An Integrated Observing Effort for *Sargassum* Monitoring and Warning in the Caribbean Sea, Tropical Atlantic, and Gulf of Mexico

By Joaquin Triñanes, Chuanmin Hu, Nathan F. Putman, Maria J. Olascoaga, Francisco J. Beron-Vera, Shuai Zhang, and Gustavo J. Goni

The floating, golden-brown algae, pelagic *Sargassum*, plays an important role in the marine ecosystem of the North Atlantic, and depending on its extension and impact, has the potential to be considered a pollutant. In the open sea, it provides a habitat to numerous fish and other species and represents a highly productive ecosystem in an otherwise low-nutrient environment. However, following an apparent regime shift in 2011, large amounts of *Sargassum* have entered the Caribbean Sea, mostly from the tropical Atlantic, washing ashore in massive amounts (Figure 1). These seasonal events have negatively affected the economies of the region's island nations, which are largely driven by tourism and, to a lesser extent, fishing. The vast amounts of *Sargassum* may also cause problems for human health (e.g., arsenic concentration), marine navigation, and coastal ecosystems. Monitoring inundation events relies on a combination of in situ and remote-sensing data that have been specifically designed to detect *Sargassum* and are used to inform numerical models that help predict the extent, amount, and movement of these algae. Interoperable tools for data distribution, information management, and visualization are critical to ensure data, and results from monitoring and predictions, are readily accessible. Such a framework would benefit essential economic, social, and environmental domains and would define the baseline needed to coordinate future science-driven monitoring and evaluation efforts, including contributions toward eventual sustainable commercial exploitation/reuse of *Sargassum*.

The complicated dynamics of *Sargassum* render routine monitoring using ships to collect in situ observations at the scale of the North Atlantic, or even the Caribbean Sea, far from practical. In contrast, satellite sensors can simultaneously observe *Sargassum* across wide swaths of ocean. Detection of pelagic *Sargassum* by satellite sensors usually relies on the measurement of red-edge reflectance using bands in the red and near-infrared. Pioneering research by James Gower and Chuanmin Hu led to the development of indices, such as the Maximum Chlorophyll Index (MCI) and the Alternative Floating Algae Index (AFAI), for detecting *Sargassum* (Figure 2). Similar products (e.g., using the Sentinel-2 Multispectral Instrument) are being developed to improve the coverage in coastal areas, where higher-resolution data are needed to monitor *Sargassum*). Several monitoring efforts are assessing the abundance of *Sargassum* in the open ocean and in coastal areas (Hu et al., 2016; Triñanes et al., 2021). Open and unrestricted access to near-real-time and historical MCI/AFAI data are provided by the University of South Florida's *Sargassum* Watch System and the National Oceanic and Atmospheric

FIGURE 1. Severe coastal inundation of *Sargassum* is shown in Belize in August 2018. Such events usually have important consequences for the local economy, public health, and the coastal ecosystem. *Photo credit: hat3m from Pixabay*

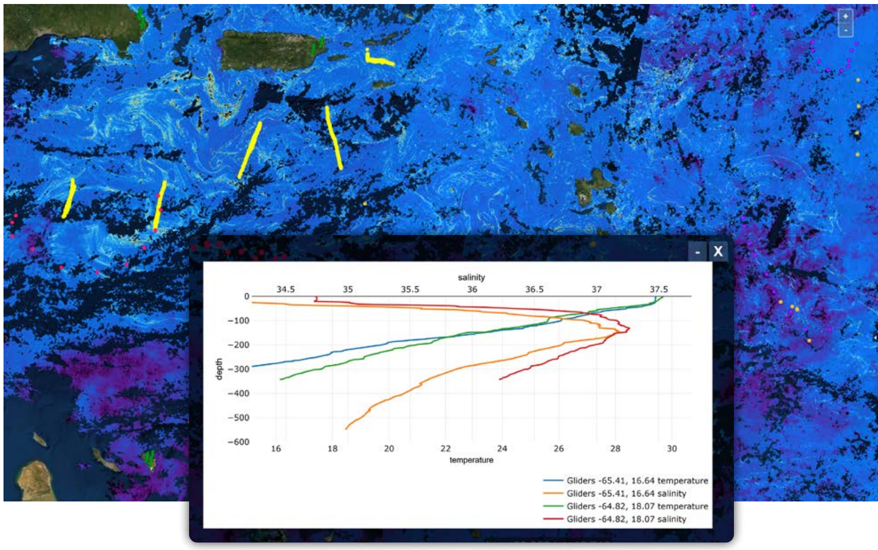

FIGURE 2. Satellite image of *Sargassum* lines in the eastern Caribbean region, as observed by satellite data from Sentinel-3 OLCI between August 31 and September 1, 2021. Color-coded locations of Argo (orange), drifter (magenta), and glider (yellow) measurements are indicated, and in situ *Sargassum* (green) observations are superimposed. The inset displays temperature and salinity profiles from in situ platforms are interactive online. The map was created using OceanViewer (https://cwcgom.aoml.noaa.gov).

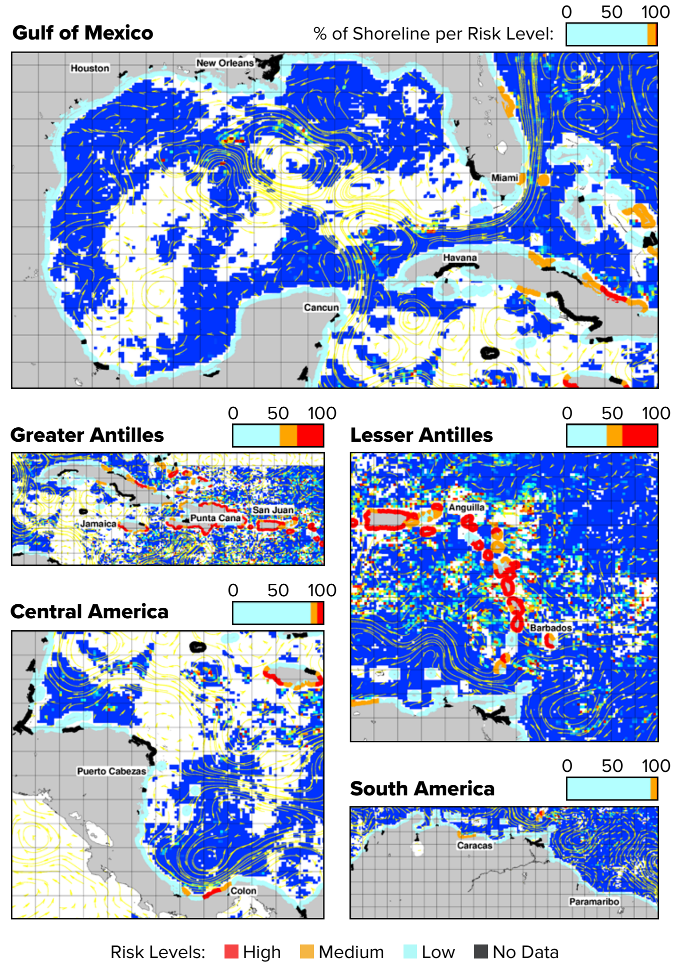

FIGURE 3. *Sargassum* Inundation Report (SIR) for August 31–September 6, 2021. The SIR classifies the risk of *Sargassum* inundation into three categories: low (blue), medium (orange), and high (red). Black indicates areas without enough data. SIR is the result of the collaboration between the NOAA/AOML, NOAA/CoastWatch/OceanWatch, and the University of South Florida.

Administration (NOAA) Atlantic OceanWatch. These data contribute to summaries designed to inform regional stakeholders and include the broad-scale monthly *Sargassum* Outlook Bulletin and a higher-resolution weekly coastal *Sargassum* Inundation Report (SIR) (Figure 3).

The validation of *Sargassum* satellite products benefits greatly from the integration of in situ data over the regions of interest. NOAA maintains a database that collects digital photos and written descriptions of *Sargassum* from several repositories, including citizen science projects organized by NOAA, Epicollect5, and SPAW/USF. Additionally, in situ research is being conducted by NOAA's Atlantic Oceanographic and Meteorological Laboratory to better predict how objects like *Sargassum* move at the ocean surface. GPS tracking devices have been affixed to *Sargassum* mats and to drifters of various shapes, sizes, and buoyancies (some of which were designed to mimic small patches of pelagic *Sargassum*), and their tracks have then been examined relative to ocean conditions (Miron et al., 2020). Analyses indicate that combining information on surface currents, winds, and the physical properties of the objects (*Sargassum* rafts) improve predictions of *Sargassum* movement and thus can contribute toward the development of forecast risk models.

The popularity and adoption of technologies, architectures, and processes linked to big data, cloud computing, machine learning, business intelligence, data integration, and service-oriented architectures (SOAs) represent an opportunity for the design and implementation of a *Sargassum* Information Hub. The increasing availability of data (structured, semi-structured, and non-structured), the user and system requirements (in terms of, e.g., security, cost, data quality, data performance, data analytics, visualization, usability), the variety of technologies, and the data integration processes must be assessed and managed to ensure they align with user goals and strategies. Under the current scheme, most of the *Sargassum* products are available through interoperable middleware, such as ERDDAP and THREDDS Data Server. Machine learning algorithms are being increasingly applied to create a new generation of products that use heterogeneous and multimodal data (e.g., satellite fields at different resolutions, vector and raster inputs). For visualization purposes, online mapping applications (e.g., OceanViewer) provide multipurpose, scalable, and easily accessible platforms for displaying and analyzing spatial data. The goal is to integrate data from multiple sources (including models) and use SOA-based Spatial Data Infrastructure to provide services to all stakeholders across government, academia, industry, and civil society. A pilot project led by IOCARIBE (a sub-commission of UNESCO's Intergovernmental Oceanographic Commission), the Association of Caribbean States, NOAA, GEO Blue Planet, and other partners from government agencies, intergovernmental initiatives, and academia, is underway to lay the foundation for monitoring *Sargassum* with the goal of enhancing the response to *Sargassum* influxes by developing an early warning system and improving forecasting.

REFERENCES

Hu, C., B. Murch, B.B. Barnes, M. Wang, J.-P. Marechal, J. Franks, D. Johnson, B. Lapointe, D.S. Goodwin, J.M. Schell, and A.N.S. Siuda. 2016. *Sargassum* watch warns of incoming seaweed. *Eos* 97(22):10–15, https://doi.org/10.1029/2016EO058355.

Miron, P., M.J. Olascoaga, F.J. Beron-Vera, N.F. Putman, J. Triñanes, R. Lumpkin, and G.J. Goni. 2020. Clustering of marine-debris- and *Sargassum*-like drifters explained by inertial particle dynamics. *Geophysical Research Letters* 47:e2020GL089874, https://doi.org/10.1029/2020GL089874.

Triñanes, J., N. Putman., G. Goñi, C. Hu, and M. Wang. 2021. Monitoring pelagic *Sargassum* inundation potential for coastal communities. *Journal of Operational Oceanography*, https://doi.org/10.1080/1755876X.2021.1902682.

ARTICLE DOI: https://doi.org/10.5670/oceanog.2021.supplement.02-26

AUTHORS

Joaquin Triñanes (joaquin.trinanes@noaa.gov), Department of Electronics and Computer Science, Universidade de Santiago de Compostela, Spain; NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML), USA; and Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine and Atmospheric Science (RSMAS), University of Miami, USA. **Chuanmin Hu**, College of Marine Science, University of South Florida (USF), USA. **Nathan F. Putman**, LGL Ecological Research Associates Inc., USA. **Maria J. Olascoaga**, Department of Ocean Sciences, RSMAS, University of Miami, USA. **Francisco J. Beron-Vera**, Department of Atmospheric Sciences, RSMAS, University of Miami, USA. **Shuai Zhang**, College of Marine Science, USF, USA. **Gustavo J. Goni**, NOAA/AOML, USA.

ARTICLE CITATION

Triñanes, J., C. Hu, N.F. Putman, M.J. Olascoaga, F.J. Beron-Vera, S. Zhang, and G.J. Goni. 2021. An integrated observing effort for *Sargassum* monitoring and warning in the Caribbean Sea, tropical Atlantic, and Gulf of Mexico. Pp. 68–69 in *Frontiers in Ocean Observing: Documenting Ecosystems, Understanding Environmental Changes, Forecasting Hazards.* E.S. Kappel, S.K. Juniper, S. Seeyave, E. Smith, and M. Visbeck, eds, A Supplement to *Oceanography* 34(4), https://doi.org/10.5670/oceanog.2021.supplement.02-26.