, has grown to be a major component of the ocean observing system. Deployments began in 2000 and continue today at the rate of about 800 per year. | http://www.argo.ucsd.edu/Argo_data_and.html |
| British Oceanographic Data Centre (BODC) | Part of the UK's National Oceanography Centre, BODC provide instant access to over 130,000 unique data sets. Including access to Conductivity, Temperature and Depth (CDT) profiles and currents data. | https://www.bodc.ac.uk/about/what_is_bodc/ |
| General Bathymetric Chart of the Oceans (GEBCO) | GEBCO’s gridded bathymetric data sets are global terrain models for ocean and land. They are maintained and distributed by BODC on behalf of GEBCO.<br>The GEBCO_2019 Grid is GEBCO's latest global terrain model at 15 arc-second intervals. The Grid is available to download:<br>• as a global file in netCDF format<br>• for user-defined areas in: netCDF, Esri ASCII raster or GeoTiff formats | https://www.bodc.ac.uk/data/hosted_data_systems/gebco_gridded_bathymetry_data/ |
| Group for High Resolution Sea Surface Temperature (GHRSST) | Provides global high-resolution (<10km) SST products to the operational oceanographic, meteorological, climate and general scientific community. Products are provided at a variety of processing levels including "gap-free" global grids. | https://www.ghrsst.org/ |
| Harmful Algae Information System (HAIS) | The Harmful Algal Information System, HAIS, provides access to information on harmful algal events, harmful algae monitoring and management systems worldwide, current use of taxonomic names of harmful algae, and information on biogeography of harmful algal species. Supplementary components are an expert directory and a bibliography. | http://haedat.iode.org/ |
| National Data Buoy Center (NDBC) | A part of the National Weather Service (NWS). NDBC designs, develops, operates, and maintains a network of | https://www.ndbc.noaa.gov/ |

| | | |
|---|---|---|
| | data collecting buoys and coastal stations. NDBC's virtual tour will give you an overview of what NDBC does, the facilities, the atmospheric and oceanographic variables measured, and the use of these data. | |
| Ocean Data Viewer (UNEP) | View and download a range of spatial datasets that are useful for informing decisions regarding conservation of marine and coastal biodiversity. These data come from internationally respected scientific institutions and other organisations that have agreed to make their data available to the global community. | https://data.unep-wcmc.org/ |
| World Ocean Database | World Ocean Database 2018 is an NCEI product and an IODE (International Oceanographic Data and Information Exchange) scientifically quality-controlled database of selected historical in-situ surface and subsurface oceanographic measurements.<br>This work is funded in partnership with the NOAA OAR Ocean Observing and Monitoring Division. | https://www.nodc.noaa.gov/OC5/WOD/pr_wod.html |
| World Register of Marine Species (WoRMS) | The aim of a World Register of Marine Species (WoRMS) is to provide an authoritative and comprehensive list of names of marine organisms, including information on synonymy. While highest priority goes to valid names, other names in use are included so that this register can serve as a guide to interpret taxonomic literature. | http://www.marinespecies.org/ |

Table 7: Sources of tide gauge data (Jevrejeva et al., 2019)

| **Source** | **Data Type** | **Website** |
|---|---|---|
| PSMSL (Permanent Service for Mean Sea Level) | Quality controlled monthly and annual data | https://psmsl.org |
| UHLSC | Research Quality (JASL): Quality controlled hourly and daily data<br>Fast Delivery: Hourly and daily data with minimal quality control | https://uhslc.soest.hawaii.edu/ |
| GESLA | Hourly and higher frequency data – assumed to be quality controlled by supplier | https://gesla.org/ |
| VLIZ | Real time data high frequency data with no quality control | http://www.ioc-sealevelmonitoring.org/ |

| | | |
|---|---|---|
| NOAA | Data from USA, US territories, and some other NOAA-operated sites. Six-minute to monthly quality controlled data. | https://tidesandcurrents.noaa.gov/ |
| SHOM | Data from France, including Overseas territories. One minute and hourly quality controlled data. | https://data.shom.fr |
| SONEL | Daily GNSS (GPS) data, and information about land movement at or near tide gauges. | http://www.sonel.org/ |

Table 8: Projects and sources of data for the Caribbean

| **Source or Project** | **Description** | **Website** |
|---|---|---|
| Caribbean Marine Atlas (CMA) | An online digital platform that stores and provides access to geospatial information (and related documents) on the "Marine Environment and Human Societies in the Wider Caribbean Region". To support regional-level Integrated Ocean Governance And Integrated Coastal Zone Management (ICZM) in IOCARIBE Member States | https://www.caribbeanmarineatlas.net/ |
| Grenadines MarSIS (Marine Resource and Space-use Information System) | The Grenadines MarSIS brings together a variety of social, economic and environmental information drawn from both scientific and local knowledge into a single information system.<br>Contains links to map data, Google Earth tutorials and research documents. | http://www.grenadinesmarsis.com/Home_Page.html |
| Caribbean Community Climate Change Centre (CCCCC) | Supports the people of the Caribbean as they address the impact of climate variability and change on all aspects of economic development, through the provision of timely forecasts and analyses of potentially hazardous impacts of both natural and man-induced climatic changes on the environment, and the development of special programmes which create opportunities for sustainable development. | https://www.caribbeanclimate.bz/ |
| Caribbean Disaster Emergency Management Agency (CDEMA) | A regional inter-governmental agency for disaster management in the Caribbean Community (CARICOM) with links to regional projects and databases. | https://www.cdema.org/ |
| Caribbean Handbook on Risk information Management (CHARIM) | The CHARIM project built capacity of government clients in the Caribbean Region to generate landslide and flood hazards and risks information. The website contains a wealth of information on methodologies and data management.<br>The Geonode contains downloadable datasets for Belize, Dominica, Grenada, St. Lucia and SVG. Since the project ended, the | http://www.charim.net/<br>http://charim-geonode.net/ |

| | | |
|---|---|---|
| | CHARIM site and GeoNode have been transferred to CDEMA. | |
| Caribbean Risk Information Service (CRIS) | Includes geospatial data, links to databases and a virtual library hosted through the CDEMA website. | https://www.cdema.org/cris |
| Commonwealth Marine Economies (CME) Programme | The UK government programme launched in 2016 to support Commonwealth SIDS in building capacity to manage marine resources and develop maritime economies. | https://projects.noc.ac.uk/cme-programme/<br>https://www.gov.uk/guidance/commonwealth-marine-economies-programme |
| CARIbbean Weather Impacts Group (CARIWIG) | Historical and modelled "future" climate data. | http://www.cariwig.org/ncl_portal/#info. |
| Caribbean Islands Land Use Cover | Land Use Cover/Land Mapping, including water bodies, rivers and streams, for St. Lucia, Grenada and SVG produced under the World Bank – European Space Agency (ESA) partnership | https://datacatalog.worldbank.org/dataset/caribbean-islands-land-use-land-cover-lulc |

# 7. Data Management

Coastal monitoring will involve generation and collation of large quantities of data, management of these data, therefore, forms an important part of any planning or decision-making process. Information on the best practice in effectively managing these data is provided below.

## Geographical Information Systems (GIS)

The use of Geographical Information Systems (GIS), such as ArcGIS or QGIS, enables agencies to map and model climate change impacts using geospatial data such as aerial photographs, satellite images, etc. etc. Without maps and satellite images it is impossible to plan effectively (Bush, 2018). GIS products provide a platform on which monitoring data can be displayed and analysed.

GIS tools enable the tracking of geophysical changes to dynamic marine and coastal areas, the checking of the progress of interventions and the extent of important ecosystems such as mangroves.

## Best Practice in Data Management

Good data management has several benefits, it: enables the sourcing and understanding of data when it is needed; gives continuity when there is staff turnover; helps avoid duplication of effort in re-collecting or re-working data; and allows data to be made easily available to consultants (Jones, 2011). In addition to good data management, it is also of benefit to store any reports generated from or relating to the datasets in the same location or, at a minimum, to reference reports or publications (including their storage location) in the associated metadata.

Metadata is data about data, which assists in the understanding of the provenance and limitations of the information sources independent of external assistance. It is vital to good data management as without it there may be too little information available about a dataset for it to be useful to future potential users. Metadata should allow users to: read the encoded data format; understand the data lineage; characterise the data quality; uniquely identify the data; and trust the data integrity.

Data management includes the storage, use and reuse of data, maintenance and archiving of the resources. It implies a number of elements (Defra, 2006):

- Data and analysis tools
- Data inventory/metadata
- Technical data management (formats, storage, archive, etc.)
- Data licensing (copyright, reproduction, publication and distribution rights)
- Data output, archiving and distribution.

Data management activities require coordination and planning not only during the data acquisition phase, but throughout the subsequent assembly and curation of the data, for this reason it is a good idea to assign someone to manage these activities (Pollard et al., 2011).

It is recommended that the following steps are fulfilled in managing data as part of the development of any strategy or management plan (Defra, 2006):

- Establish a metadata index to record reports and datasets used in development of any plan. This should include both newly acquired and historic datasets and reports commissioned by authorities.

- Collate all existing relevant datasets and analyse update requirements
- Identify existing regional and local datasets and acquire and convert to appropriate formats
- Incorporate spatial data within a GIS system
- Identify information gaps and areas where updates or new data capture is required
- Create metadata for all datasets and reports generated as part of plan development and execution
- Once completed data should be made available for distribution.

The following best practices for data management should be adhered to (Hook et al., 2010):

- File names should reflect the contents of the file and include enough information to uniquely identify the data file. The file name should be provided in the documentation and in the first line of the header rows in the file itself.
- In choosing a file format, data collectors should select a consistent format that can be read well into the future and is independent of changes in applications. For example, Excel is a useful tool for data manipulation and visualisation, but versions may become obsolete and not easily readable in the long-term. Creating an export in a stable, well-documented, non-proprietary format (such as a text, *.txt, or comma-delimited, *.csv, file) is important to maximize the potential to use and build upon data.
- Data set titles should be as descriptive as possible for ease of reference in the future. They may be the first thing a person sees when searching for a data set and should therefore be as descriptive as possible.
- The contents of the data files should be well defined. In order for others to use your data, they must fully understand the contents of the data set, including the parameter names, units of measure, formats, and definitions of coded values such as flags and missing values. Provide the English language translation of any data values and descriptors (e.g. coded fields, variable classes, and GIS coverage attributes) that are in another language.
- Basic data quality assurance (QA) should be performed (in addition to any scientific QA) on the data files prior to sharing. When QA is finished, describe the overall quality level of the data as part of the metadata. Within the data itself clear QA flags should be used that cannot be mistaken for data values.
- All data must be thoroughly documented in order that it may be easily identified, accessed and therefore used by others in the future. The metadata accompanying your data set should be future-proofed.  You must ensure that the metadata can be understood by a user who is unfamiliar with the project and/or by the methods used within it.

When commissioning future data collection from an external source, e.g. monitoring or socio-economic data, it should be specified that consultants comply with the data management plan and provide data, metadata and reports in appropriate, accessible formats. Very often GIS is used as a standard tool to capture, store, manipulate, analyse, manage, and present spatial or geographic data. These tools are evolving systems, which can be continuously updated whilst recording data captured previously. Defining and utilising a set of standardised tools to support the needs of data and coastal management facilitates information sharing between those working with or researching coastal processes.

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