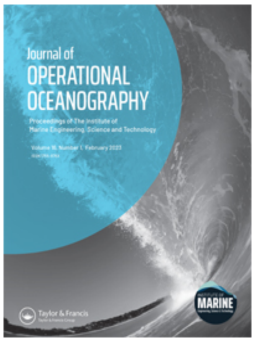

Journal of Operational Oceanography

ISSN: 1755-876X (Print) 1755-8778 (Online) Journal homepage: www.tandfonline.com/journals/tjoo20

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To cite this article: Joaquin Trinanes, N.F. Putman, G. Goni, C. Hu & M. Wang (2023) Monitoring pelagic *Sargassum* inundation potential for coastal communities, Journal of Operational Oceanography, 16:1, 48-59, DOI: 10.1080/1755876X.2021.1902682

To link to this article: https://doi.org/10.1080/1755876X.2021.1902682

Published online: 18 Mar 2021.

JOURNAL OF OPERATIONAL OCEANOGRAPHY
2023, VOL. 16, NO. 1, 48–59
https://doi.org/10.1080/1755876X.2021.1902682

Monitoring pelagic *Sargassum* inundation potential for coastal communities

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ABSTRACT

Pelagic *Sargassum* is a buoyant macroalgae that forms rafts at the ocean surface and serves as a biologically rich habitat for hundreds of diverse marine species. Since 2011, massive blooms of *Sargassum* have occurred in the tropical Atlantic and swept through the western tropical Atlantic, Caribbean Sea, and Gulf of Mexico. These recurring annual events have caused significant disruptions to coastal communities throughout the region, negatively impacting human health, tourism, fishing, navigation, and nearshore ecosystems. We present here the *Sargassum* Inundation Report (SIR), a product that uses satellite-based methodology to estimate and predict the future coastal inundation of pelagic *Sargassum*. Results from one year of SIRs show strong spatiotemporal differences in the potential of coastal inundation across the Intra-American Seas, and provide a comprehensive method for assessing its geographic distribution and temporal variation. Comparisons of SIRs to opportunistically collected photographs indicate a qualitative concordance between satellite and in situ observations. This work highlights the value of satellite observations, basin-wide and seasonal monitoring, and emphasises the need for sub-regional and weekly forecasting. SIRs show considerable promise as a tool that can eventually incorporate improved spatiotemporal resolution *Sargassum* imagery, ocean circulation, wind, and wave conditions to forecast the movement of *Sargassum* into coastal areas.

ARTICLE HISTORY
Received 15 October 2020
Accepted 1 March 2021

1. Introduction

Pelagic *Sargassum* is a floating macroalgae that was first definitively noted in the reports of Christopher Columbus during his voyages to the Americas (Gower and King 2019). The two pelagic species of *Sargassum* (*S. fluitans* and *S. natans*) form large rafts that function as a drifting ecosystem, providing valuable habitat for diverse marine organisms (Jones 1879; Wells and Rooker 2004a, 2004b; Witherington et al. 2012; Bertola et al. 2020). The historical distribution of *Sargassum* has primarily been within the Gulf of Mexico and western North Atlantic, with the centre of mass in the aptly named Sargasso Sea (Butler and Stoner 1984). Beginning in 2011, massive amounts of pelagic *Sargassum* algae began washing ashore along islands throughout the Caribbean Sea. The sudden occurrence of this unprecedented amount of this floating algae disrupted shipping, tourism, fishing, and coastal ecosystems (Gower et al. 2013; Hu et al. 2016). Studies conducted using remote sensing techniques by satellite showed that the bulk of the *Sargassum* that entered the Caribbean Sea arrived from the tropical Atlantic Ocean, a region previously unknown to host such dense mats of *Sargassum* (Gower et al. 2013). Similar results were obtained from particle backtracking in ocean models (Putman et al. 2018). The following year the scale of *Sargassum* inundations in the Caribbean Sea lessened and in 2013 the amount had fallen to the lower levels similar to the previous decade (Putman et al. 2018; Wang et al. 2019). However, rather than being a relatively short-lived and rare event, major blooms of pelagic *Sargassum* returned to the tropical Atlantic in 2014 and have swept through the Caribbean Sea, Gulf of Mexico, and along the eastern U.S. coast annually to date thereafter (Wang et al. 2019).

The movement of pelagic *Sargassum* through the North Atlantic Ocean generally follows major ocean circulation features (e.g. the North Equatorial Current and the North Brazil Current System in the tropical Atlantic, the Caribbean Current through the Caribbean Sea, the

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Loop Current and its associated rings in the Gulf of Mexico, and the Gulf Stream in the western North Atlantic) (Johns et al. 2020). Changes in wind patterns, such as related to the North Atlantic Oscillation, and nutrient availability at the ocean surface likewise play important roles in the basin-scale distribution and abundance of *Sargassum* (Brooks et al. 2018; Wang et al. 2019; Berline et al. 2020; Johns et al. 2020). At meso-spatial scales and synoptic temporal scales, recent experiments tracking mats of *Sargassum* and *Sargassum*-like drifters demonstrate that winds contribute additional velocity to floating *Sargassum*, altering its trajectory relative to water currents (Miron et al. 2020; Olascoaga et al. 2020; Putman et al. 2020). Accounting for wind and other inertial effects produces better predictions of *Sargassum* movement (Brooks et al. 2019; Putman et al. 2020).

As *Sargassum* approaches coastal areas wind effects become increasingly influential on its movement and greatly complicate predictions of where and when it may wash ashore (Putman et al. 2020). Similarly, the satellite observations that have allowed comprehensive analyses of pelagic *Sargassum* distributions extension and motion across the Atlantic basin provide scarce data in nearshore areas. The most common algorithms for detecting *Sargassum* are based on the red-edge reflectance of vegetation (Gower et al 2006; Hu 2009; Wang and Hu 2016; Ody et al. 2019). In these nearshore regions, the algorithm's performance for detecting *Sargassum* is affected by high concentrations of chlorophyll not associated with *Sargassum* and artefacts from benthic sources. These data gaps in our ability to predict and monitor the coastal inundations of *Sargassum*, are extremely problematic, because it is in this area where negative impacts are typically the greatest (Maréchal et al. 2017).

Pelagic *Sargassum* has various impacts in open ocean and coastal ecosystems. The decomposition of massive amounts of *Sargassum* in coastal areas produces hydrogen sulfide and ammonia which can lead to serious health complications for people (Resiere et al. 2018) in addition to unpleasant odours that attract insects and diminish tourism (Hu et al. 2016). Other negative impacts include suffocation of coastal organisms associated with seagrasses and coral reefs in addition to fish kills and rendering sea turtle nesting beaches unusable (Maurer et al. 2015; van Tussenbroek et al. 2017; Rodríguez-Martínez et al. 2019). These negative impacts may become exacerbated under certain environmental conditions where enrichment of waters with phosphate and nitrate (e.g. from fertiliser runoff) cause a burst of *Sargassum* growth before it eventually beaches and dies (Lapointe 1995).

We present here a methodology that can quantify and monitor the potential of *Sargassum* coastal inundation on a regular and continuous basis throughout the Caribbean Sea region, Gulf of Mexico, and extending to the east coast of Florida and the Bahamas. In Section 2 we describe the satellite-based AFAI (Alternative Floating Algae Index) and derived FA (Floating Algae) density index, which are the underlying fields that contribute to *Sargassum* Inundation Reports (SIRs), an experimental monitoring of coastal potential of *Sargassum* inundation. This includes the (a) satellite observations, (b) derived products, and (c) algorithm that determines the potential for inundation. In Section 3 we explain (a) the production, structure, and validation of SIRs as well as (b) show differences in *Sargassum* inundation potential across this region for the past year (July 2019 to July 2020). In section 4 we discuss how future improvements may be implemented, both for increasing the spatiotemporal resolution of *Sargassum* imagery and producing forecast models based on ocean current, wind, and wave conditions. The implementation of this product provides a robust way to continuously monitor the evolving inundation potential of *Sargassum* throughout the Intra-American Seas (Figure 1).

2. Data and methods

2.1. Satellite observations

The increasing number and capabilities of satellite sensors enhance the coverage and the range and value of products that can be created from the received telemetry. Examples of satellite ocean-related applications are multiple and varied (fisheries, operational oceanography, data assimilation, ecosystem monitoring, etc.), but only recently and on the grounds of advances in ocean colour remote sensing, different methodologies (Gower et al. 2006; Hu 2009) have been proposed for detecting *Sargassum* from space. The advantages of using satellites for monitoring purposes are that they allow tracking pelagic *Sargassum* mats over large regions at the same time, studying their dynamics and providing time series to identify trends and patterns. This represents a significant improvement over the traditional in-situ and coastal observational practices, and lays the foundations for the development and implementation of satellite-based products for monitoring *Sargassum* inundation events. Advancements in computing, data storage and management, and interoperability make it possible to create and access all the required inputs operationally, to build long-term time series for analysis, and to verify and validate the results with field observations.

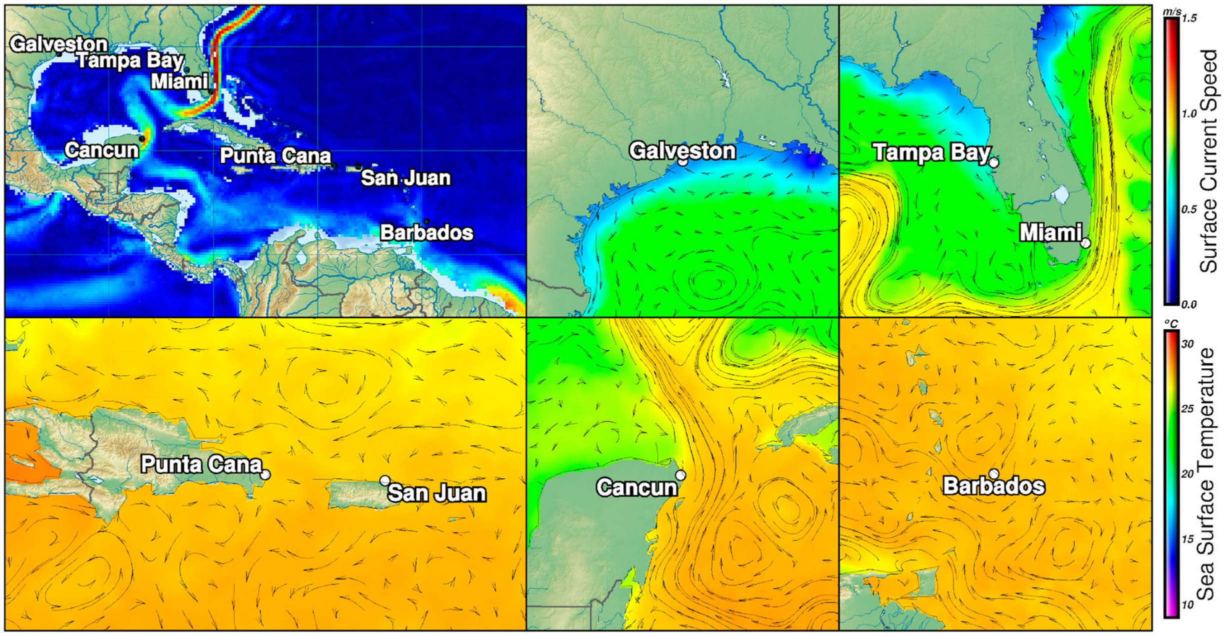

Figure 1. (Upper Left) Map of study area where satellite data are obtained to compute *Sargassum* (AFAI) fields and assess inundation potential along coastlines. The background field represents the annual surface current speed (Laurindo et al. 2017). The other figures show the sea surface temperatures and ocean circulation patterns in the vicinity of each of the locations used for validating the SIR fields. Those fields are available operationally on a daily basis from Atlantic OceanWatch. The fields shown on the figures correspond to Jan 6th, 2020.

Sensors with bands in the visible and near-infrared range, specifically between 550 and 1200 nm are good candidates for *Sargassum* detection. This is a requirement among other constraints related to the signal-to-noise ratio, and the spatial, spectral and radiometric resolutions. Data from the full set of bands contribute to the improvement of the quality of the final product, masking out the pixels contaminated by clouds, sunglint, land or setting any other sensor-specific quality flags. The underlying data that contribute to the Experimental Weekly Sargassum Inundation Reports are based on satellite observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) on *Terra* and *Aqua*, and from the Visible Infrared Imaging Radiometer Suite (VIIRS) on *Suomi National Polar-orbiting Partnership* (S-NPP). Each satellite views the entire Earth surface on a near-daily basis, collecting information in multiple bands (36 for MODIS, and 22 for VIIRS) at different spatial resolutions (250–500–1000 m MODIS, 375–750 m VIIRS). The sun-synchronous polar orbit guarantees that each pass takes place at similar solar times, providing consistent lighting.

2.2. The alternative floating algal index (AFAI)

The AFAI serves as a measure of the magnitude of red-edge reflectance of floating vegetation. Technically, it is defined as the MODIS Rayleigh-corrected reflectance at 748 nm referenced against a linear baseline between two neighbourhood bands at 869 and 667 nm (Wang and Hu 2016). It is an alternative form of the original FAI where all the centre band and the baseline bands are from MODIS land bands that have higher spatial resolution than the MODIS ocean bands, and that do not saturate over bright targets such as clouds. However, masking clouds in FAI imagery using the land bands over the ocean is problematic, thus its alternative form (i.e. AFAI) is used. Field measurements suggest that AFAI is a monotonic function of *Sargassum* areal density (% coverage within a unit area or an image pixel) and biomass density (kg m^{-2}) (Wang et al. 2018), with higher AFAI values reflecting higher densities. Therefore, both areal density and biomass density can be derived from the AFAI of a pixel. In practice, a series of steps are needed to remove noise and other image artifacts before estimating the areal density (Wang and Hu 2016) and biomass density (Wang et al. 2018). For MODIS, typical AFAI values in areas where *Sargassum* is present range from $1.79*10^{-4}$ (corresponding to >0% *Sargassum* areal density, Wang and Hu 2016) to maximum values around 0.044 (corresponding to 100% *Sargassum* density within a pixel). For VIIRS, the lower threshold is $2.0*10^{-4}$ (Wang and Hu 2018).

Since 2016 and 2018, respectively, MODIS and VIIRS data have been processed to generate AFAI and weekly FA density imagery (Figure 2) in near real time for

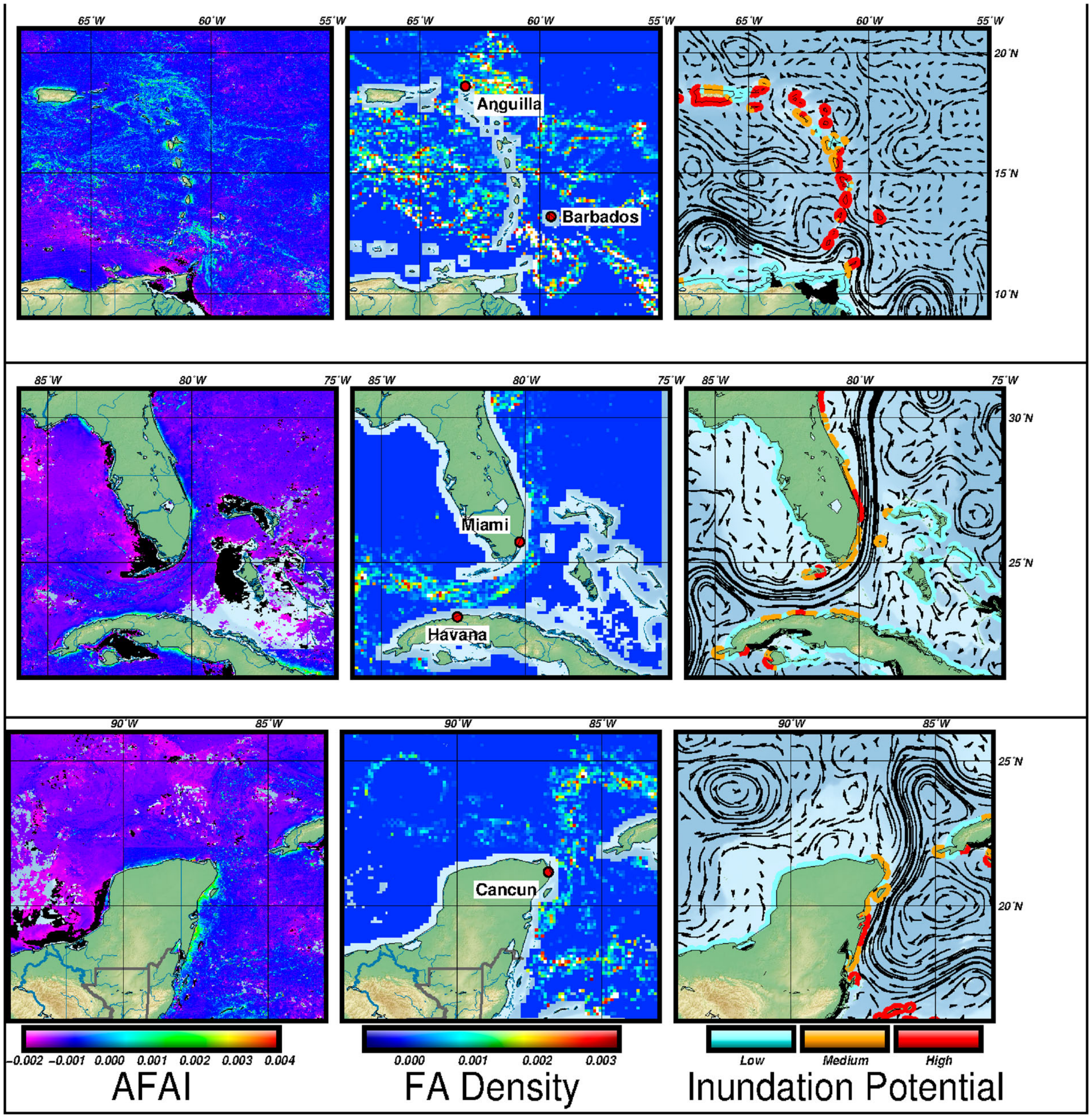

Figure 2. (Figure left.) 7-day composite AFAI fields ending Jul 20th, 2020. Based on the spatial distribution and temporal variability, most of the pixels outside the coastal regions showing positive AFAI values correspond to areas covered by *Sargassum*. (Figure centre.) 7-day Floating Algae density ending Jul 20th, 2020 (Wang and Hu 2016). This field, based on the AFAI estimates, represents the area covered by *Sargassum*. The coastal waters (30 km from shoreline) are masked in the 7-day FA density images due to lack of reliable algorithms to extract floating algae features from these waters. The SIR algorithm uses these FA density fields to determine inundation potential. (Figure right.) Image from SIR v1.2 spanning the week of July 14th, 2020 to Jul 20th, 2020. Coastal areas with high *Sargassum* inundation potential are outlined in red, medium potential in orange, low potential in blue and insufficiency of data in black. Background lines indicate the direction of geostrophic ocean currents.

several regions in the Atlantic (e.g. Gulf of Mexico, Caribbean Sea, Central West Atlantic) by the University of South Florida's Optical Oceanography Laboratory through the Sargassum Watch System (Hu et al. 2016; https://optics.marine.usf.edu/projects/saws.html).

The AFAI has been used in a wide array of analyses pertaining to *Sargassum* ecology including describing seasonal variability in transport, beaching, bloom dynamics and prediction, and wind-effects on transport (Maréchal et al. 2017; Wang and Hu 2017; Putman et al. 2018; Berline et al. 2020) and produces results similar to other satellite-based *Sargassum* detection methods such as the Maximum Chlorophyll Index (MCI) (Gower and King 2011, 2020). Since early 2018, the FA density products have also been used to generate monthly *Sargassum* outlook bulletins for various stakeholders.

2.3. Coastal *Sargassum* inundation

The SIR algorithm for Coastal *Sargassum* Inundation uses the 7-day Floating Algae (FA) density fields (Wang and Hu 2016, see section b) to estimate the potential for *Sargassum* washing ashore. The 7-day FA density maps have 1/10 degree resolution, where each grid cell has a value representing either no observation or the *Sargassum* areal density during the 7-day period. The process of determining inundation potential analyses the satellite-derived *Sargassum* areal density estimates in a fixed radius of 50 km from the coastline. The inundation potential is categorised into 3 levels: low, medium, and high. When the FA density in the vicinity rises above 0.002 (this is the *Sargassum* areal density, which is equivalent to 0.2%), the section of coastline is marked with high potential for coastal inundation. For areal densities between 0.0005 and 0.002, the inundation potential is considered medium and it is low when the values are below 0.0005. The values of these thresholds rest on the pair-to-pair comparison of the estimates produced for SIR and in-situ observations.

2.4. Sources of validation data

A core element of the proposed assessment of inundation potential is the design, development and implementation of a validation scheme. This aspect of the work is currently underway. The processes of tuning and validating this product requires ground truth data over the target areas. For this purpose, an in-house database was designed and implemented to collect data from different repositories of *Sargassum* in-situ observations. This effort is completed with an ArcGIS Survey123 (https://survey123.arcgis.com) form to collect in-situ observations in the form of descriptions and photographs (https://arcg.is/Sq8aC). These observations are also publicly available at the CoastWatch OceanViewer webpage (https://cwcgom.aoml.noaa.gov). For our purposes, the main source of available data are in-situ citizen science projects, such as Epicollect5 *Sargassum* Watch, SPAW/USF online questionnaire and NOAA/AOML/CW ESRI Survey. All of these observations are being integrated into a NOAA–managed single, unified and freely available database comprising various data types, including graphical inputs. Other resources that have been identified and may be integrated into the database are daily time series from webcams (e.g. webcamgalore.com) and high resolution satellite *Sargassum* retrievals (e.g. from Sentinel-2 constellation). The availability of satellite-derived *Sargassum* estimates and fields of coastal inundation potential that can be integrated with other data types, provide the opportunity for machine learning algorithms to automatically detect and quantify the amount of *Sargassum* from webcams and photographs. For a qualitative comparison here, we show how SIRs compare to photos obtained from three locations: Cancun, Quintana Roo Mexico (from a news article), Miami, Florida USA (from Epicollect5 *Sargassum* Watch) and Punta Cana, Dominican Republic (from time-series of webcam photos available for the past 365 days at webcamgalore.com). For the time-series, photos were selected based on availability (some days were missing), visibility (some images were obscured by weather conditions or objects on the beach), and without people in the foreground. Finally, we selected dates that represented low, medium, and high *Sargassum* inundation potential.

3. *Sargassum* inundation reports

3.1. SIR structure and validation

The SIRs are presently generated experimentally on a weekly basis and are distributed online and in PDF format by NOAA/AOML.[1] SIRs are presented for 5 regions: the Gulf of Mexico, Central America, the Greater Antilles, the Lesser Antilles, and South America. Coastlines along these regions are colour coded according to the potential for *Sargassum* reaching the coast based on the FA density fields described above. The inundation assessments are also available in GeoJSON format, which enhances interoperability and the use of information by decision managers and other users requiring digital georeferenced datasets.

Qualitative comparisons between SIR estimates and available photo observations suggest a reasonable agreement between SIR and in-situ conditions, especially for false negatives (areas showing high amounts of *Sargassum* being classified as low risk). This is particularly relevant for decision making purposes, as the SIR can serve as a proxy for assess the risk of massive arrival of *Sargassum*. A photo taken by a photographic agency shows large amounts of *Sargassum* in Cancun, Quintana Roo Mexico following high inundation potential determined by SIR for that region (Figure 3A,B). Similarly, a photo obtained from the Epicollect5 App and the '*Sargassum* Watch' citizen science project along the beach in Miami, Florida USA indicate moderate levels of *Sargassum* washed ashore during a period when SIR indicated medium potential for the area (Figure 3C,D). A time-series of photos obtained from a tourist resort's webcam in the eastern Dominican Republic, near Punta Cana show little *Sargassum* on the beach during periods of low inundation potential, moderate amounts of *Sargassum* during periods of medium inundation potential,

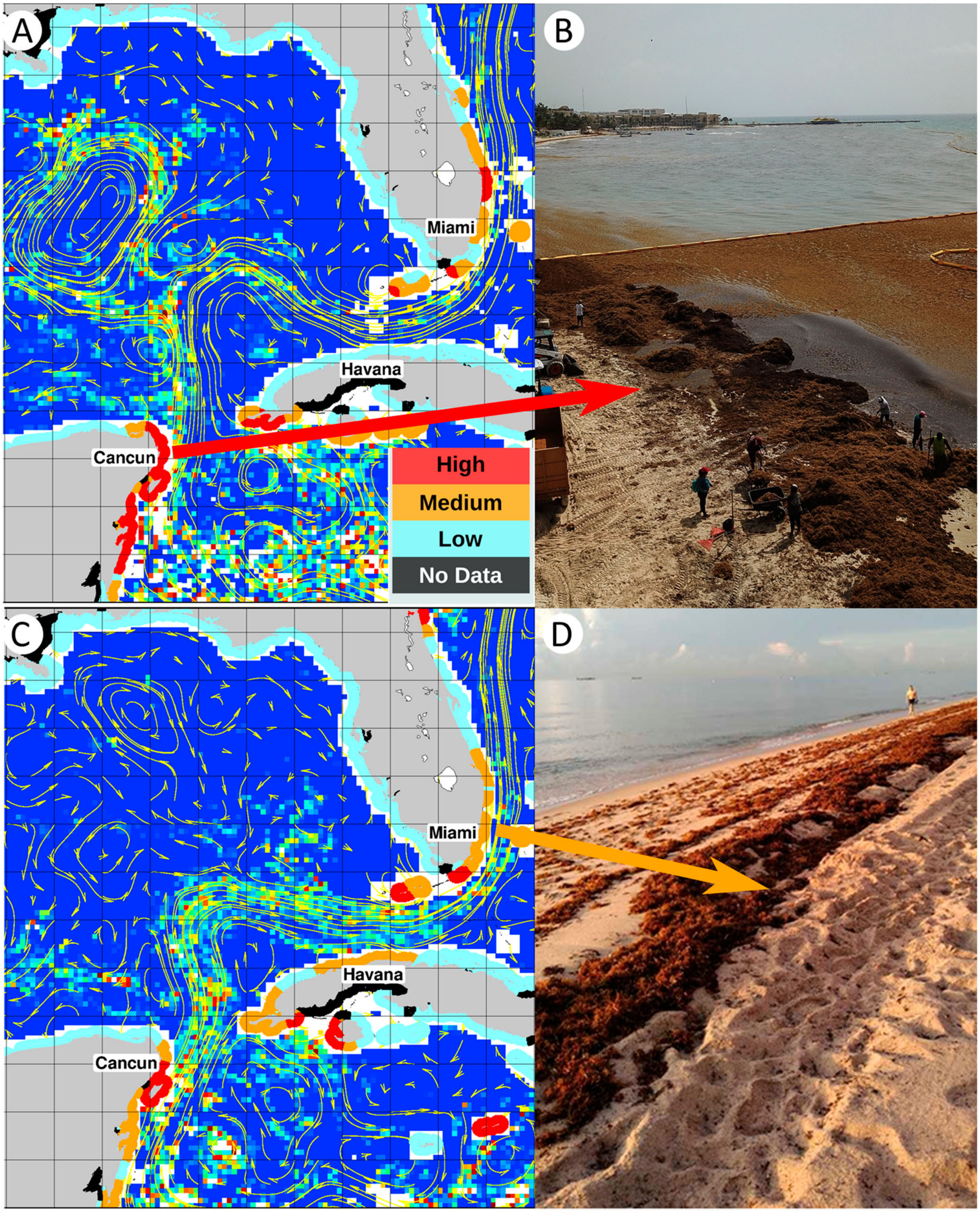

Figure 3. (A) SIR for July 2–8, 2019 that indicates high (red) *Sargassum* inundation potential for Cancun and (B) a photo showing severe coastal inundation of *Sargassum* in Cancun (20.630 N, 87.066 W), Quintana Roo Mexico on July 12th, 2019 (Source: Isaac Esquivel/Cuartooscuro.com). (C) SIR for July 7–13, 2020 that indicate medium (orange) inundation potential for Miami and (D) a photo showing moderate levels of *Sargassum* along the beach in Miami (26.156 N, 80.1 W), Florida USA on July 8th, 2020 (Source: Marine Macroalgae Research Lab - Florida International University (MMRL-FIU). "Sargassum Watch" Epicollect5 Project.

and larger amounts of *Sargassum* during and following periods of high inundation potential (Figure 4).

While these examples indicate a general correspondence between SIR and amounts of *Sargassum* washing ashore, we do not anticipate that an area with low inundation potential would necessarily show no *Sargassum* or an area with high inundation potential would show major amounts of *Sargassum*. The purpose of this product is to provide information about the presence of *Sargassum* in the vicinity of the region of interest, while other coastal processes, mostly winds, waves, and currents, would ultimately determine how much of the pelagic algae would wash ashore.

3.2. Spatiotemporal changes in the potential of coastal inundation

We present here a time-series of potential *Sargassum* Inundation over the period July 2019 to July 2020 (55 weeks) in seven coastal areas located close to major population centres to demonstrate the value of the information on the potential of *Sargassum* inundation at both the broad regional scale and at specific areas. These locations include Galveston, Texas (USA); Tampa Bay, Florida (USA); Miami, Florida (USA); Cancun, Quintana Roo (Mexico), Punta Cana (Dominican Republic); San Juan, Puerto Rico (USA); and the eastern (westward) coast of Barbados in Ragged Point (Figure 1). Across the area monitored, the potential for *Sargassum* inundation varied considerably among areas and showed different temporal patterns (Figure 5). For instance, in the northwestern Gulf of Mexico, Galveston, Texas had low potential for *Sargassum* inundation throughout the year (Figure 6), whereas in the eastern Gulf of Mexico, Tampa Bay, Florida saw an isolated week with a high potential for *Sargassum* inundation, but otherwise had low inundation potential. On the Atlantic coast of Florida, Miami experienced medium inundation potential (34% of the time or 19 weeks) throughout much of the timeseries. Cancun, Mexico (situated on the western side of the Yucatan Channel) and Punta Cana, Dominican Republic (in the north central Caribbean Sea and on the eastern side of the island) were both exposed to high *Sargassum* inundation potential (15% and 34.5% of the time, equivalent to 8 and 19 weeks, respectively), especially during the summers of 2019 and 2020, and medium potential (24.5% and 29% of the time, equivalent to 13 and 16 weeks, respectively) through much of the remainder of the year (Figures 5 and 6). In contrast, San Juan, Puerto Rico (also in the north Central Caribbean Sea but on the northern/Atlantic side of the island) had medium to high inundation potential during the summer (for a total of 16.4% of the time, or 3 weeks), but low inundation potential throughout the remainder of the year (83.6% of the time, or 46 weeks). The east coast of Barbados is vulnerable to the large mats of *Sargassum* coming from the tropical Atlantic and experienced high inundation potential from spring through early autumn and only a brief low period of inundation potential in November and December (Figure 5). At the basin level, a large percentage of the shoreline experienced medium to high inundation potential (Table 1). The areas showing low values along the full series are concentrated in the northern Gulf of Mexico and the Caribbean and northwestern South America.

3.3. Discussion and conclusions

The *Sargassum* Inundation Reports (SIR) are created as a response to the need to improve the management of *Sargassum* influxes in the region (e.g. coordinate clean-up), which have major economic, social, environmental and public health impacts. This product provides assessments of the presence and amount of *Sargassum* in the vicinity of a coastline throughout the Intra-American Sea. Thus, SIRs represent a first stage and the first publicly available resource to account for the potential of *Sargassum* presence in the vicinity of coastal areas and to promote informed decision-making, while more sophisticated coastal models are currently being developed and implemented (Prakash et al. 2018). The present implementation of SIR assumes inundation potential based on the FA density value within 50 km of coastal regions. The amounts of *Sargassum* likely to wash ashore depend upon the complex interaction among ocean currents, surface winds, waves, tides, and the physical properties of the *Sargassum* aggregation in ways that are not yet fully understood (Beron-Vera and Miron 2020; Miron et al. 2020; Olascoaga et al. 2020; Putman et al. 2020). Thus, at this stage, SIR assumes that coastal areas flanked by large amounts of *Sargassum* have greater inundation potential than areas where less *Sargassum* is nearby. Preliminary comparisons of SIR to concurrently taken photographs at different sites across the region suggests this simple method does identify when and where *Sargassum* is likely to wash ashore (Figures 3 and 4). This platform thus represents an initial step towards a qualitative approach that supports data-driven decision making and planning.

The synoptic capabilities of satellite sensors make them an ideal platform for monitoring and mapping ocean processes. In this study, and as a first prototype, we use floating algae density fields, which have been

Figure 4. Weekly time series of *Sargassum* inundation potential derived from SIR for July 2019 to July 2020 for Punta Cana, Dominican Republic. For comparison to in situ observations, we show photographs from this location (18.693 N, 68.424 W) during different periods of inundation potential. (A) October 1, 2019, no obvious *Sargassum* and low inundation potential. (B) October 19, 2020, a thin line of *Sargassum* along the beach and medium inundation potential. (C) February 3, 2020, no obvious *Sargassum* and low inundation potential. (D) March 24, 2020, small amounts of *Sargassum* and low inundation potential, but following a week of high inundation potential and several weeks of medium inundation potential. (E) May 4, 2020, an accumulation of *Sargassum* and high inundation potential, following a week of medium inundation potential. (F) July 30, 2020, a large accumulation of *Sargassum* and high inundation potential, following a period of prolonged high to medium inundation potential. (Source: Palladium Hotel Group). Dates were selected to compare low, medium, and high *Sargassum* inundation potential predicted by SIR to available photos. The general abundance of *Sargassum* in the daily images matches consistently with the observable trend in the weekly SIR for that period.

estimated by USF from MODIS and VIIRS. These fields serve to evaluate the risk associated with *Sargassum* inundation events in the coastal areas of the Caribbean Sea and Gulf of Mexico. Future work will include utilising a new generation of satellite sensors (e.g. Ocean Land Colour Instrument-OLCI, VIIRS, or the

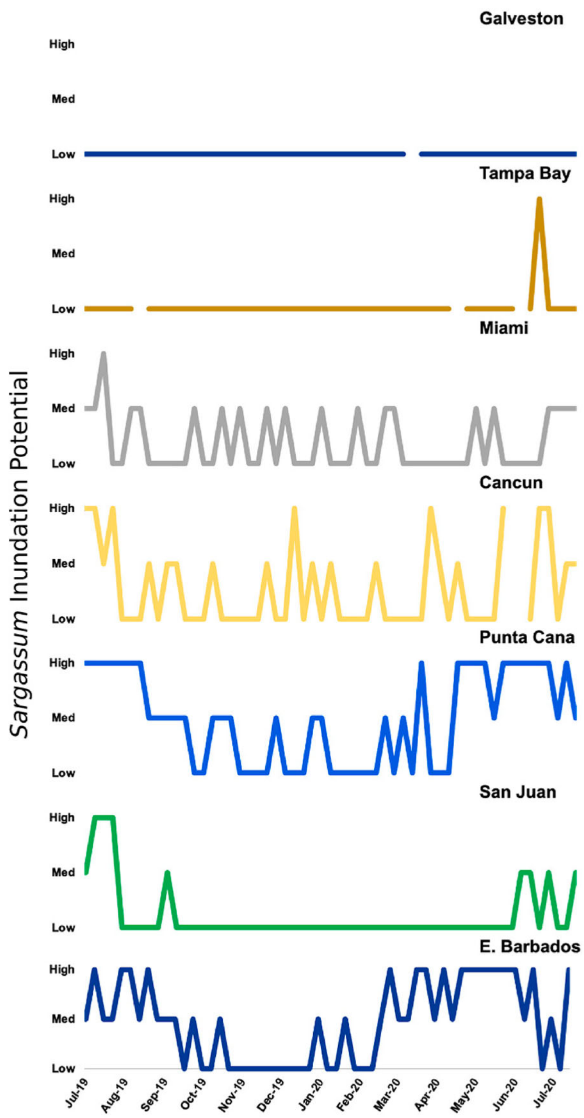

Figure 5. Weekly time series of *Sargassum* inundation potential from SIR for July 2019 to July 2020. Each panel is for a different coastal area, which is represented by the SIR collocated values at each location, and displays the changing inundation potential (low, medium, high) for *Sargassum* inundation through time. Locations of coastal areas are shown in Figure 1.

MultiSpectral Instrument-MSI) provide multiresolution data in the near and near-infrared wavelengths. For pelagic *Sargassum* detection and monitoring, each sensor requires a tuned algorithm which best suits the final product and accommodates the different spatial, spectral, radiometric and temporal resolutions.

Ensuring the continuity of the time series is an essential aspect to consider. MODIS sensors are nearing the end of their life, causing an important component of the present data for monitoring *Sargassum* to become limited in the future. This fact highlights the importance of developing similar algorithms for other satellite sensors, promoting the continuity of the time series, expanding the temporal and geographic coverage, and ensuring data availability in the case of single-sensor failure (Wang and Hu 2018).

Our algorithm analyses the FA density values within 50 km of each coastal pixel, classifying the inundation potential into three categories (low, medium, and high). The present implementation of this product has been distributed in experimental operational mode from July 2019 to July 2020, provides a new way to continuously monitor the evolving potential for *Sargassum* inundation throughout the Intra-American Seas, and is freely available.[2]

There are a number of activities that will guide future improvements and are currently being addressed by the authors. One area of improvement will be related to accounting for growth and mortality (sinking) of *Sargassum*. SIRs implicitly assume the rate of change in the density of *Sargassum* around coastal regions due to these processes occurs at frequencies lower than the weekly schedule of reports, but this assumption needs further validation. *Sargassum* propagates exclusively via vegetative growth and fragmentation which varies as a function of nutrients, sunlight, temperatures, and other factors (Lapointe 1986; Johns et al. 2020). These factors likely vary significantly from one part of the SIR domain to another, making a single growth rate applied to AFAI field untenable. Directly linking a *Sargassum* growth model to SIRs would be complex and may not be cost-effective, requiring growth rate experiments under a variety of environmental conditions. Another possible solution that indirectly accounts for growth/mortality dynamics is to increase the temporal resolution of AFAI (and other similar indexes) *Sargassum* fields. This can be accomplished by incorporating data from other satellite sensors and would also improve coastal coverage and simultaneously provide higher spatial resolution data.

While nearshore continuous coverage improves with the number of sensors, challenges remain. *Sargassum* detection is still affected by the presence of clouds, aerosols and sun-glint conditions. In general, there is a compromise between the spatial resolution and the revisiting time. Similarly, increasing the frequency in the delivery of SIR is likely to increase the number of gaps in the estimates compared to the weekly SIR. Thus, increased spatiotemporal resolution of SIR needs to be further enhanced by accounting for the role of ocean currents, winds, and waves on the movement of *Sargassum*. Initial work to model trajectories of pelagic *Sargassum* (Putman et al. 2020) and drifters designed to mimic small patches of *Sargassum* (Miron et al. 2020; Olascoaga et al. 2020) has already been conducted.

In principle, it is possible to use the existing AFAI fields and forward track their positions using forecasted

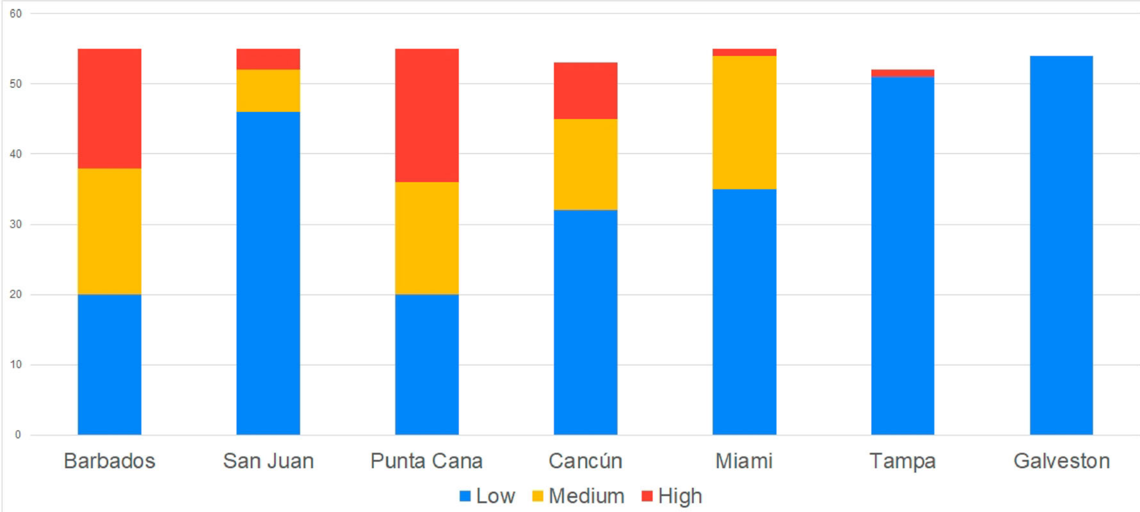

Figure 6. The number of weeks (*y*-axis) that selected locations experienced low, medium, and high potential for *Sargassum* inundation (July 2019 to July 2020, for a total of 55 weeks). Locations (*x*-axis) are shown in Figure 1. The potential for *Sargassum* inundation decreases with latitude, with the exception of San Juan, probably due to its northern, Atlantic-facing location in Puerto Rico. For Cancun, Miami and Tampa, the total number of weeks displayed is below 55, as the cloud cover caused some data gaps in the weekly fields.

winds, waves, and currents and estimate how likely it is for *Sargassum* to wash ashore given the prevailing conditions. Given the positive buoyancy of *Sargassum* accounting for winds may be especially important to predict its movement into and within coastal areas (Miron et al. 2020; Olascoaga et al. 2020; Putman et al. 2020). However, near coastal areas, the spatial heterogeneity and temporal variability of wind effects are higher and often affected by bathymetry, tides, local currents among other processes. Thus, it is likely that such computational modelling would be most effective for subsets of the overall region, in places where higher-resolution models and observations of wind, wave, and current conditions are available. Such areas would benefit from the use of reliable satellite observations of *Sargassum* from open ocean areas and subsequent predictions of its movement using trajectory models that assimilate realistic, higher resolution coastal data (e.g. currents from HF radars) that have been tuned to best represent local conditions and *Sargassum* movement.

Table 1. Percentage of shoreline experiencing low, medium, and high potential for *Sargassum* inundation across the 5 different regions covered by SIR (Period Jul 2019 to Jul 2020).

	Low	Medium	High
Gulf of Mexico	28	28	44
Greater Antilles	9	17	74
Lesser Antilles	17	13	70
Central America	9	22	69
South America	62	19	19

Due to optical complexity in nearshore waters, the current AFAI and FA algorithms do not work well on MODIS and VIIRS data over such waters, result in data gaps within 30 km from shoreline. Future efforts will be dedicated to use sensors in Sentinel-2 or others that provide finer-resolution data to fill these gaps (e.g. Wang and Hu 2020).

Our results show that SIRs are a valuable initial tool for assessing the potential of *Sargassum* inundation in the Caribbean and Gulf of Mexico regions, showing promise as a platform that can assimilate new data sources and integrate with forecast models. It can also provide a long-term time series to identify spatio-temporal trends and variability, to detect extreme events, and to facilitate cross-validation with other datasets.

Notes

1. https://www.aoml.noaa.gov/phod/sargassum_inundation_report/.
2. https://www.aoml.noaa.gov/phod/sargassum_inundation_report/.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was funded by the National Oceanic and Atmospheric Administration (NOAA) Atlantic Oceanographic and Meteorological Laboratory and NOAA OceanWatch, by the

University of Miami's Cooperative Institute for Marine and Atmospheric Studies, by the U.S. National Aeronautics and Space Administration (NASA) Ocean Biology and Biogeochemistry Program [grant number NNX16AR74G] and Ecological Forecast Program [grant number NNX17AF57G and 80NSSC20M0264] and by the National Oceanic and Atmospheric Administration (NOAA) RESTORE Science Program [grant number NA17NOS4510099].

Data availability

The Experimental Weekly *Sargassum* Inundation Report (SIR v1.2) described in this paper can be obtained freely from https://www.aoml.noaa.gov/phod/sargassum_inundation_report/.The original AFAI and FA density imagery can be accessed through SaWS at https://optics.marine.usf.edu/projects/saws.html.

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