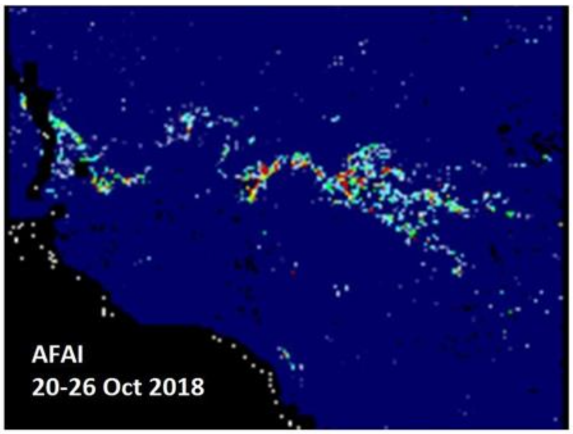
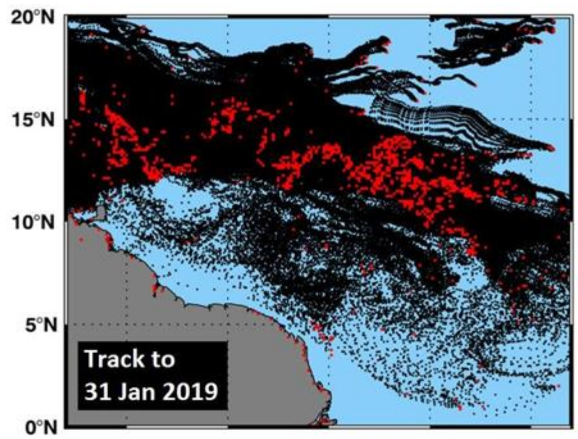
Final Report on Prediction of Pelagic Sargassum Incursions: Model Development

D. Johnson and J. Franks





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Cover photograph: Courtesy of the University of Southern Mississippi

Abstract

Unprecedented incursions of sargassum is one of the latest climate-related impacts on the eastern Caribbean fishery sector. As such, a 'sargassum subproject' was approved within the FAO/GEF Climate Change Adaptation in the Eastern Caribbean Fisheries Sector (CC4FISH) project to investigate the relationships between sargassum incursions and key fishery species. Here we present the development of a model to predict sargassum arrivals to the eastern Caribbean island chain over the medium term (several months ahead), in order to help the fisheries and other impacted sectors better prepare for and manage the incursions.

Barbados, at 13^{o}N, is located near the separation between water masses of the North Atlantic Gyre and the system of equatorial currents whose origin, in part, is in the South Atlantic. Seasonal and inter- annual variations in local currents and water masses at Barbados are high due to variations in the boundary between the gyre and the equatorial current system. In observations and models, this boundary occurs near 15^{o}N with considerable fluctuation. Local sargassum incursion events can be back-tracked to a broad range of locations in the equatorial Atlantic, dependent on season and dominance of either system of currents. Complex forcing mechanisms driving seasonal variations in local sargassum coverage include the Amazon River discharge, equatorial current branching and seasonal winds over the North Atlantic.

Efforts to predict sargassum incursions to the Lesser Antilles several months in advance are described. Archived currents from drifters and from two models (Hycom and Oscar) were used to predict incursions up to 92 days in advanced from satellite derived starting locations and dates where sargassum was seen in the images. Predictions were compared to actual arrivals in 3 regions near the Lesser Antilles as determined by satellite images. Satellite coverage due to clouds and insufficient resolution to find smaller, spread out, patches hampered the ability to predict and to validate the predictions. It was determined that relative threat levels from the models in three regions of the Lesser Antilles provided a reasonable warning of seasonal threat levels. At present these threat levels can only be validated by comparison with previous years' incursions.

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Contents

Introduction

Commercial fisheries in the Lesser Antilles have been seriously impacted by the incursion of unprecedented masses of holopelagic sargassum since the spring/summer of 2011. Transported by ocean currents, small quantities of sargassum have previously been noted throughout the tropical North Atlantic (tNA) including West Africa, but recent unusually large in-situ blooms (Johnson et al. 2013; Gower et al. 2013; Franks et al 2016) have created serious problems for economically important tourist and fisheries industries on both sides of the Atlantic. In this study we present efforts at predicting the arrival of sargassum as it passes from the tNA into the Caribbean.

Barbados, at 13°N and 59.5°W, is located near the separation between water masses of the North Atlantic Gyre and the system of equatorial currents whose principal origin is in the South Atlantic. Seasonal and inter-annual variations in local currents and water masses at Barbados vary according to the boundary between the gyre and the equatorial waters. In observations and models, this boundary occurs near 15°N, but with considerable variation. Local sargassum incursion events at Barbados, then, can be back-tracked to a broad range of locations in the equatorial Atlantic, dependent on season and dominance of either system of currents. Complex forcing mechanisms driving seasonal variations in local sargassum incursions include the Amazon River discharge and equatorial channel current systems, neither of which are adequately represented in available finite difference or diagnostic models. It also includes winter breakdown of the principal summer recirculation pattern in the tNA and a resulting connection between the tNA and the North Atlantic Gyre (Johnson and Franks, 2018).

Predictions of sargassum arrivals allow both the fishing and tourism industries to adjust to conditions. However, predictions are presently being made using nowcasts out through 7-day forecasts (https://www.hycom.org/dataserver/gofs-3pt1/analysis), which is too narrow a window for adequate preparation. Using current fields from two climatological hydrographic models and from satellite tracked drifter records, together with color satellite imagery, we demonstrate the potential to predict sargassum arrival in the Lesser Antilles on seasonal time scales.

Methods

Surface current models

Archived current data used for the predictions came from three sources: (1) satellite tracked mixed- layer drifters, (2) Hycom (HYbrid COordinate Model), and (3) Oscar (Ocean Surface Current Analysis Real-time). The basic features of these modelled data sets and the way in which we used them are summarized here.

1. **Drifters**: Satellite tracked mixed-layer drifters (drogue element at 15 m) are deployed around the globe, with data on position, temperature and a drogue-off flag. Current vector components are calculated at 6-hour intervals from sequential positions (Lumpkin et al. 2013) and the data archived at http://www.aoml.noaa.gov/phod/gdp. For our study a climatological field of currents was derived by interpolating current components to a $1/12^{th}$ degree longitude and latitude grid at year- day time steps. Interpolation was done with a Gaussian interpolator with e-folding radius of 1 degree and cut-off of 2 degrees. The result is a highly smoothed 365-day field of currents on the Hycom grid. This is a climatological (averaged)

field of currents from 1979 to 2017. The principal disadvantage of drifters for our study is the drag element at 15 m depth with unclear representation of currents at the surface.

2. **Hycom:** A finite global difference numerical model at 1/12th degree grid with principal forcing from observed winds and observed satellite altimetry sea surface height (data assimilation). A significant advantage of Hycom is its ability to phase lock (time and location) into real events such as movement of strong current systems. Its disadvantage is poor representation at the equator and weak representation of major river discharge, such as the Amazon River. A climatological field was formed by taking the mean of currents from 2009-2016. Current fields can be obtained at http://www.hycom.org.
3. **Oscar:** A diagnostic model using observed wind fields and observed satellite altimetry of sea surface height, interpolated to the Hycom grid. Gridded fields at 1/3rd degree and 5-day time intervals are interpolated (Gaussian) to 1/12th degree grid and 1-day interval. Currents represent averages over the upper ocean so climatological wind (averaged 2010-2017) is added to the currents (1% of the wind vector) in order to represent surface currents. A climatological field was formed by taking the daily mean of currents from 2009-2018. Current fields can be obtained from https://podaac.jpl.nasa.gov/dataset/OSCAR_L4_OC_third-deg.

We used a simple forward tracking algorithm with each of these fields of currents. As part of the process of developing the best fit model we used each ocean current model independently and in various combinations to track sargassum from locations in the western tNA to the Caribbean

Selection of starting points

Sargassum locations in the western tNA (up-current of the eastern Caribbean island chain) were detected visually from 7-day composite satellite images of the Alternative Floating Algae Index (AFAI; Wang and Hu 2016) obtained at http://optics.marine.usf.edu. We selected approximately 1000 starting points for each model run that were spread along the various 'axes' of highest sargassum abundance (brightest pixels) seen in the images (Figure 1).

Selection of 'finishing line'

The 60^{o} W meridian fronting the Lesser Antilles was chosen as the 'finishing line' for the predictive models (Figure 2A). The number of tracking points that crossed this meridian, with dates of arrival, serves as a simple prediction index (uncalibrated level of threat). In the process of developing the model we also partitioned the line into two segments (north and south) (Figure 2B) and subsequently into three segments (north, middle, south) (Figure 2C) to better reflect the different current fields the Lesser Antilles based on current inflow into the Caribbean. Previous work with drifters (Chérubin and Richardson 2007) indicated three jets in the Eastern Caribbean at 11^{o}N, 14^{o}N and 17^{o}N. It is noted that the North segment also conforms, principally, to water from the North Atlantic gyre entering the Caribbean.

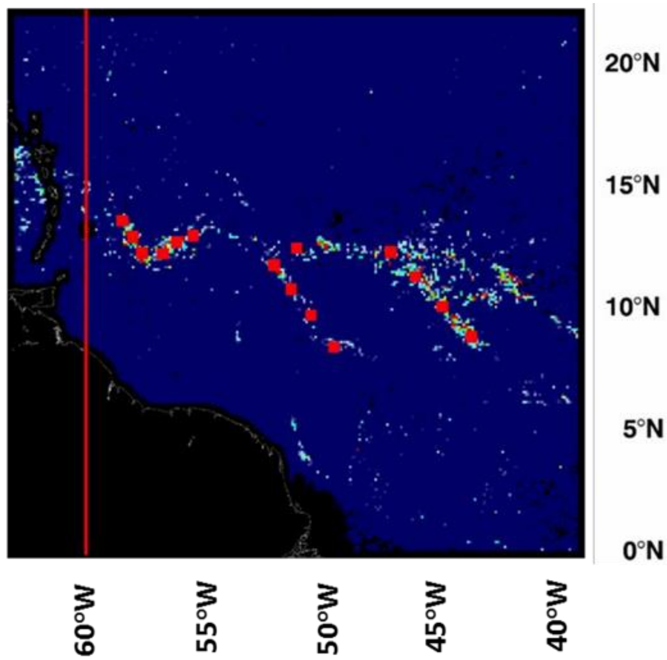

Figure 1: Diagramatic example of selecting starting points for model run from 7-day composite satellite AFAI image (in reality the model used approx. 1000 starting points). Sargassum presence is indicated by bright-coloured pixels (pale blue through red).

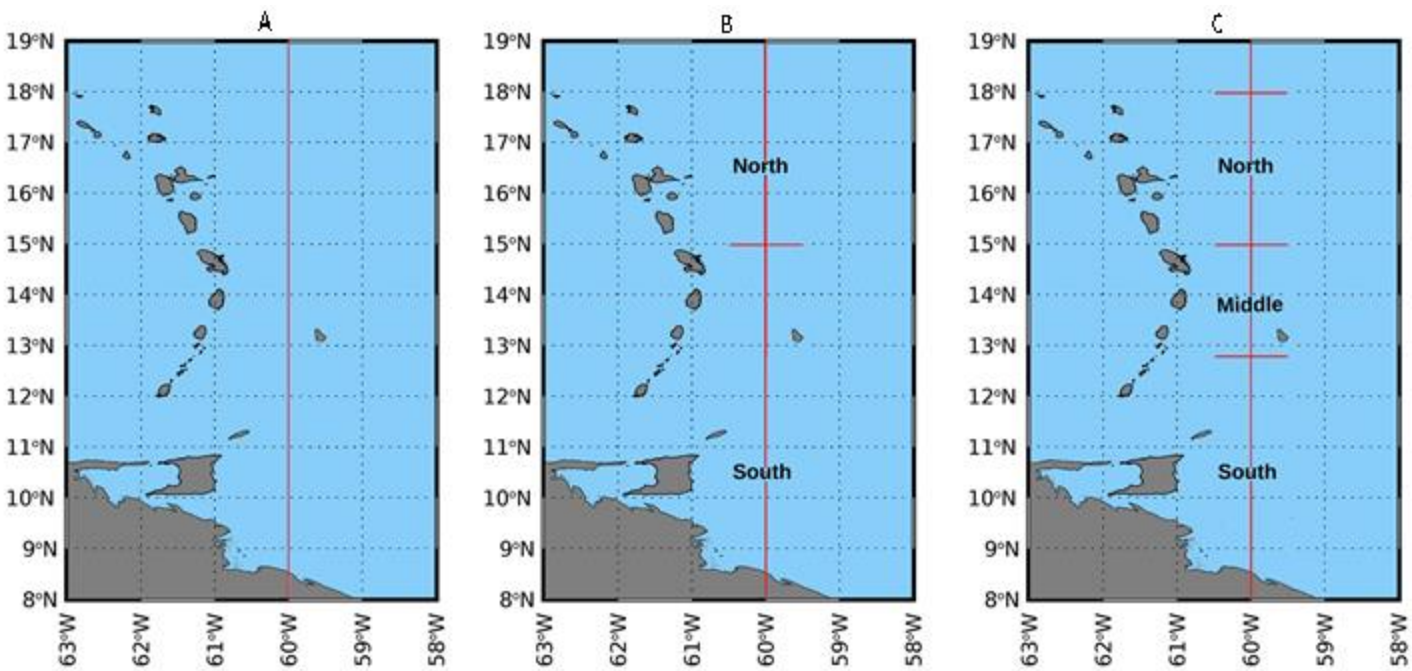

Figure 2. Map of the prediction area showing the Lesser Antilles island chain and the 60° W meridian line (in red). (A) shows the entire line used for the first model predictions, (B) shows the separation into north and south segments used in the subsequent set of predictions, and (C) shows the three segments used in the final models giving higher resolution predictions.

Results

Forward tracking

Comparisons of model runs forward tracking selected points over a 3-month period using each of the different ocean current models indicated that the Hycom and Oscar models generally gave very similar results, whereas the drifter model showed a somewhat different pattern (Figure 3). In this example the

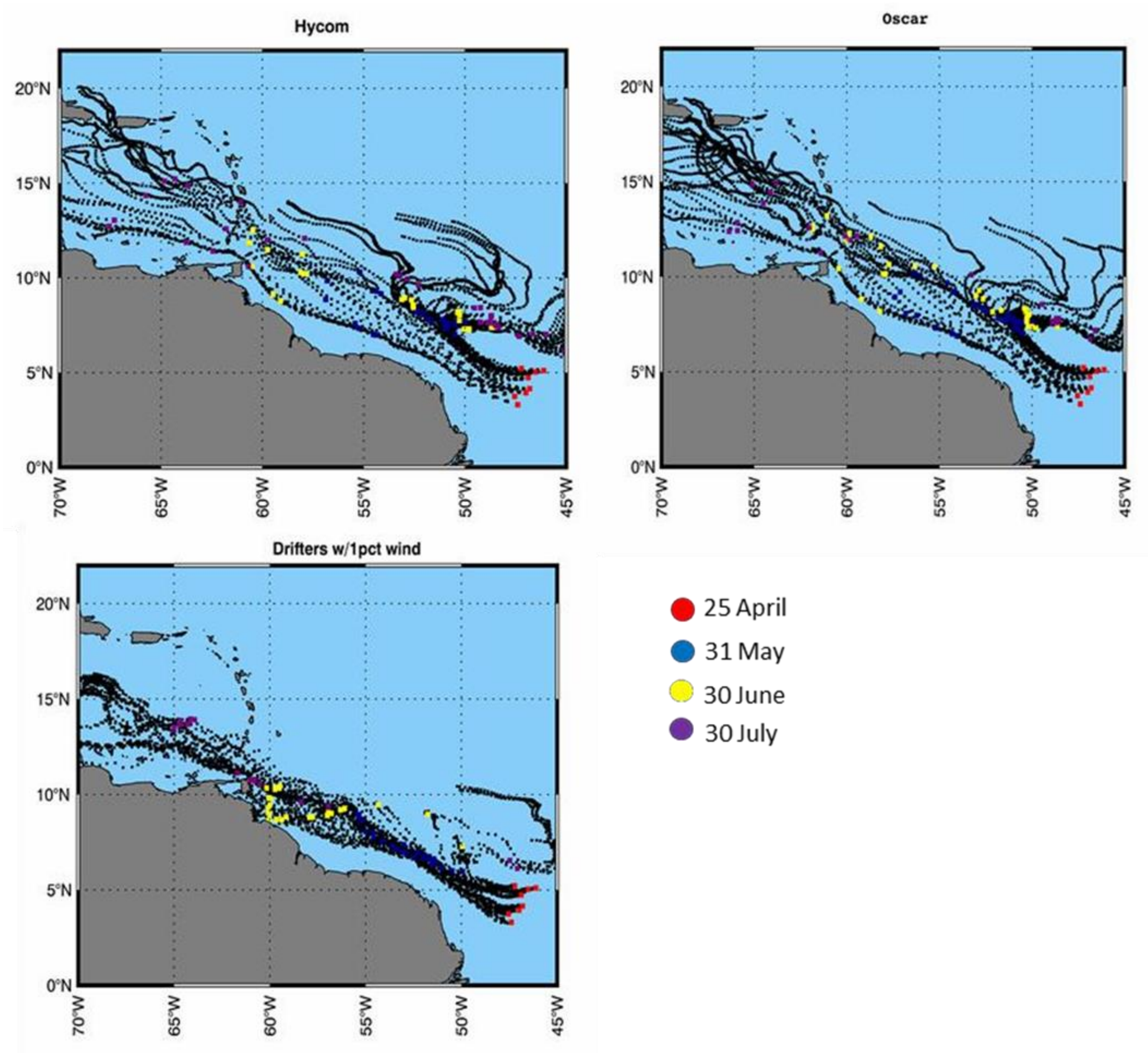

Figure 3. Comparison of forward tracks for selected sargassum pixels using the Hycom, Drifters, and Oscar ocean current models. Coloured dots indicate positions of a few selected pixels each month. Starting positions on 25 April 2018 are shown by red dots.

Hycom and Oscar models indicate that sargassum would cover much of the Lesser Antilles island chain, compared with the Drifter model which suggests a more restricted area of impact with coverage being restricted to the southern-most islands.

Quantifying the sargassum arrival (uncalibrated sargassum threat) at the 60°W meridian for each of the models gave a clear comparison among them and indicated that prediction could be improved by considering different segments of the meridian line separately to better reflect the current fields experienced by islands in the chain. An example of the quantification of sargassum arrivals predicted by the three models is shown in Figure 4 for the northern and southern segments separately. In this

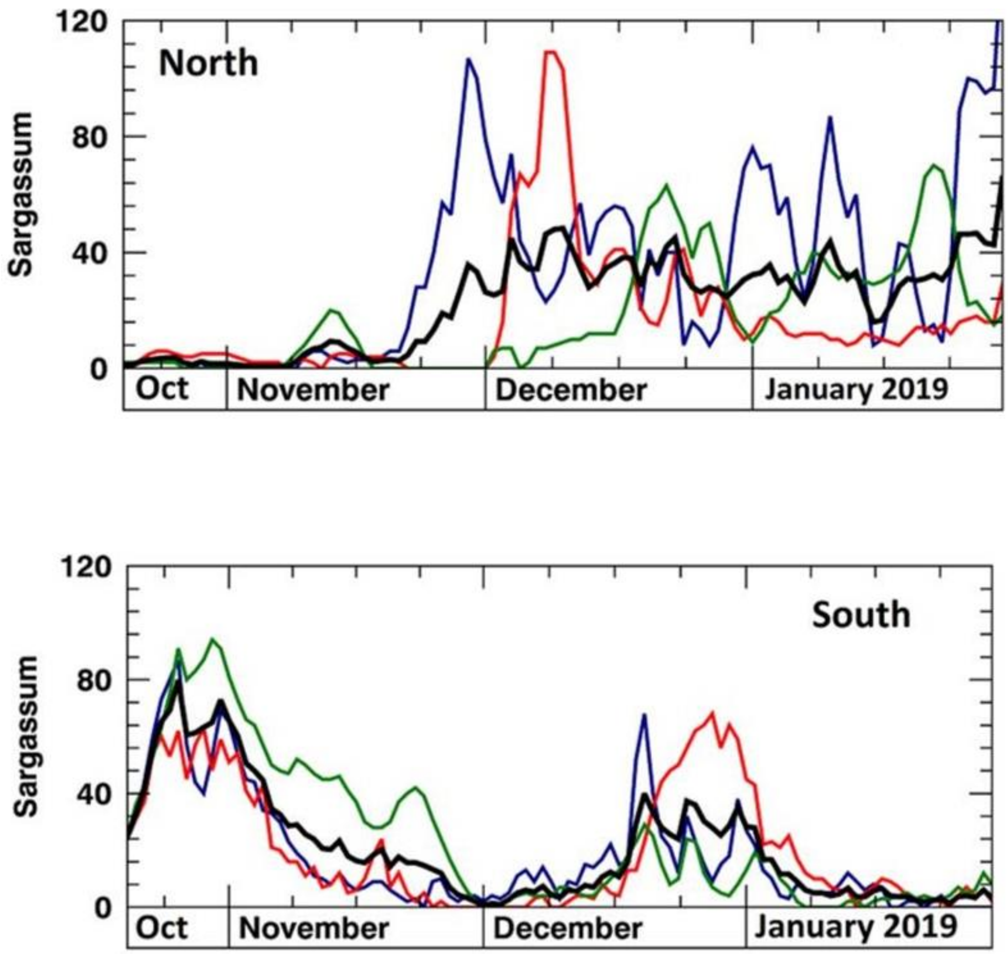

Figure 4. Comparison of predicted sargassum arrivals by the different ocean current models for the northern segment (top) and southern segment (bottom) of the 60°W meridian. Starting points were selected on 7-day composite image of 20-26 October 2018. Blue line uses drifter currents, red line uses Hycom currents and green line uses Oscar currents. Black line is the average of the three data sets. North and south Line segments of meridian shown in Figure 2.

example, there was good corroboration of the three models for the southern section, which all indicated a threat of sargassum arrivals occurring in two peak periods: October through the beginning of

November; and end of December. In the northern segment, the threat of sargassum arrivals was quite different from the southern segment. Although the models were less consistent with each other, all were in general agreement and showed a moderate threat beginning at the end of November and continuing through January 2019, when the threat appears to increase sharply (Figure 4). Comparison of threats generated by the drifter, Hycom and Oscar climatologies were not highly consistent in the north section but good in the south section.

Predictive model accuracy

Composite imagery of *Sargassum* in the western topical Atlantic was made available (http://optics.marine.usf.edu) beginning in March of 2018. By November of 2018 enough composites at 7-day intervals were collected to create time series of *Sargassum* in the three regions (South, Middle and North) fronting the Lesser Antilles. These time series consisted of the number of sargassum pixels from the composite imagery observed in boxes (Figure 5) defining the three regions. Climatological currents from the two models (Hycom and Oscar) and the satellite tracked drifters were then used to forward track for 92 days from points in the imagery in the west Atlantic. Arrival of tracked points in three boxes was then compared to the time series in the boxes from the imagery (Figure 6) and an assessment of predictive skill made.

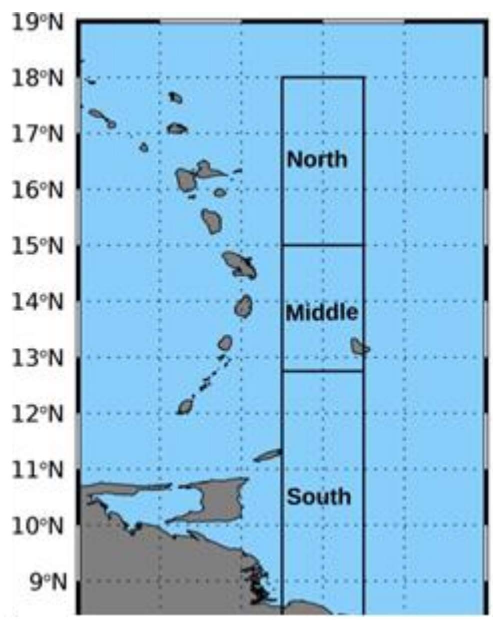

Figure 5. Map of the prediction area showing the Lesser Antilles island chain and the bounding boxes for assessing threat level.

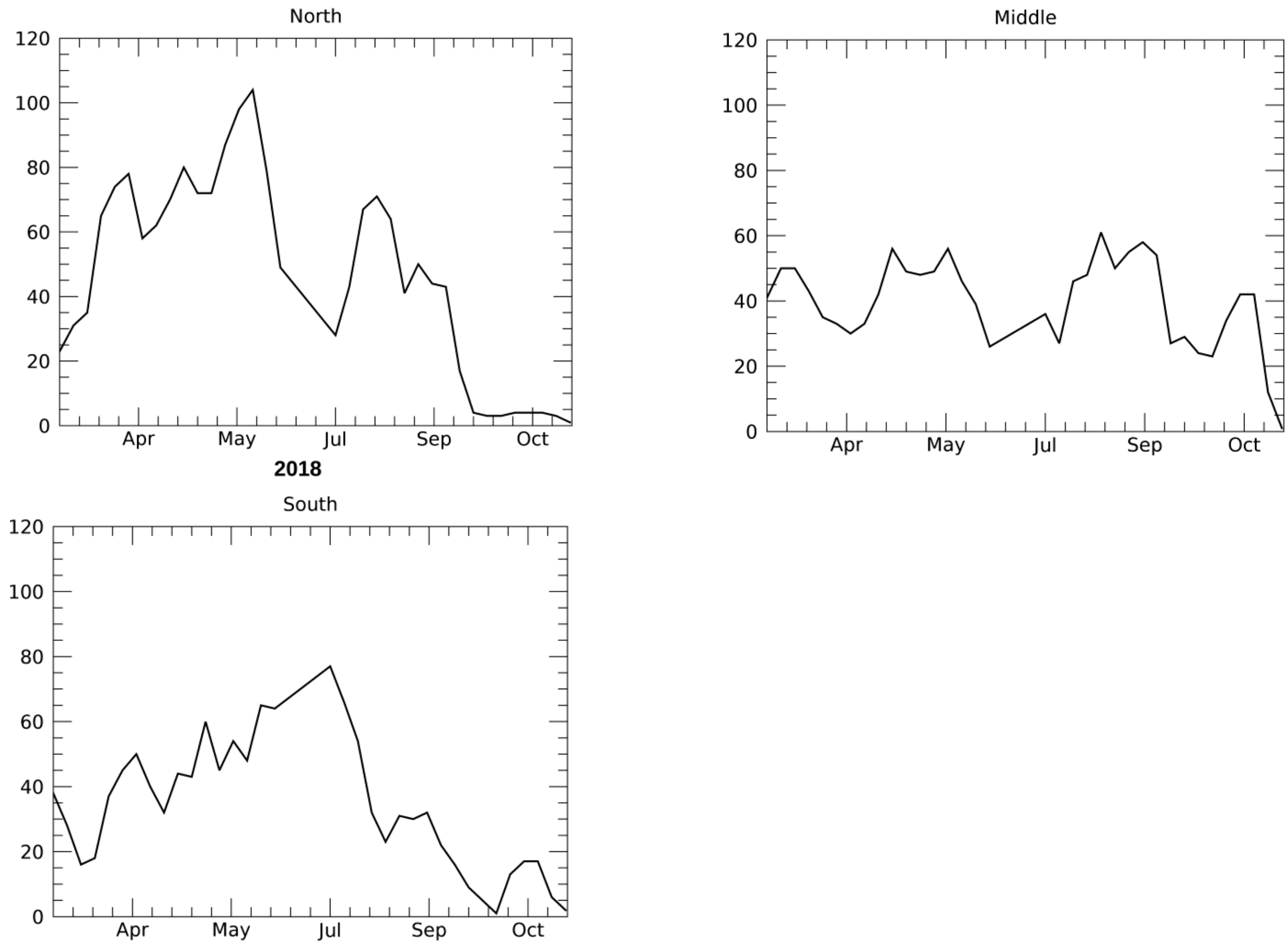

Figure 6. Time series of Sargassum pixels in boxes from March to November 2018. 3-pt Tukey filter applied to reduce sampling error.

Using the three current fields (Hycom, Oscar and drifters), forward tracking was done to reproduce the time series in Figure 6. A skill level was estimated in the following manner:

Skill =1.-P

Where P=∑(n-n')/∑n

n=actual number in each box and n' is predicted number

All tests ran with skill levels between 0.38 and 0.45. A level of 0.40 means that for 100 points in the box, prediction will likely be between 40 and 160.

There are two general conclusions that can be made about the validity of prediction attempt as outlined here:

1. Skill is relatively weak.

2. There is little difference in results among the models used.

These two conclusions are likely related and the result of insufficient sargassum identification in the composite images. Clouds are one of the main sources of difficulties with the images; a second is insufficient resolution for identifying smaller patches. This problem affects both the starting points and the arrival boxes.

Best fit model

Although our prediction capability is not as high as hoped, and the predicted location is not as precise as hoped, it is still sufficient to provide a measure of warning that a threat is coming in the following 3 months. The threat level, however, is a relative measure that can only be evaluated over time. To evaluate what the threat level means relative to prior experience, a time series over the same 92 days was taken from previous years of composite imagery.

In the present, best prediction, a run was made on 31 March 2019 from a composite image of that date. Results of that run are shown in Figure 7 for the three boxes. Along with the prediction, the time series covering the same period (April-June 2018) is presented. This provides a measure of how the past year compares to the present year.

The prediction was made using the average of Hycom, Oscar with 1% wind and drifters with 1% wind.

Discussion

Efforts at prediction of sargassum arrival in the Lesser Antilles on seasonal scales has three main purposes. It provides notice to fishers and processors/vendors that adjustments need to be made because of coming threats, it provides a mechanism (validated tracking techniques) to determine the regions of sargassum bloom and its path to the fishery, and it informs management initiatives being made by fisheries authorities.

Since Hycom only forecasts for 7 days (https://optics.marine.usf.edu/projects/SaWS.html), either climatologies or currents from previous years must be employed for tracking on seasonal scales. A study using Hycom currents from years prior to the forecast years (Johnson et al. 2017) gave results that were highly scattered. In this study we have used climatologies from three different current data sets, a finite difference model, a diagnostic model and observations, together with composite images of the Alternative Floating Algae Index to provide a threat level. Future work will involve using the images to determine success of tracking using various current data sets and to validate the process.

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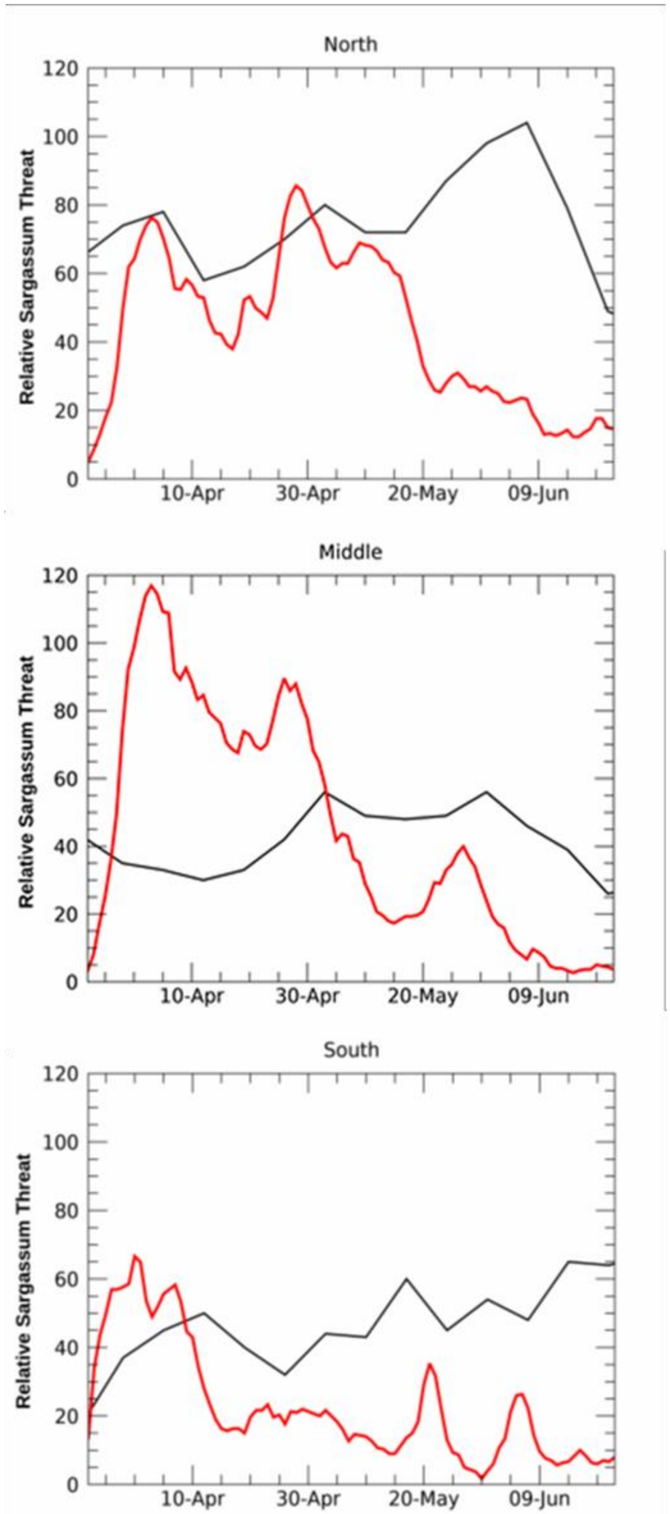

Figure 7. Predicted sargassum arrivals (red line) for April - June 2019 to date for the north, middle and south boxes of the 60°W meridian (shown in Figure 5). Starting points were selected on 7-day composite image of 22-28 March 2019. The threat level is compared to the coverage of sargassum detected in the north, middle and south boxes (shown in Figure 6 for the same 92-day period in 2018 (black line).

Since Hycom only forecasts for 7 days (https://optics.marine.usf.edu/projects/SaWS.html), either climatologies or currents from previous years must be employed for tracking on seasonal scales. A study using Hycom currents from years prior to the forecast years (Johnson et al. 2017) gave results that were highly scattered. In this study we have used climatologies from three different current data sets, a finite difference model, a diagnostic model and observations, together with composite images of the Alternative Floating Algae Index to provide a threat level. Future work will involve using the images to determine success of tracking using various current data sets and to validate the process.

The accuracy of model tracking over a 3-month period and difficulties with identifying all sargassum in satellite images make tracking to specific islands very problematic. Instead, regional predictions were made based on known current patterns which tend to group into three sets, a southern, middle and northern flow through the Lesser Antilles and into the Caribbean. Each of the three regions showed significant differences over nearly a year of prediction and validation suggesting different source regions at different times of the year for different regions.

Success in prediction can be considered weak. At this stage, we can predict significant threats for regions of the Lesser Antilles and compare it to previous years' threat level. Future work must involve evaluation and quantification of threat level. We also need to determine the impact of adding wind to the models for model improvement.

References

Chérubin LM and PL Richardson. 2007. Caribbean current variability and the influence of the Amazon and Orinoco fresh water plumes. Deep-Sea Research Part I. 54:1451–1473.

Franks, J.S., D.R. Johnson and D.-S. Ko. 2016. Pelagic *Sargassum* in the Tropical North Atlantic. Gulf and Caribbean Research 27 (1): SC6-SC11.

Gower, J. E. Young and S. King. 2013. Satellite images suggest a new *Sargassum* source region in 2011. Remote Sensing Letters, 4: 764-773.

Johnson, D. R, D.-S. Ko, J. S. Franks, P. Moreno and G. Sanchez-Rubio. 2013. The *Sargassum* invasion of the Eastern Caribbean and dynamics of the equatorial North Atlantic. Proceedings of the 65th Gulf and Caribbean Fisheries Institute, 102-103.

Johnson, D.R., J. S. Franks, J.-P. Marechal and C. Hu. 2017. Pelagic *Sargassum* in the North Tropical Atlantic: Efforts at predicting coastal invasions. Proceedings of the 69th Gulf and Caribbean Fisheries Institute, 207-211.

Johnson, D R. and J.S. Franks. 2018. Pelagic Sargassum in the North Tropical Atlantic: Mortality, growth and seasonal prediction. Proceedings of the 70th Gulf and Caribbean Fisheries Institute (in press).

Lumpkin, R., S.A. Grodsky, L. Centurioni, M.-H. Rio, J.A. Carton and D. Lee. 2013. Removing spurious low-frequency variability in drifter velocities. Journal of Atmospheric and Oceanic Technology 30: 353-360.

Wang, M., and C. Hu. 2016. Mapping and quantifying Sargassum distribution and coverage in the Central West Atlantic using MODIS observations. Remote Sensing of the Environment 183: 356-367.