

Article

Dispersion Modeling to Characterize Air Pollution Exposure from *Sargassum* in Martinique

Brian Naess ^{1,*} , Vlad Isakov ¹  and Mathilde Teyssier ²

¹ Institute for the Environment, University of North Carolina at Chapel Hill, 123 W. Franklin St., Suite 330B, CB 1105, Chapel Hill, NC 27516, USA; visakov@unc.edu

² Impact Mer, 20 Rue Karukera—Cluny, Martinique FWI, 97200 Fort-de-France, France; mteyssier@impact-mer.fr

* Correspondence: naess@unc.edu; Tel.: +1-(919)-943-6110

Abstract

The massive influx and subsequent anaerobic decomposition of pelagic *Sargassum* on Caribbean coasts release toxic gases, including hydrogen sulfide (H₂S), and pose a real public health hazard, as evidenced by thousands of reported acute exposure cases in Martinique in 2018. To effectively characterize exposure and identify at-risk areas, we utilized the interactive web-based dispersion modeling system C-PORT, representing *Sargassum* accumulation zones as area sources derived from recent aerial and in situ monitoring data. Inverse modeling, comparing C-PORT output against Madinair observation data from 2024 to 2025, established emission flux rates ranging from 0.45 to 3.58 mg/m² per second for H₂S, depending on *Sargassum* density. The resulting modeled concentrations exhibit a low average fractional bias (approx. 0.04) when compared to observations. This study demonstrates that C-PORT can be used to estimate spatially resolved concentrations for H₂S, generate health-risk maps for H₂S, evaluate options to mitigate exposure from varying *Sargassum* intensity levels, and serve as a crucial tool for public health agencies across vulnerable coastal regions.

Keywords: air quality; *Sargassum*; Caribbean; hydrogen sulfide; exposure; dispersion modeling; ammonia

1. Introduction

Areal coverage of free-floating pelagic *Sargassum* species (*Sargassum natans* and *Sargassum fluitans*) across the tropical Atlantic Ocean has increased alarmingly since 2011 compared to 2000–2009 [1]. Previously confined primarily to the North Atlantic in an area known as the Sargasso Sea, *Sargassum* was transported to the tropical Atlantic where seasonal blooms now form an extensive region stretching from the east coast of Brazil to the west coast of Africa, known as the Great Atlantic Sargassum Belt (GASB) [2]. Driven by easterly trade winds, *Sargassum* accumulates in rafts along the Inter-Tropical Convergence Zone (ITCZ) [3], particularly in the spring and summer months, and subsequently inundates coastlines throughout the Caribbean, the Yucatan peninsula, and West Africa. Fed primarily by upwelling phosphorus and nitrogen-fixing cyanobacteria [4] and thriving in warm water, it is reasonable to assume that *Sargassum* influxes will be an important issue for the foreseeable future [5], though the growth of certain *Sargassum* morphotypes may be limited by higher sea surface temperatures [6–8].

Sargassum rafts are important ecologically, serving as habitat and nursery areas for fish, sea turtles, and marine invertebrates and are designated as an Essential Fish Habitat



Academic Editors: Elisabete Carolino and Liliana Aranha Caetano

Received: 15 January 2026

Revised: 17 February 2026

Accepted: 19 February 2026

Published: 28 February 2026

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in the U.S. South Atlantic and Gulf of Mexico [9], but *Sargassum* inundation events (SIEs) can have profoundly negative effects on tourism, fisheries, coastal ecosystems, and human health [10,11]. *Sargassum* thrives in pelagic conditions characterized by winds, waves, and water movement but quickly begins to decompose when washed ashore or in the more stagnant conditions typical of the nearshore environment around Caribbean islands, where numerous cays, coves, and mangrove areas receive an influx of *Sargassum* without a hydrodynamic mechanism for dispersing the accumulated macroalgal biomass. *Sargassum* typically begins to decompose after 48 h, and the decomposition process releases hydrogen sulfide (H_2S) and, potentially, ammonia (NH_3) gases [12]. When *Sargassum* mats accumulate on shorelines or in nearshore waters, beaches can become undesirable due to foul odors from H_2S , and swimming areas can become inaccessible, impacting the tourism industry, one of the region's most important economic drivers. *Sargassum* blooms can entangle boat propellers and fishing gear, and the decomposition process can lead to anoxic conditions in nearshore waters, potentially leading to fish kills, coral bleaching, and impacts on seagrass beds [11,13]. Of particular concern to coastal residents and visitors alike is the potential acute exposure to high H_2S concentrations during the summer months when SIEs are most common. In 2018, more than 3300 cases in Guadeloupe and over 8000 cases in Martinique related to H_2S exposure were reported by doctors [12], and the recurring nature of SIEs suggests that some patients may suffer from chronic exposure. A 2021 study by Resiere et al. explored the health issues stemming from the 2018 SIEs on Martinique and found a wide range of health complaints including neurological, digestive, and respiratory disorders, among others, correlated with the patients' geographical origins. Furthermore, they found that patients living near areas with recurring stranded and stagnant *Sargassum* could be exposed to H_2S levels above 5 ppm for 50 days annually [14].

Given the associations between *Sargassum* and H_2S levels, several studies have examined H_2S emissions from the decomposition process. An in situ study conducted on the Yucatan peninsula in Mexico used low-cost sensors (SENKO SGT-P industrial safety monitor with a limit of detection of 0.1–100 ppm, 0.1 ppm resolution) to measure H_2S emissions from the decomposition of *Sargassum* on beaches [15,16]. They found H_2S concentrations often exceeded 5 ppm beneath beached piles of *Sargassum*, but that H_2S concentrations were much lower at 1.5 m above the piles and dropped off quickly with distance to below 0.1 ppm 30 m away from the pile. Researchers in Brazil collected a total of 20 kg of *Sargassum* from a beach in Brazil along with 6 L of seawater for “hydrating the *Sargassum*” and built a “continuous flow chamber” to measure the emissions of H_2S , methane, carbon monoxide (CO), and oxygen from three different masses of *Sargassum* (4, 6, and 10 kg) using AKSO[®], SP2nd- NH_3 and MULTIGAS PRO gas sensors [17]. They found that H_2S emissions typically did not climb for several days and estimated an average daily emission rate of 192 g/h/m², and they did not detect NH_3 [17]. Kwak et al. used chamber-based experiments with “high-sensitivity analytical instrumentation” to calculate “emission factors for total sulfur, hydrogen sulfide, and sulfur dioxide” from the decomposition of *Sargassum* [18]. They collected *Sargassum* and seawater from shoreline areas in Key Biscayne, FL during summer (April–July) and winter (November–January) to evaluate the emissions from *Sargassum* for summer/winter and with and without the presence of seawater. They noted a distinct difference between summer and winter *Sargassum*, but they did not taxonomically identify the *Sargassum* species [18], and the difference in color could have been due to varying levels of decay when collected. They estimated emission rates for H_2S to range from 251 to 543 $\mu\text{g/kg-day}$ for summer *Sargassum*, with higher emissions from *Sargassum* with seawater. Winter *Sargassum* emissions were also higher in the presence of seawater, but they only ranged from 20 to 20.8 $\mu\text{g/kg-day}$.

Situated in the eastern Caribbean Sea, the island of Martinique is geographically positioned to experience frequent SIEs [19]. Martinique has an irregular coastline with both exposed areas and sheltered areas containing a mix of beaches, mangrove areas, and developed areas. Starting in 2011 and expanding in 2015, Martinique's Madininair, an air-quality-monitoring association, began installing Cairnet H₂S and NH₃ sensors from ENVEA on the eastern and southern coasts, and they provide web-based access to daily average concentration data at over 15 different sites on Martinique [20]. The Cairnet networkable air-monitoring station includes H₂S Cairsens microsenors with a limit of detection of 0.01–20 ppm, 0.001 ppm resolution and NH₃ Cairsens microsenors with a limit of detection of 0.5–25 ppm, 0.001 ppm resolution [21]. Data show a large number of days above 1 ppm at seven monitor locations (142 days at Baie Cayol, 90 days at Pontalery Nord, 112 days at Four a Chaux, 63 days at Pointe Hyacinthe, 67 days at Chateau Paille, 51 days at Pointe Faula, and two days at Anse Cafard) between 1 November 2024 and 31 October 2025 [20]. Madininair is also a key member of SARG'COOP, a cooperative program to combat *Sargassum*, and they are actively helping to install monitoring networks on other islands [22].

While sensor data is a fantastic resource for quantifying air quality conditions at a specific location, funding constraints and other technical limitations prevent the installation of sensors at a sufficient resolution to comprehensively assess the ambient air quality. Dispersion air quality models that can predict how pollutants like H₂S move through the lower atmosphere are well-suited for local-scale studies and can be used to characterize air pollution in areas with sparse monitoring. Community Air Quality Tools (C-TOOLS) [23] is a collection of web-based dispersion models for interactive scenario analysis that uses custom meteorology inputs and spatially defined emission sources to calculate pollutant concentrations at regularly spaced receptor locations in a user-defined domain. C-TOOLS allows the user to calculate annual average concentrations or short-term concentrations based on representative hourly conditions at one of four time periods: morning, mid-day, evening, and off-peak. The Community model for near-PORT applications (C-PORT), a research-grade member of C-TOOLS initially designed to model air quality issues associated with seaport operations, allows for the modeling of point, line, and area sources [24,25]. Given that *Sargassum* tends to aggregate in large clusters when floating or when stranded upon a beach, the emissions from *Sargassum* can be considered area sources.

Numerous clinically focused studies have shown strong connections between *Sargassum*, H₂S exposure, and acute and chronic health conditions [12,14,26], and several studies have calculated emission rates for H₂S from decaying *Sargassum* [15,17,18]. However, there has been little research to demonstrate how emissions from decaying *Sargassum* can be modeled using a dispersion model to assess island-scale air quality. Using an inverse modeling approach with observation data from November 2024 to October 2025, this study provides estimates of H₂S and NH₃ emissions from *Sargassum* polygon area sources and the resulting H₂S and NH₃ concentrations to demonstrate how a web-based dispersion model can predict H₂S and NH₃ air pollution at three different sub-domains on Martinique from varying levels of *Sargassum* accumulation during SIEs. These concentration maps provide more complete geographic resolution of potentially hazardous H₂S exposure at any location at risk of future SIEs than the existing monitoring network.

2. Materials and Methods

2.1. Modeling Approach

One of the primary goals of this study was to demonstrate that H₂S air pollution from the decomposition of *Sargassum* could be modeled using the functionality built into C-PORT. C-PORT provides 24 ready-to-use seaport domains throughout the continental

United States, but it is possible to use C-PORT to model air pollution anywhere in the world if the user can provide polygon-based shapes to represent emission sources, meteorological data, and emissions magnitudes for those sources. C-PORT also allows for scenario analysis through a comparison of two model runs. Users have the option to compare model runs with the same pollutant in the same domain by allowing the user to choose the “base” model run and the “new” model run. C-PORT then calculates the difference in concentrations by subtracting the “base” values from the “new” values. C-PORT is currently limited to eleven pollutants typically associated with traffic-based pollution studies, like nitrogen oxides (NO_x), carbon monoxide (CO), sulfur dioxide (SO₂), and fine particulate matter (PM_{2.5}). However, in a dispersion model like C-PORT, there are no photochemical reactions, and the dispersion mechanisms are the same no matter the pollutant, so it is possible to model an inert pollutant like CO as a proxy for H₂S or NH₃ using C-PORT and then use unit conversions to calculate the appropriate concentrations. For this study, we conducted all C-PORT modeling using CO and then converted the C-PORT output concentrations from CO in parts per million (ppm) to H₂S and NH₃ using the following scaling factors: 1.39/1.15 for H₂S and 0.70/1.15 for NH₃ based on CDC NIOSH conversion factors for H₂S (1 ppm = 1.39 mg/m³ using molecular weight (MW) of 34.08 g/mol at 25 °C and 1 atmosphere), NH₃ (1 ppm = 0.70 mg/m³ using MW = 17.03 g/mol), and CO (1 ppm = 1.15 mg/m³ using MW = 28.01 g/mol) [27]. For this study, receptor concentrations were clipped by the island boundary to limit the results to land-based receptors.

2.2. Sargassum Shapes

Many approaches have been used to identify and classify *Sargassum* clusters in coastal areas, including those based on satellite data [28,29] and aerial photos [13,30], community-based photos [31] and in situ data collection [32], and approaches that blend imagery with machine learning [33]. Given the availability of sensor data and the abundance of published evidence connecting SIEs with negative health outcomes in Martinique [26,34], this study relied on shapefiles developed by Teyssier et al. [13]. Teyssier used aerial monitoring from twenty different days between 22 May 2022 and 29 December 2023 to create polygon shapes representing *Sargassum* on the eastern and southern coastlines of Martinique. Shapes distinguished between *Sargassum* that had washed ashore (stranded), *Sargassum* stuck in the water column (stagnant), or leachates and particulate organic matter in the water column (brown water). Furthermore, Teyssier estimated *Sargassum* density and derived a pressure indicator based on the areal extent and density of *Sargassum* over the domain. Figure 1, which is a reproduction with permission from the authors of Teyssier et al. [13], provides context for how Teyssier classified density. The left panel A shows zoomed-in examples, while the right panel B shows examples at the bay scale. In this study, density was used to scale the emission rate.

Due to data availability constraints, Madinair sensor data for the 2022–2023 time-frame were not publicly available or made available to us upon request, ruling out a temporally matched comparison of C-PORT modeled concentrations with sensor observations. Instead, the shapes developed by Teyssier et al. [13] for stranded and stagnant *Sargassum* from 20 shapefiles from the 20 aerial surveys were combined into a single non-temporal dataset using GIS software [35,36] to identify overlapping shapes. The number of overlaps were then counted, and a likelihood score was assigned based on the number of times the shapes overlapped (Table 1). The more often *Sargassum* rafts were mapped to the same spatial area, the more overlaps occurred, and the more likely it was to find *Sargassum* in that place during SIEs. The overlapping shapes were dissolved on the likelihood score, and shapes with an area less than 19 m² were removed, since these were the smallest shapes in the original dataset from Teyssier et al. [13].

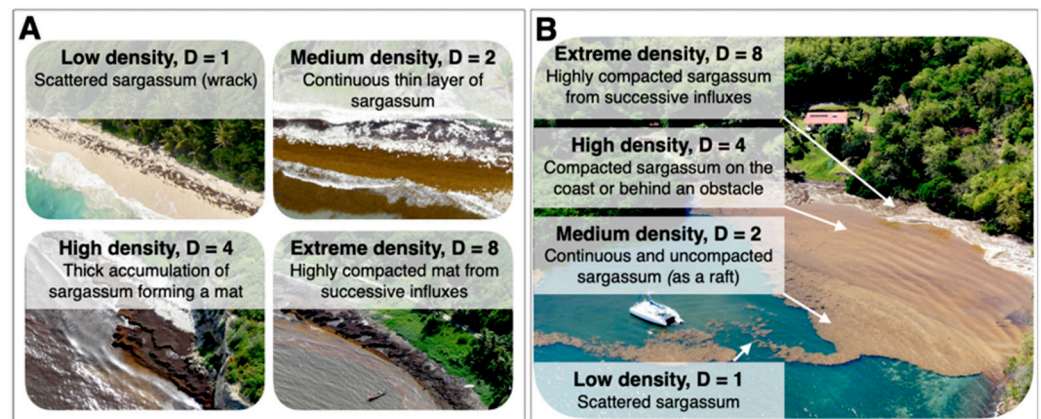


Figure 1. Examples of *Sargassum* with density values (A) zoomed-in and (B) at the bay scale from Teyssier et al. [13] (reproduced with permission from the author).

Table 1. Methodology for determining likelihood score.

Likelihood Category	Likelihood Score	Overlap Range
Unlikely	1	0–3
Likely	2	3–7
Typical	3	8–14
Certain	4	15–20

Finally, the dissolved, overlapping shapes were rejoined to the non-temporal dataset to get a median density for each shape. This geoprocessing resulted in a temporally independent dataset that represents *Sargassum* as polygon shapes with fields representing *Sargassum* type (stranded versus stagnant), likelihood score, and density (ranging from 1 to 8) with a calculated area. Figure A1 depicts the *Sargassum* polygons in the Le Robert area.

2.3. Meteorological Data

As a research screening model, C-PORT includes pre-loaded meteorological inputs to allow the user to conduct online model simulations for selected meteorological conditions—Stable, Slightly Stable, Neutral, Slightly Convective, and Convective—and for each season (winter and summer). The pre-loaded meteorological inputs are based on hourly weather observations from the U.S. National Weather Service (NWS) monitoring sites for 2011. The model also allows the user to upload custom meteorological inputs for other simulation periods and for simulations outside the continental U.S. The meteorological inputs include wind speed, horizontal and vertical friction velocity (u_{Star} , w_{Star}), convective mixing height, mechanical mixing height, Monin–Obukhov length, surface roughness, and reference height. In this study, we used historical meteorological observations from Martinique Aimé Césaire International Airport (ICAO-TFFF, IATA-FDF) from 2020 to 2025, downloaded from the National Centers for Environmental Information [37]. The data were processed through AERMET [38], a meteorological data preprocessor for AERMOD.

Wind roses of hourly surface observations from 2020 to 2025 at the Martinique Aimé Césaire International Airport are shown in Figure 2. As can be seen from the figure, the winds are predominantly from the east-southeast. During the summer, the wind patterns are similar for the whole period, and the average wind speed is 4.75 m/s. While the winds are mostly from the east-southeast during morning hours, the winds become easterly during the evening (Figure 2). The calmest period is during the night and early morning hours, as shown in Figure 3b.

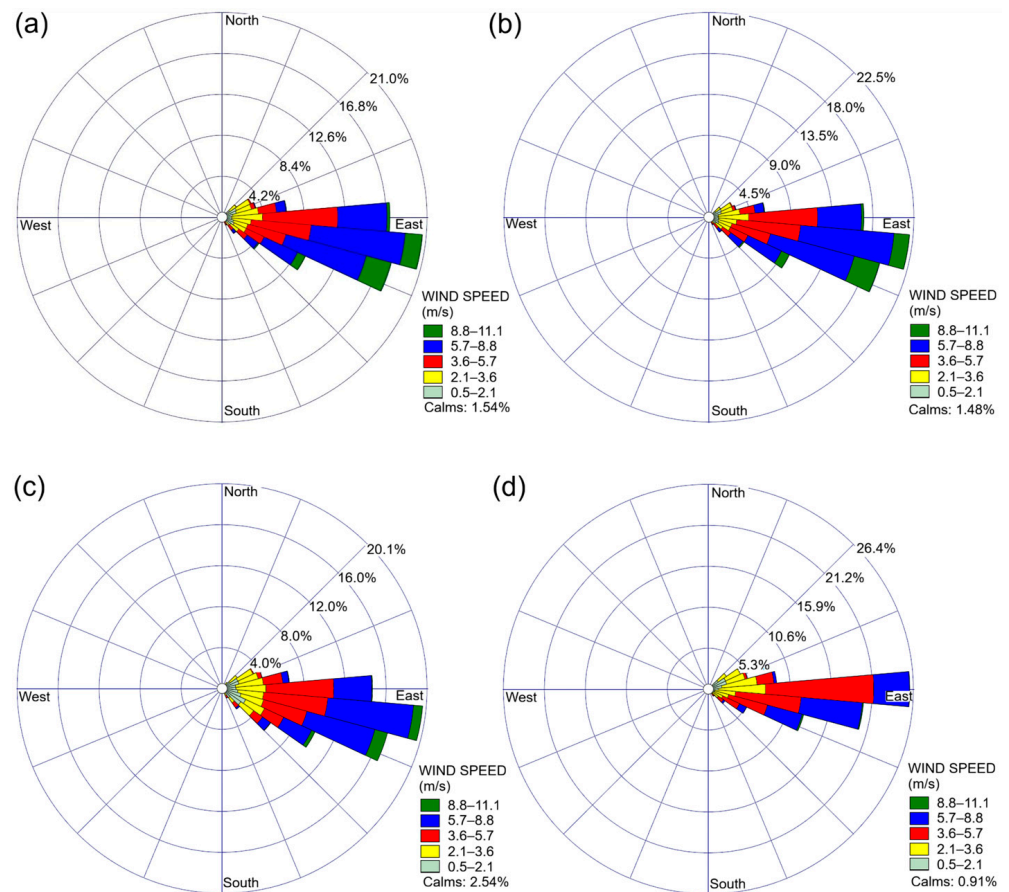


Figure 2. Wind roses of hourly surface observations at the Martinique Aimé Césaire International Airport from 2020 to 2025: all hours (a); summer (May to August), all hours (b); morning hours, 5 am to 9 am (c); evening hours, 6 pm to 10 pm (d).

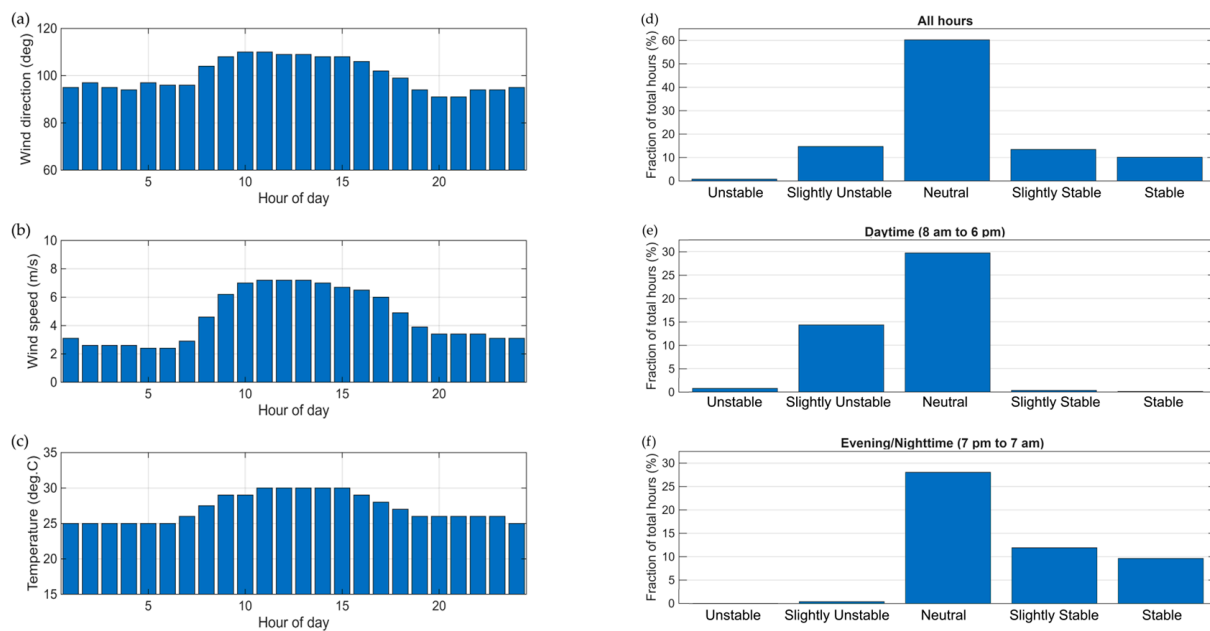


Figure 3. Median values of wind direction (a), wind speed (b), and ambient temperature (c) for all hourly surface observations at the Martinique Aimé Césaire International Airport from 2020 to 2025, and distribution of stability classes for all hours (d), daytime hours (e), and evening hours and nighttime hours (f).

One of the most critical parameters affecting the dispersion of pollutants is atmospheric stability. In this study, we prepared custom meteorological inputs for C-PORT using the five most recent years of hourly observations at the Martinique Aimé Césaire International Airport processed through AERMET to determine the stability classes. All valid hourly observations are separated into Stable (Monin–Obukov Length (L) > 0) and Convective ($L < 0$) conditions. These subsets are then ranked by L -value, from smallest to largest. The “Stable” hour is selected as the 5th-percentile ranked hour, then “Slightly Stable” hour is selected as the 50th-percentile ranked hour. Likewise, when the convective hours are ranked from smallest to largest (L is negative in Convective conditions), the “Convective” hour is selected as the 95th-percentile ranked hour, and the “Slightly Convective” hour is selected as the 50th-percentile ranked hour. The “Neutral” hour is selected when all hours are ranked by the absolute value of their L -value and the 99th-percentile ranked hour is selected. In all cases, the selected hour contains the wind speed, $uStar$, $wStar$, convective mixing height, mechanical mixing height, L , surface roughness, and reference height.

The distribution of stability classes for all hourly observations at the Martinique Aimé Césaire International Airport from 2020 to 2025 are shown in Figure 3d–f. As can be seen from the figure, neutral stability occurs most of the time. Stable and slightly stable conditions are typical for evening and nighttime hours, while unstable conditions occur during the daytime. The distribution of stability classes during summer months is similar to the entire year.

2.4. Inverse Modeling to Estimate H_2S Emissions

While the release of toxic gas emissions from the decomposition of *Sargassum* is well documented [12], separate emission rates for the decomposition of stranded and stagnant *Sargassum* were not yet available (Kwak et al. [18] was released after this manuscript went into review). Average emission rates for H_2S from stranded *Sargassum* as calculated by Silva et al. [17] were 192 g/h/m² or 53.4 mg/m² per second, while Kwak et al. estimated H_2S emissions rates for dry *Sargassum* (which can be considered a proxy for stranded *Sargassum*) to be between 20 and 251 µg/kg-day or 5.08×10^{-6} – 6.37×10^{-5} mg/m² per second (assuming a typical surface area of 0.114 m² for a 29 L polypropylene container). Given the wide range in these estimates, the absence of NH_3 emission rates from *Sargassum* decomposition in the literature, and the predominance of stagnant *Sargassum* in Martinique, we used an inverse modeling approach to estimate emission fluxes from observational data in Martinique using C-PORT rather than relying on previously published emission rates. Using the polygon shapes and custom meteorology based on hourly observations at the Martinique Aimé Césaire International Airport in 2025, a suite of C-PORT model runs was set up to calculate hourly concentrations from four different *Sargassum* accumulation scenarios with four different stability classes (neutral, slightly stable, stable, and slightly convective) at five different wind directions: 45°, 67°, 90°, 112°, and 135°. *Sargassum* shapes were grouped based on the likelihood score following the methodology outlined in Table 2. A low *Sargassum* accumulation scenario has the fewest shapes (1134 polygons island-wide), while an extreme *Sargassum* accumulation scenario uses all shapes (2357 polygons island-wide). Given the complexity of the *Sargassum* polygons and the computational burden on C-PORT, which is proportional to the number of vertices in each modeling shape and the total number of shapes, it was necessary to divide the modeling into three different domains as shown in Figure 4: an area in Le Robert commune, an area in Le Vauclin commune, and an area in Le Diamant commune. A composite image showing the C-PORT modeling domains (23 km x 13 km with receptors placed at 20 m resolution) encompassing multiple Madininair monitor sites in Martinique is shown in Figure A2.

Table 2. Likelihood score and *Sargassum* accumulation scenarios.

Sargassum Accumulation Scenario	Likelihood Scores
Low	1
Medium	1, 2
High	1–3
Extreme	1–4

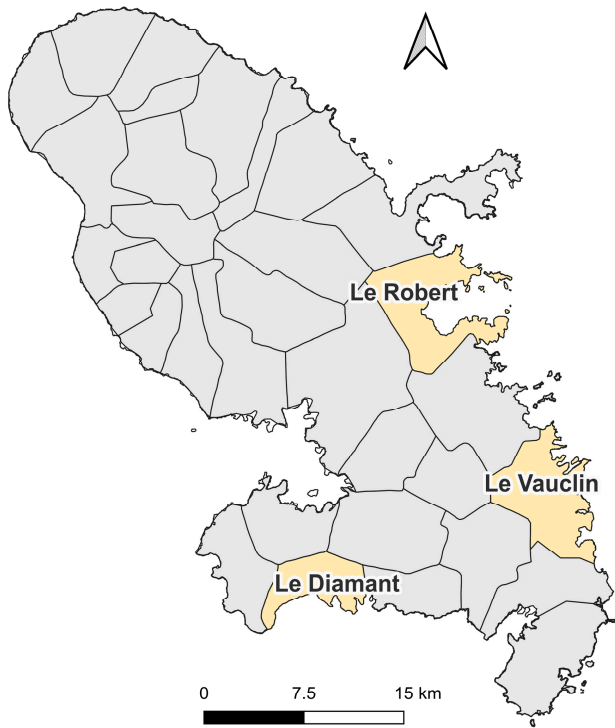


Figure 4. Martinique commune boundaries [39] with the three modeling domains highlighted.

Monitor data from November 2024 to October 2025 were downloaded for all available sites from Madininair [20], though latitude and longitude locations for the Madininair sensor locations were not included. This research uses approximate locations based on the map provided on the Madininair website [20], and monitor locations ranged from 3 m to 75 m from the closest coastal point, as represented by the island boundary. Given the uncertainty in exact location and the sensitivity of model concentrations with distance from the source, land-based receptor concentrations within one hundred meters around each approximate monitor location were used for statistical comparisons of observed versus model concentrations. With a receptor spacing of approximately every 40 m, this approach allowed for comparing monitor locations with up to a maximum of 21 receptor concentrations. However, when concentrations are clipped by the island boundary, receptor counts per monitor location range from 10 to 19 depending on the proximity of the approximate monitor location to the island boundary. Model results at these selected receptors were post-processed to calculate daily average concentrations using the frequency of occurrence of various stability categories from 2020 to 2025 (60.2% of hours during neutral stability conditions, 13.5%—slightly stable, 10.1%—stable, and 14.7%—slightly convective) for comparison with Madininair observations and health-related exposure guidelines. For each domain and wind direction, a daily average concentration for H₂S and NH₃ was calculated using Equation (1).

$$Conc24_{avg} = (Conc_{Neutral} \times 15 + Conc_{SStable} \times 4 + Conc_{Stable} \times 2 + Conc_{SConv} \times 3) / 24 \tag{1}$$

where

$Conc_{24_{avg}}$ = Pollutant Daily Average Concentration (ppm);

$Conc_{Neutral}$ = Pollutant Concentration (ppm) from Neutral conditions;

$Conc_{SStable}$ = Pollutant Concentration (ppm) from Slightly Stable conditions;

$Conc_{Stable}$ = Pollutant Concentration (ppm) from Stable conditions;

$Conc_{SConv}$ = Pollutant Concentration (ppm) from Slightly Convective conditions.

The inverse modeling approach included multiple model simulations, starting with an initial guess for emissions, and then manual adjustment of emissions after comparison with observations in multiple iterations. For the initial modeling, an emission flux rate of 2.54 [mg/(m²s)] was used for the shapes with the highest density $D = 8$, and the flux rate was scaled by density for shapes with lower densities (i.e., 1.91 for $D = 6$, 1.27 for $D = 4$, 0.64 for $D = 2$, and 0.32 for $D = 1$). The initial range of estimated *Sargassum* H₂S emission fluxes was informed by several different sources given the presence of both stranded and stagnant *Sargassum* in Martinique. Hog lagoon studies, which provided insight into theoretical upper and lower limits of stagnant *Sargassum* emissions, estimated H₂S flux rates from 0.007 mg/(m²s) [40] to 100 mg/(m²s) [41]. Stranded *Sargassum* emission flux rates ranged from a calculated flux rate of 2.50 mg/(m²s), corresponding to the median value of 1 ppm H₂S concentrations measured at the source (right above the *Sargassum* pile) as reported by Rodríguez-Martínez et al. [15], to 53.4 mg/m² per second measured by Silva et al. [17]. Given the wide range of H₂S emission flux rates, we decided to start our iterative modeling near the median value measured in situ by Rodríguez-Martínez et al. [15]. The flux rate was then multiplied by the shape area to determine an emission rate for each shape.

Model results were then compared with observations, and the Normalized Square Mean Error (NMSE) [42] was calculated using Equation (2) for distributions of modeled and observed concentrations at seven monitor locations: Baie Cayol, Pontalery Nord, Four a Chaux, Pointe Hyacinthe, Chateau Paille, Pointe Faula, and Anse Cafard.

$$NMSE = 1/N \sum (C_{Obs} - C_{Mod})^2 / (Conc_{Obs} \times Conc_{Mod}) \quad (2)$$

where

C_{Obs} = Observed concentrations (ppm);

C_{Mod} = Modeled concentrations (ppm);

N = number of observations or model predictions in dataset;

$Conc_{Obs}$ = Observed concentration averaged over dataset (ppm);

$Conc_{Mod}$ = Modeled concentration averaged over dataset (ppm).

Multiple model iterations were conducted to minimize the NMSE to find the emission rates for which model concentrations best matched with observations across the modeling domain. First, the emission inputs were adjusted manually using subjective criteria. Then, C-PORT simulations were performed with adjusted emissions, and model results were compared with observations. Since C-PORT is optimized for computational efficiency and designed for quick diagnostic analyses, it was feasible to conduct multiple model simulations (in the range of 10–20 iterations) to estimate emission inputs which provide better agreement with observations (i.e., the lowest value of NMSE).

3. Results

After a series of modeling rounds to minimize the NMSE, a final series of C-PORT modeling runs was initiated for each of the three domains using the emission flux rates for H₂S and NH₃ delineated by *Sargassum* density and presented in Table 3. The zip archive S1 contains all the files necessary to run C-PORT to recreate the output from this study.

Table 3. H₂S and NH₃ emission flux rates (mg/m² per second) by *Sargassum* density.

Density	H ₂ S	NH ₃
1	0.45	0.25
2	0.89	0.51
3	1.34	0.76
4	1.79	1.02
5	2.23	1.27
6	2.68	1.53
8	3.58	2.03

The estimated flux rates vary within an order of magnitude depending on density—from 0.45 to 3.58 mg/(m²s) for H₂S and from 0.25 to 2.03 mg/(m²s) for NH₃. It is important to note that the emissions flux rates did not differentiate by *Sargassum* type, i.e., stranded or stagnant, as it was not possible to isolate emissions from a single *Sargassum* type in this study, and at the time this study was conducted, there were no published comparisons of emission flux rates for H₂S dry *Sargassum* (stranded) or *Sargassum* in the presence of seawater (stagnant). Emission flux rates were converted to emission rates in terms of tons per year for C-PORT modeling by multiplying the flux values by the emission source area and then converting to tons per year. A summary of emission rates for H₂S and NH₃, respectively, are shown in Tables A1 and A2.

The resulting raw C-PORT short-term concentrations from the final series of C-PORT modeling runs were post-processed to calculate the daily average concentrations by *Sargassum* intensity level and wind direction and evaluated through several statistical methods. A comparison of distributions of modeled versus observed daily average concentrations for H₂S is shown in Figure 5. For each monitor location, modeled distribution values comprise daily average concentrations at five different wind directions for model results within 100 m of the estimated monitor location, while observed distribution values comprise data from November 2024 to October 2025. Both mean and median values of distributions of model predictions match the observations at monitoring sites with elevated levels (Pontalery Nord, Four a Chaux, and Pointe Hyacinthe) and low levels of concentrations (Chateau Paille, Pointe Faula, and Anse Cafard), indicating that the model can reproduce the spatial patterns of H₂S concentrations due to emissions from *Sargassum* decomposition.

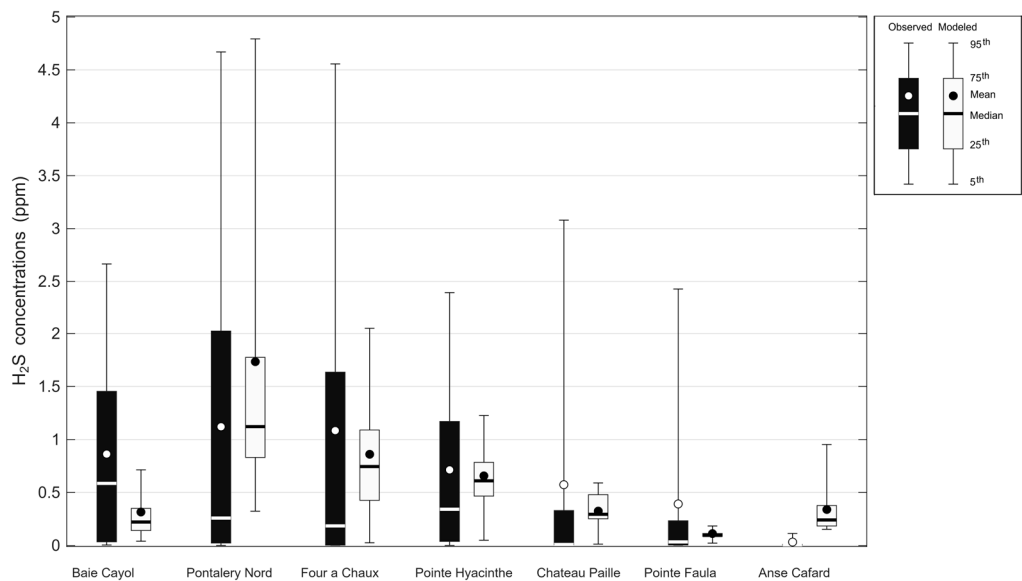


Figure 5. Distributions of observed and modeled daily H₂S concentrations.

Distributions of observed versus modeled daily average concentrations for H_2S for four different *Sargassum* accumulation scenarios (low, medium, high, and extreme) are shown in Figure 6. This plot highlights how *Sargassum* intensity influences the predicted concentrations, primarily due to the number of *Sargassum* shapes modeled in each intensity scenario. Furthermore, it demonstrates that modeled concentrations increase as expected from low- to extreme-intensity scenarios.

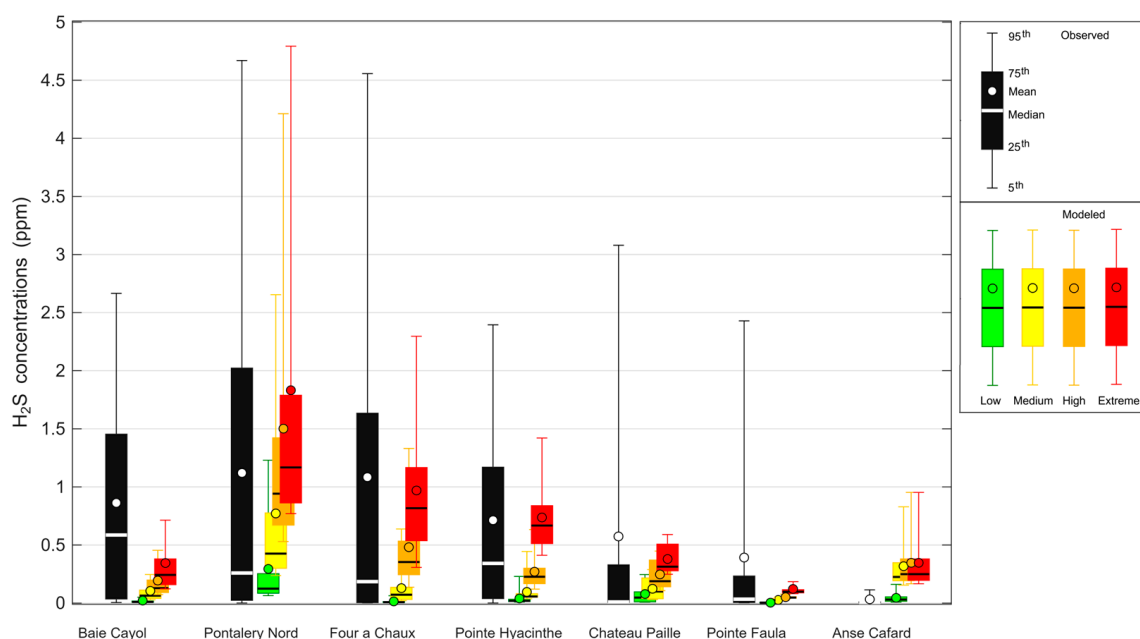


Figure 6. Distributions of observed and modeled (differentiated by *Sargassum* accumulation scenario) daily H_2S concentrations.

A comparison of the distributions of observed versus modeled daily average concentrations for NH_3 for all scenarios combined, and for four different *Sargassum* accumulation scenarios (low, medium, high, and extreme) are shown separately in Figures 7 and 8.

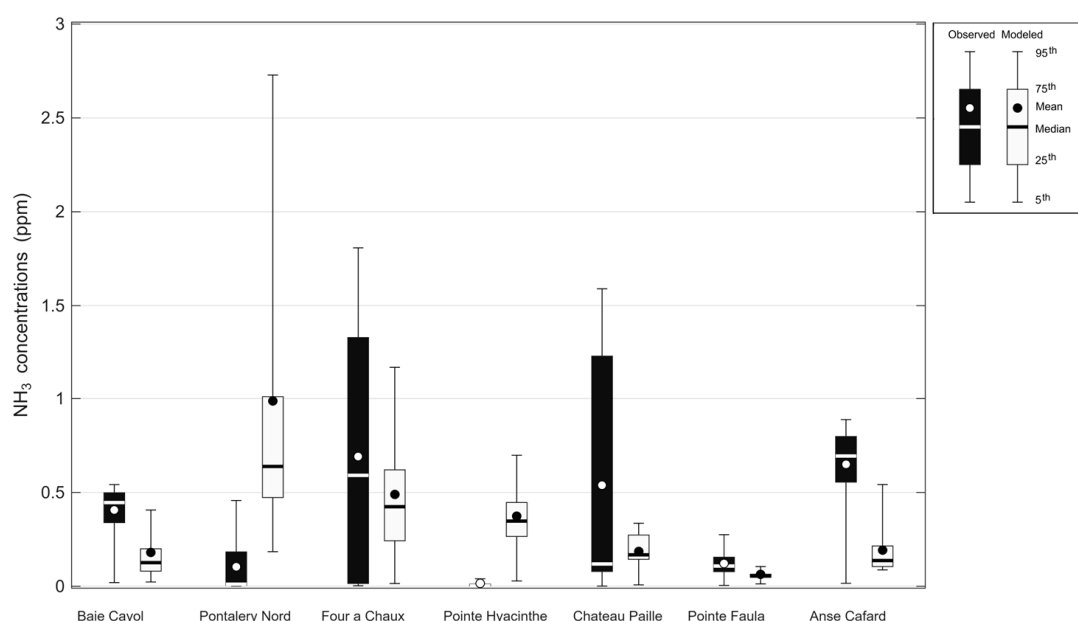


Figure 7. Distributions of observed and modeled daily NH_3 concentrations.

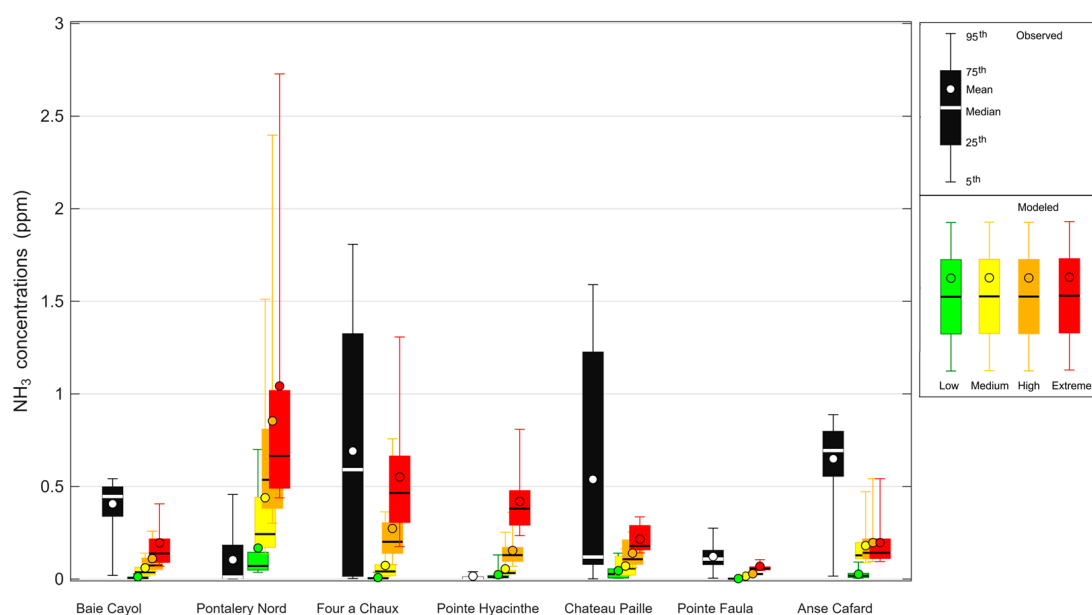


Figure 8. Distributions of observed and modeled (differentiated by *Sargassum* accumulation scenario) daily NH_3 concentrations.

The model does not reliably reproduce the spatial patterns of observed NH_3 concentrations from stranded and stagnant *Sargassum* decomposition, though modeled concentrations increase as expected from low- to extreme-intensity scenarios.

3.1. Evaluating Model Performance

Model performance statistics for the final C-PORT daily average concentrations were calculated for all monitors using distributions of model predictions unpaired in space and time. These statistics include NMSE (Equation (2)) and Fractional Bias (FB) (Equation (3)) [42]:

$$FB = 2((Conc_{Obs} - Conc_{Mod}) / (Conc_{Obs} + Conc_{Mod})) \quad (3)$$

where

$Conc_{Obs}$ = Observed concentration averaged over dataset (ppm);

$Conc_{Mod}$ = Modeled concentration averaged over dataset (ppm).

An ideal model performance will be when $FB = 0$ and $NMSE = 0$. According to Kumar et al. [43], the performance of a model can be deemed as acceptable if NMSE is less than or equal to 0.5 and FB is between -0.5 and 0.5 . Model performance metrics FB and NMSE across seven monitoring sites for H_2S and NH_3 are summarized in Tables 4 and 5.

Table 4. Model performance metrics: FB for H_2S and NH_3 .

Monitoring Site	FB H_2S	FB NH_3
Baie Cayol	0.92	0.77
Pontalery Nord	−0.43	−1.62
Four a Chaux	0.23	0.34
Pointe Hyacinthe	0.08	−1.84
Chateau Paille	0.55	0.98
Pointe Faula	1.11	0.62
Anse Cafard	−1.65	1.09
All sites	0.042	0.037

Table 5. Model performance metrics: NMSE for H₂S and NH₃.

Monitoring Site	NMSE H ₂ S	NMSE NH ₃
All sites	0.324	1.50

While FB is often outside of the 0.5 threshold for individual sites, the combined FB across all sites is less than 0.05 for both H₂S and NH₃, indicating good overall model performance for both H₂S and NH₃. While NMSE for H₂S falls within the 0.5 limit, it is well outside those limits for NH₃, indicating that the emission flux rates for NH₃ should be revisited.

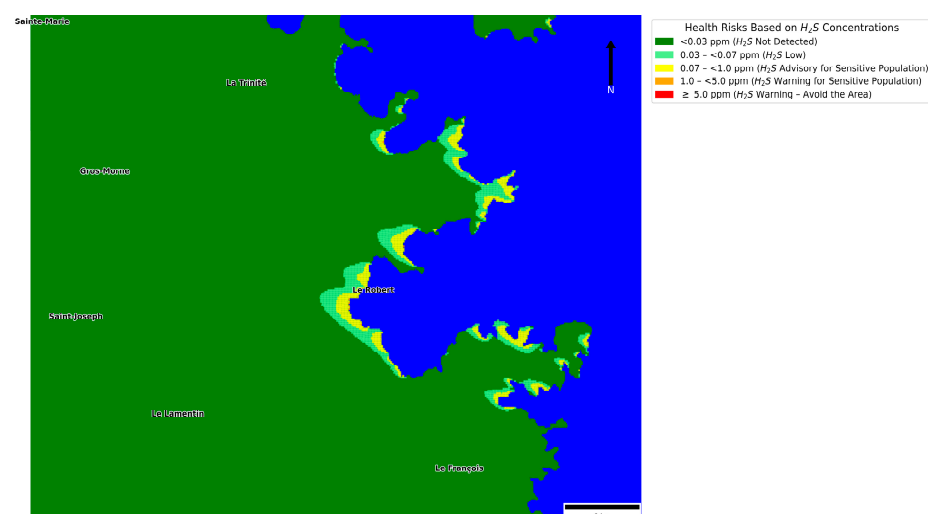
3.2. Mapping Health Risks

As mentioned previously, raw short-term C-PORT concentrations were post-processed to calculate the daily average concentrations by *Sargassum* intensity level and wind direction, and model concentrations were clipped by island boundaries to emphasize onshore impacts. The highest H₂S concentrations in all three domains were associated with 90° winds (Table 6).

Table 6. Maximum daily average H₂S concentrations from extreme inundation by wind direction.

Domain	45°	67°	90°	112°	135°
Le Robert	1.79	1.69	5.11	1.95	1.89
Le Vauclin	1.28	1.44	4.69	1.33	1.81
Le Diamant	0.89	0.97	3.42	1.24	1.24

Concentration values were binned using guidance developed by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) [44] and shown on the Madinair website to generate health risk maps. Figure 9 shows the health risks associated with the extreme *Sargassum* inundation in Le Robert with east-southeast (112°) winds, the dominant wind direction. Daily average concentrations of H₂S can reach almost 2 ppm in some locations under these conditions (Figure A3). Similar concentrations and subsequent health risks were also estimated in the Le Vauclin domain (Figure A4), while slightly lower concentrations and risks were modeled in the Le Diamant domain (Figure A5). None of the domains exceeded the 5 ppm H₂S daily average threshold when east-southeast (112°) winds were modeled.

**Figure 9.** Health risk map in Le Robert from the extreme *Sargassum* inundation scenario with 112° winds.

3.3. Scenario Analysis

The functionality built into C-PORT’s scenario analysis capability was used to calculate the potential air quality benefits associated with *Sargassum* mitigation measures like deploying booms or netting or collecting *Sargassum* before it reaches the coastline. For this analysis, it was assumed that the deployment of *Sargassum* mitigation measures would reduce the intensity of SIEs from extreme to low. Table 7 highlights the median modeled concentration values at the seven monitor locations in the extreme and low accumulation scenarios and shows how the difference between the scenarios could result in reducing *Sargassum* concentrations by 0.47 ppm (93%) for H₂S and by 0.27 ppm (93%) for NH₃. Note that median modeled concentrations for extreme *Sargassum* accumulation scenarios are all above the 0.07 ppm ANSES “yellow” threshold, too, with the Pontalery Nord monitor location above the 1 ppm “orange” threshold. Low accumulation scenarios are all below the 0.07 ANSES “yellow” threshold except at Pontalery Nord, implying that the mitigation measures could reduce or even eliminate adverse health effects at most sites.

Table 7. Difference between extreme and low accumulation scenarios for H₂S and NH₃ concentrations (ppm).

Metric	Scenario	Baie Cayol	Pontalery Nord	Four a Chaux	Pointe Hyacinthe	Chateau Paille	Pointe Faula	Anse Cafard
H ₂ S	Low	0.010	0.125	0.008	0.019	0.047	0.004	0.031
	Extreme	0.243	1.168	0.817	0.668	0.314	0.098	0.249
	Difference	0.233	1.043	0.809	0.649	0.267	0.095	0.218
	% Difference	96	89	99	97	85	96	88
NH ₃	Low	0.006	0.071	0.005	0.011	0.027	0.002	0.018
	Extreme	0.138	0.665	0.465	0.380	0.179	0.056	0.142
	Difference	0.133	0.594	0.460	0.370	0.152	0.054	0.124
	% Difference	96	89	99	97	85	96	88

4. Discussion

Sargassum continues to be a problem for coastal communities from West Africa to the Caribbean and into the Gulf of Mexico. Overwhelming quantities of *Sargassum* associated with SIEs negatively impact coastal ecosystems, tourism, and human health, and estimates of the economic impacts are in billions of dollars each year in Puerto Rico, the U.S. Virgin Islands, and coastal Florida alone [45]. Given the scope of the crisis, there is surprisingly little published research on the air quality concerns associated with *Sargassum* decomposition, other than the work of Resiere et al. in Martinique [12,14,26]. Published estimates of H₂S emission rates from decaying *Sargassum* vary significantly with several orders of magnitude separating the lowest emission flux rates [18] from experimental measurements for both stranded and stagnant *Sargassum* from Florida, the in situ estimates of H₂S concentrations from stranded *Sargassum* [15] in Mexico, and the experimental average flux rate of stranded *Sargassum* from Brazil [17]. This study uses inverse modeling to compare C-PORT short-term concentrations against Madininair observation data from 2024 to 2025 to establish blended emission flux rates for H₂S and NH₃ from the decomposition of stranded and stagnant *Sargassum* for varying levels of SIEs. Furthermore, modeled concentrations for three different domains on Martinique are used to generate health risk maps for H₂S exposure to demonstrate how the C-PORT dispersion model can serve as a valuable tool for public health agencies during SIEs.

The emission flux rates presented in this study represent a blend of emissions from stranded *Sargassum* and stagnant *Sargassum*, and they are several of orders of magnitude higher than the rates calculated based on Kwak et al. [18] but an order of magnitude lower than the rate reported by Silva et al. [17]. The flux rates are slightly higher than

the median rate calculated from Rodríguez-Martínez et al. [15] at 1 m above stranded *Sargassum* piles, which is supported by the higher flux rates for *Sargassum* in the presence of seawater presented in Kwak et al. [18], though their findings suggest that stagnant *Sargassum* emission flux rates could be twice the level of stranded *Sargassum*. It is important to note that this type of inverse modeling to estimate the emission flux rates based on monitor data propagate throughout the rest of the study and can result in flux rates that are site-specific and may not be applicable at other sites or in other scenarios. As already noted, the flux rates used in this study represent an environment with both stranded and stagnant *Sargassum*, while other areas that are dominated by stranded *Sargassum* would likely use a different, lower emission flux rate.

The model performance in terms of FB for H₂S and NH₃ predictions was good overall when considering all seven Madinair monitor locations used in this study, though FB at individual sites ranged from −1.65 to 1.11 for H₂S with similar ranges for NH₃. NMSE for H₂S predictions was acceptable when evaluating all locations, though NMSE for NH₃ did not meet the 0.5 threshold. Given that Silva et al. [17] did not find any measurable NH₃ in their study, it may be that the decomposition of stranded or stagnant *Sargassum* is not a primary contributor to ambient NH₃ concentrations at the monitor locations. If the decomposition of stranded or stagnant *Sargassum* does not meaningfully impact NH₃ concentrations, it is not surprising that the model performance for NH₃ predictions was poor.

While Rodríguez-Martínez et al. [15] found highly elevated levels of H₂S under stranded *Sargassum*, the concentrations 1.5 m directly above the piles were much less, and concentrations quickly dropped below health advisory criteria (1 ppm) at 30 m and beyond. Accordingly, they found that stranded *Sargassum* did not pose an acute exposure risk for nearby tourists or residents. Recent Madinair monitor data showed a large number of days above 1 ppm at the seven sites [20]. When considered together, these two findings suggest that some or all Madinair monitor locations with elevated H₂S concentrations are located 10 m or less from the shoreline, and for monitor locations with daily average concentrations at or above health advisory criteria located more than 10 m away from the shore, emissions from stagnant *Sargassum* likely play an important role in nearshore air quality. This finding is supported by Kwak et al. [18] who reported H₂S emission flux rates for summer *Sargassum* in the presence of seawater over twice the rate for dry *Sargassum*. For islands like Martinique with complex coastlines and varied coastal topography and hydrodynamics, emissions from stagnant *Sargassum* are likely a key contributor to air quality concerns during periods of SIEs.

The methodology employed in this study can be used to model the air quality impacts associated with *Sargassum* anywhere in the world. Modeled concentration outputs can help islands without H₂S monitors to identify areas of concern or be paired with in situ observation networks to provide a more comprehensive assessment of the air quality impacts of SIEs. Public health officials can leverage existing *Sargassum* forecasts like those from CARICOOS [46], NOAA [47], the Sargassum Watch System (SaWS) [48], SAMtool [49], and others to inform C-PORT model runs to create early-warning systems designed to minimize human exposure to unhealthy H₂S concentrations. Furthermore, the scenario analysis capabilities built into C-PORT can be used to model the air quality benefits associated with *Sargassum* mitigation measures like floating barriers, nets, and booms, harvesting vessels, or even beach collection and removal [50]. C-PORT can be used to estimate the concentrations before mitigation and then after mitigation to calculate the difference in concentrations.

In terms of mitigation strategies, U.S. sites face regulatory hurdles associated with harvesting *Sargassum* due to its designation as an Essential Fish Habitat [50] and other federal statutes like the United States Endangered Species Act of 1973 [51]. Many coastal

areas are protected by regulation, are difficult to access, or have substrates that do not lend themselves to *Sargassum* removal after the *Sargassum* has washed ashore. Existing regulations may therefore create a situation where *Sargassum* is allowed to decompose, creating economic, ecological, and human health concerns. Given the scope of the problems associated with SIEs, it may be that U.S. federal regulators need to reevaluate the Essential Fish Habitat designation to increase the number of viable mitigation strategies available to coastal communities.

There were several important limitations affecting the results of this study. First, this study was limited by not having the exact locations of the Madinair monitor locations. Since this study used approximate monitor locations, statistical analyses showing correlations between the distance from the shore and both observed concentrations and modeled concentrations were not possible, nor could this study definitively rule out the possibility that monitors with regular H_2S concentrations above 1 ppm were located within 10 m of the shoreline. This, in turn, prevented a conclusive statement about the potential contributions of stagnant *Sargassum* emissions. Second, the inverse modeling approach and the diverse collection of *Sargassum* input polygons with different *Sargassum* types at all study locations did not allow for the calculation of separate emission flux rates for different *Sargassum* types. Kwak et al. [18] demonstrated that *Sargassum* in the presence of seawater has a higher H_2S emission flux rate than dry *Sargassum*, particularly for what they termed “summer” *Sargassum*, and that the emission flux rates change over time while *Sargassum* decomposes. However, the emission flux rates calculated in this study were several orders of magnitude higher than the experimental values recorded by Kwak et al. [18]. The differences in flux rates could be related to the density of *Sargassum* in the field compared to the density used in the lab-based studies. Kwak et al. [18] used small-mass experiments (2.5 g of *Sargassum*) while Silva et al. [17] used between 4 and 6 kg of *Sargassum* in their experiments. Given that density is a measure of mass per unit volume, it is possible that the Kwak et al. [18] *Sargassum* was lightly compressed, while the Silva et al. [17] *Sargassum* was highly compressed in order to fit into their chamber. If the resulting densities used in both of those lab-based studies differed from typical in situ densities, this could explain the large differences in H_2S emission flux rates. The inverse modeling approach used in this study, where H_2S emission flux rates are based on matching model predictions with observations, may be more representative of typical *Sargassum* densities in Martinique. Additional research to develop a standardized methodology to assess *Sargassum* density in the field and identify the age and vitality of the *Sargassum* based on its color, particularly if that methodology is based on aerial or satellite-based estimates, could help provide better context on appropriate flux rates to use in future dispersion modeling. In addition, having separate emission flux rates for stranded and stagnant *Sargassum* used in tandem with real-time *Sargassum* forecasts can provide the best available air quality forecasts, as different flux rates over time could be employed to better capture the decomposition timeframe. Third, the current available version of C-PORT v5.1 is now over seven years old, and it does not natively calculate H_2S or NH_3 daily average concentrations. A new version of C-PORT specifically designed for modeling *Sargassum* could improve the usability of the tool and expand the feature set for *Sargassum*-based applications. Finally, this study would have benefited from the use of observed H_2S and NH_3 concentrations to match the data collection window described in Teyssier et al. [13]. Matching *Sargassum* shapes with their original densities and comparing C-PORT model results with temporally matched observation data would have led to more refined emission flux rates for both H_2S and NH_3 , though the approach used in this study with accumulation scenarios based on a likelihood score and a median density value is more flexible and can be applied to different study locations.

5. Conclusions

This work demonstrated how C-PORT, a web-based dispersion model, could be used to characterize H₂S concentrations from the decomposition of *Sargassum* over several regions of Martinique. The research quantified the blended H₂S emission flux rates from stranded and stagnant *Sargassum* based on an iterative inverse modeling approach that compared monitor concentrations with dispersion model receptor concentrations at seven sites in Martinique and compared the flux rates with other published research. Model performance for H₂S concentrations, as evaluated by FB and NMSE across the seven sites, was good, though performance for NH₃ concentrations did not meet acceptable levels for NMSE, and it may be that *Sargassum* decomposition does not meaningfully contribute to NH₃ concentrations.

The findings support the potential utility of C-PORT for modeling SIEs, and the methodology can serve as a template for modeling the air quality impacts of *Sargassum* emissions at locations across the Caribbean or the Gulf of Mexico. The approach also demonstrates how C-PORT could be used to characterize the air quality benefits of mitigation strategies by comparing air quality concentrations from an extreme-intensity SIE with that of a low-intensity SIE. Future research should work to develop a standardized approach to identify *Sargassum* vitality and classify *Sargassum* density based on aerial or satellite imagery to ensure that appropriate H₂S emission flux rates are used in air quality modeling.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/air4010004/s1>, File S1: supplementary_materials_sargassum_dispersion_modeling.zip.

Author Contributions: Conceptualization, B.N. and V.I.; methodology, B.N., V.I. and M.T.; validation, B.N. and V.I.; formal analysis, B.N. and V.I.; writing—original draft preparation, B.N. and V.I.; writing—review and editing, B.N., V.I. and M.T.; visualization, B.N. and V.I. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Files required to generate the C-PORT output are provided in the Supplementary Materials in a zip archive S1. The zip archive contains the following files: Readme.txt; metdata4CPORT2025.csv; LeRobert-CPORT-inputs-by-inundation-intensity.zip; LeVauclin-CPORT-inputs-by-inundation-intensity.zip; LeDiamant-CPORT-inputs-by-inundation-intensity.zip; island_boundary_plus_islands.zip. Further data is available on request due to privacy restrictions. C-PORT is available for use at <https://cmascenter.org/c-tools/c-port.cfm> accessed on 14 January 2026. Users need to create a free CMAS account to access the tool.

Use of Artificial Intelligence: AI or AI-assisted tools were not used in drafting any aspect of this manuscript.

Acknowledgments: The authors would like to thank the anonymous reviewers who took the time to review this work. Their insightful feedback improved this manuscript immensely. The authors would also like to thank the Institute for the Environment for providing the time and resources to complete this research. The authors would finally like to acknowledge that part of an image in the graphical abstract came from Lajara and Samten, 2025 [52].

Conflicts of Interest: Author Brian Naess was employed by the Institute for the Environment. Author Mathilde Teyssier is employed by the company Impact Mer. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ANSES	French Agency for Food, Environmental and Occupational Health & Safety
CO	Carbon monoxide
C-PORT	Community model for near-PORT applications
C-TOOLS	Community Air Quality Tools
FB	Fractional Bias
GASB	Great Atlantic Sargassum Belt
H ₂ S	Hydrogen sulfide
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ITCZ	Inter-Tropical Convergence Zone
L	Monin-Obukov Length
NH ₃	Ammonia
NMSE	Normalized Mean Square Error
NOAA	National Oceanic and Atmospheric Administration
NO _x	Nitrogen oxides
NWS	National Weather Service
PM _{2.5}	Fine particulate matter
ppm	Parts per million
SaWS	Sargassum Watch System
SIes	<i>Sargassum</i> inundation events
SO ₂	Sulfur dioxide
U.S.	United States
<i>uStar</i>	horizontal friction velocity
<i>wStar</i>	vertical friction velocity

Appendix A



Figure A1. *Sargassum* type (stagnant versus stranded) and density in the Le Robert domain.

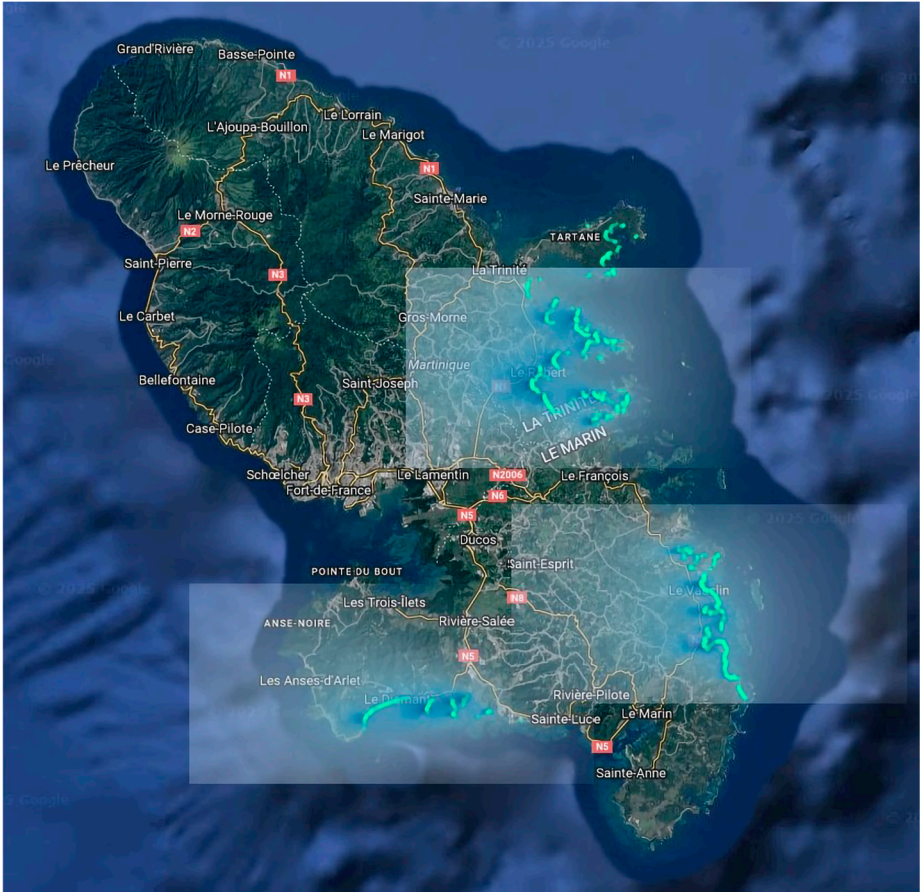


Figure A2. Composite C-PORT image showing the three modeling domains in Martinique on a Google Maps satellite background with place and road labels [53].

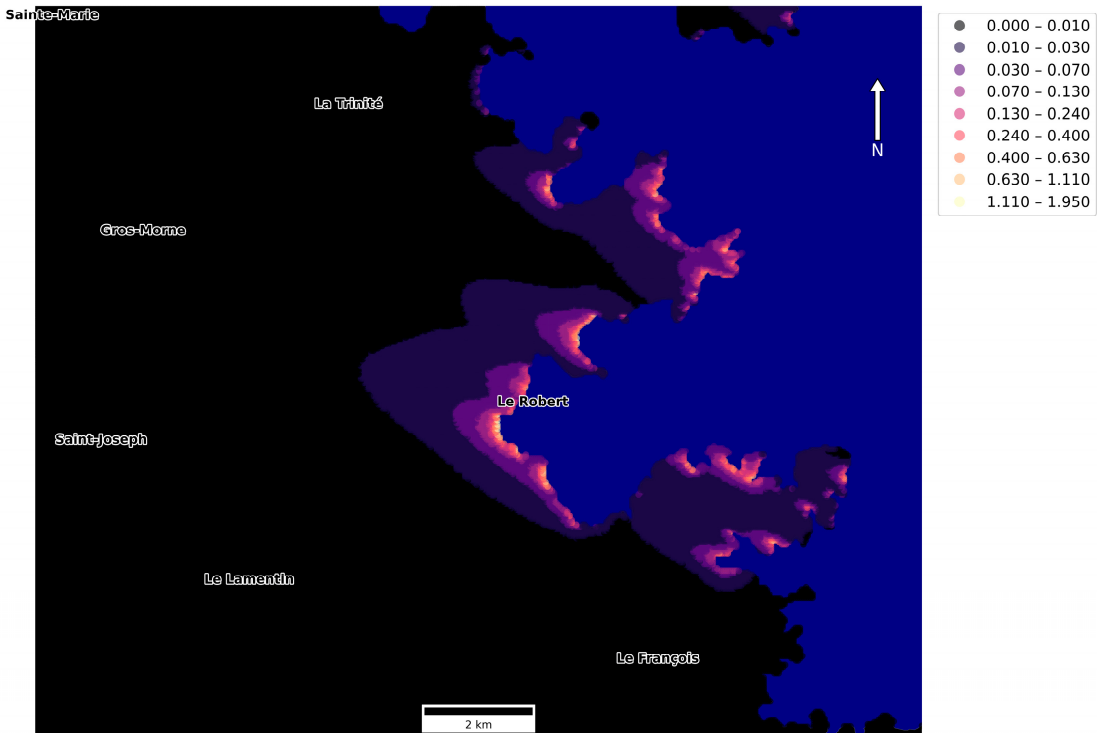


Figure A3. Daily average H₂S concentrations (ppm) from the extreme *Sargassum* inundation scenario with 112° winds.

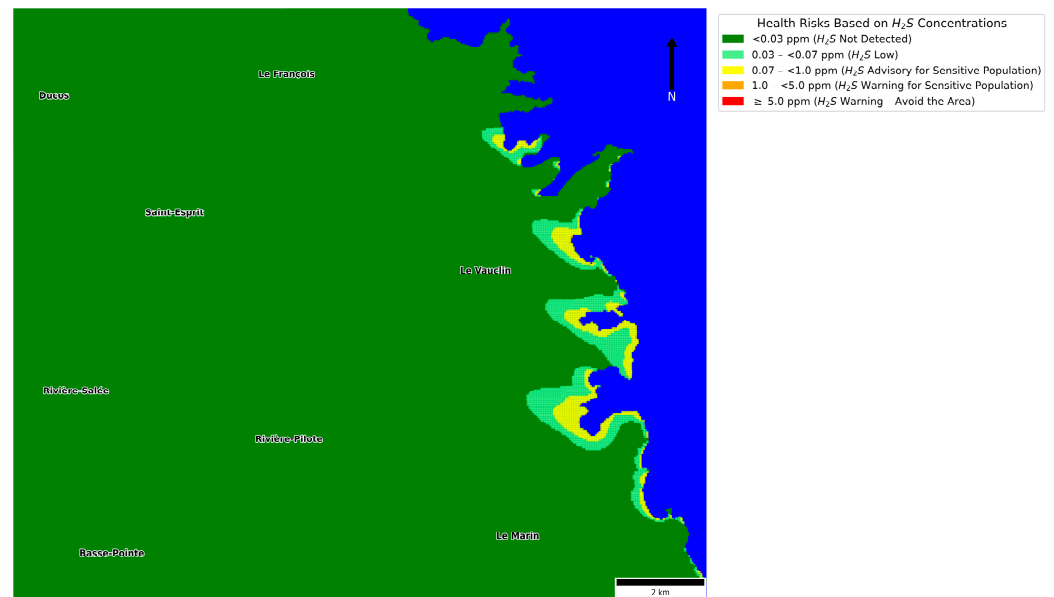


Figure A4. Health risk map in Le Vauclin from the extreme *Sargassum* inundation scenario with 112° winds.

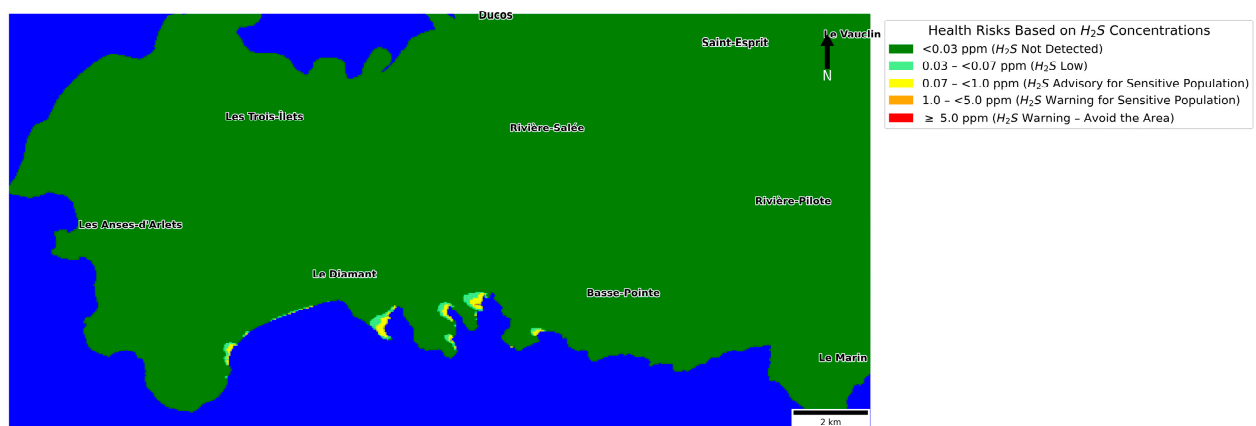


Figure A5. Health risk map in Le Diamant from the extreme *Sargassum* inundation scenario with 112° winds.

Table A1. H₂S Emissions summary.

Accumulation	Type	Density	Emis. Flux Rate (mg m ⁻² s ⁻¹)	Emissions (kg/day)			Area (m ²)		
				Median	Min	Max	Median	Min	Max
extreme	stagnant	1	0.45	47.76	3.75	494.26	1236.97	97.12	12,800.39
	stagnant	2	0.89	46.42	1.49	3505.94	601.06	19.32	45,398.14
	stagnant	3	1.34	62.56	4.13	2015.53	540.05	35.62	17,399.27
	stagnant	4	1.79	55.31	2.96	14,348.52	358.07	19.16	92,898.89
	stagnant	6	2.23	91.17	8.58	2706.97	393.54	37.05	11,684.11
	stagnant	8	2.68	117.74	5.89	3665.12	381.13	19.08	11,864.82
	stranded	1	0.45	4.57	0.96	339.77	118.38	24.8	8799.39
	stranded	2	0.89	11.7	1.83	487.74	151.49	23.74	6315.66
	stranded	3	1.34	8.58	3.89	106.58	74.09	33.57	920.03
	stranded	4	1.79	16.78	2.96	515.21	108.61	19.16	3335.71
	stranded	6	2.23	18.63	4.45	96.6	80.4	19.2	416.96
	stranded	8	2.68	35.89	6.1	412.18	116.16	19.73	1334.31

Table A1. Cont.

Accumulation	Type	Density	Emis. Flux Rate (mg m ⁻² s ⁻¹)	Emissions (kg/day)			Area (m ²)		
				Median	Min	Max	Median	Min	Max
high	stagnant	1	0.45	47.26	3.75	494.26	1223.92	97.12	12,800.39
	stagnant	2	0.89	46.42	1.49	3505.94	601.06	19.32	45,398.14
	stagnant	3	1.34	58.47	4.13	430.13	504.73	35.62	3713.14
	stagnant	4	1.79	98.82	2.96	3397.4	172.64	19.16	21,996.3
	stagnant	6	2.23	150.63	8.58	2706.97	650.14	37.05	11,684.11
	stagnant	8	2.68	220.06	5.89	3665.12	712.38	19.08	11,864.82
	stranded	1	0.45	4.57	0.96	339.77	118.38	24.8	8799.39
	stranded	2	0.89	11.7	1.83	487.74	151.49	23.74	6315.66
	stranded	3	1.34	8.58	3.89	106.58	74.09	33.57	920.03
	stranded	4	1.79	18.85	2.96	515.21	121.99	19.16	3335.71
	stranded	6	2.23	32.69	4.57	96.6	141.09	19.72	416.96
	stranded	8	2.68	66.38	6.1	412.18	214.88	19.73	1334.31
medium	stagnant	1	0.45	47.26	6.75	463.13	1223.92	174.71	11,994.16
	stagnant	2	0.89	27.3	2.58	3505.94	353.48	33.43	45,398.14
	stagnant	3	1.34	66.65	4.12	2015.53	575.36	35.62	17,399.27
	stagnant	4	1.79	82.59	3.54	3117.79	534.72	22.92	20,186.02
	stagnant	6	2.23	150.63	8.58	2706.97	650.14	37.05	11,684.11
	stagnant	8	2.68	249.82	5.89	2322.19	808.72	19.08	7517.47
	stranded	1	0.45	7.05	1.05	339.77	182.52	27.2	8799.39
	stranded	2	0.89	10.48	3.34	487.74	135.63	43.31	6315.66
	stranded	3	1.34	4.77	3.89	56.25	41.17	33.57	485.56
	stranded	4	1.79	31.87	2.96	515.21	206.37	19.16	3335.71
	stranded	6	2.23	4.57	4.57	4.57	19.72	19.72	19.72
	stranded	8	2.68	180.68	74.29	412.18	584.89	240.48	1334.31
low	stagnant	1	0.45	124.46	26.09	463.13	3223.17	675.67	11,994.16
	stagnant	2	0.89	65.53	9.26	3505.94	848.56	119.93	45,398.14
	stagnant	3	1.34	1022.27	29.01	2015.53	8824.87	250.46	17,399.27
	stagnant	4	1.79	42.9	3.54	3117.79	277.73	22.92	20,186.02
	stagnant	6	2.23	1399.08	91.18	2706.97	6038.83	393.54	11,684.11
	stagnant	8	2.68	181.71	16.87	1406.6	588.24	54.6	4553.49
	stranded	1	0.45	4.57	1.05	339.77	118.38	27.2	8799.39
	stranded	2	0.89	7.69	2.16	487.74	99.58	27.91	6315.66
	stranded	3	1.34	4.66	3.89	4.88	40.2	33.57	42.13
	stranded	4	1.79	18.18	3.53	515.21	117.73	22.86	3335.71
	stranded	8	2.68	180.68	85.39	412.18	584.89	276.41	1334.31

Table A2. NH₃ Emissions summary.

Accumulation	Type	Density	Emis. Flux Rate (mg m ⁻² s ⁻¹)	Emissions (kg/day)			Area (m ²)		
				Median	Min	Max	Median	Min	Max
extreme	stagnant	1	0.25	27.18	2.13	281.32	1236.97	97.12	12,800.39
	stagnant	2	0.51	26.42	0.85	1995.44	601.06	19.32	45,398.14
	stagnant	3	0.76	35.61	2.35	1147.16	540.05	35.62	17,399.27
	stagnant	4	1.02	31.48	1.68	8166.59	358.07	19.16	92,898.89
	stagnant	6	1.53	51.89	4.89	1540.7	393.54	37.05	11,684.11
	stagnant	8	2.03	67.01	3.35	2086.03	381.13	19.08	11,864.82
	stranded	1	0.25	2.6	0.55	193.38	118.38	24.8	8799.39
	stranded	2	0.51	6.66	1.04	277.6	151.49	23.74	6315.66
	stranded	3	0.76	4.88	2.21	60.66	74.09	33.57	920.03
	stranded	4	1.02	9.55	1.68	293.24	108.61	19.16	3335.71
	stranded	6	1.53	10.6	2.53	54.98	80.4	19.2	416.96
	stranded	8	2.03	20.43	3.47	234.59	116.16	19.73	1334.31

Table A2. Cont.

Accumulation	Type	Density	Emis. Flux Rate (mg m ⁻² s ⁻¹)	Emissions (kg/day)			Area (m ²)		
				Median	Min	Max	Median	Min	Max
high	stagnant	1	0.25	2.13	26.9	281.32	1223.92	97.12	12,800.39
	stagnant	2	0.51	0.85	26.42	1995.44	601.06	19.32	45,398.14
	stagnant	3	0.76	2.35	33.28	244.81	504.73	35.62	3713.14
	stagnant	4	1.02	1.68	56.24	1933.66	172.64	19.16	21,996.3
	stagnant	6	1.53	4.89	85.73	1540.7	650.14	37.05	11,684.11
	stagnant	8	2.03	3.35	125.25	2086.03	712.38	19.08	11,864.82
	stranded	1	0.25	0.54	2.6	193.38	118.38	24.8	8799.39
	stranded	2	0.51	1.04	6.66	277.6	151.49	23.74	6315.66
	stranded	3	0.76	2.21	4.88	60.66	74.09	33.57	920.03
	stranded	4	1.02	1.68	10.73	293.24	121.99	19.16	3335.71
	stranded	6	1.53	2.6	18.6	54.98	141.09	19.72	416.96
	stranded	8	2.03	3.47	37.78	234.59	214.88	19.73	1334.31
medium	stagnant	1	0.25	26.9	3.84	263.6	1223.92	174.71	11,994.16
	stagnant	2	0.51	15.54	1.47	1995.44	353.48	33.43	45,398.14
	stagnant	3	0.76	37.93	2.35	1147.16	575.36	35.62	17,399.27
	stagnant	4	1.02	47.01	2.01	1774.52	534.72	22.92	20,186.02
	stagnant	6	1.53	85.73	4.89	1540.7	650.14	37.05	11,684.11
	stagnant	8	2.03	142.19	3.35	1321.7	808.72	19.08	7517.47
	stranded	1	0.25	4.01	0.6	193.38	182.52	27.2	8799.39
	stranded	2	0.51	5.96	1.9	277.6	135.63	43.31	6315.66
	stranded	3	0.76	2.72	2.21	32.01	41.17	33.57	485.56
	stranded	4	1.02	18.14	1.68	293.24	206.37	19.16	3335.71
	stranded	6	1.53	2.6	2.6	2.6	19.72	19.72	19.72
	stranded	8	2.03	102.83	42.28	234.59	584.89	240.48	1334.31
low	stagnant	1	0.25	70.84	14.85	463.13	3223.17	675.67	11,994.16
	stagnant	2	0.51	37.3	5.27	3505.94	848.56	119.93	45,398.14
	stagnant	3	0.76	581.84	16.51	2015.53	8824.87	250.46	17,399.27
	stagnant	4	1.02	24.42	2.01	3117.79	277.73	22.92	20,186.02
	stagnant	6	1.53	796.3	51.89	2706.97	6038.83	393.54	11,684.11
	stagnant	8	2.03	103.42	9.6	1406.6	588.24	54.6	4553.49
	stranded	1	0.25	2.6	0.6	339.77	118.38	27.2	8799.39
	stranded	2	0.51	4.38	1.23	487.74	99.58	27.91	6315.66
	stranded	3	0.76	2.65	2.21	4.88	40.2	33.57	42.13
	stranded	4	1.02	10.35	2.01	515.21	117.73	22.86	3335.71
	stranded	8	2.03	102.83	48.6	412.18	584.89	276.41	1334.31

References

1. Wang, M.; Hu, C. Mapping and Quantifying *Sargassum* Distribution and Coverage in the Central West Atlantic Using MODIS Observations. *Remote Sens. Environ.* **2016**, *183*, 350–367. [\[CrossRef\]](#)
2. Wang, M.; Hu, C.; Barnes, B.B.; Mitchum, G.; Lapointe, B.; Montoya, J.P. The Great Atlantic *Sargassum* Belt. *Science* **2019**, *365*, 83–87. [\[CrossRef\]](#)
3. Johns, E.M.; Lumpkin, R.; Putman, N.F.; Smith, R.H.; Muller-Karger, F.E.; Rueda-Roa, D.T.; Hu, C.; Wang, M.; Brooks, M.T.; Gramer, L.J.; et al. The Establishment of a Pelagic *Sargassum* Population in the Tropical Atlantic: Biological Consequences of a Basin-Scale Long Distance Dispersal Event. *Prog. Oceanogr.* **2020**, *182*, 102269. [\[CrossRef\]](#)
4. Jung, J.; Duprey, N.N.; Foreman, A.D.; D’Olivo, J.P.; Pellio, C.; Ryu, Y.; Murphy, E.L.; Romshoo, B.; Kersting, D.K.; Cardoso, G.O.; et al. Equatorial Upwelling of Phosphorus Drives Atlantic N₂ Fixation and *Sargassum* Blooms. *Nat. Geosci.* **2025**, *18*, 259–1265. [\[CrossRef\]](#)
5. United Nations Environment Programme; Caribbean Environment Programme. *Sargassum* White Paper: Turning the Crisis into an Opportunity. In *Proceedings of the Ninth Meeting of the Scientific and Technical Advisory Committee (STAC) to the Protocol Concerning Specially Protected Areas and Wildlife (SPA) in the Wider Caribbean Region, Online, 17–19 March 2021*; Caribbean Environment Programme: Kingston, Jamaica, 2021.

6. Marsh, R.; Skliris, N.; Tompkins, E.L.; Dash, J.; Almela, V.D.; Tonon, T.; Oxenford, H.A.; Webber, M. Climate-Sargassum Interactions across Scales in the Tropical Atlantic. *PLoS Clim.* **2023**, *2*, e0000253. [CrossRef]
7. Schell, J.M.; Goodwin, D.S.; Volk, R.H.; Siuda, A.N. Preliminary Explorations of Environmental Tolerances and Growth Rates of Holopelagic *Sargassum* Morphotypes. *Aquat. Bot.* **2024**, *190*, 103723. [CrossRef]
8. Hatt, D.C.; Nauer, F.; Collado-Vides, L.; Campbell, J.E. Physiological Responses of Pelagic *Sargassum* (Phaeophyceae) to Thermal Stress Vary by Species and Morphotype. *Appl. Phycol.* **2025**, *6*, 1–19. [CrossRef]
9. United States Environmental Protection Agency. Basic Information on *Sargassum*. Available online: <https://www.epa.gov/habs/basic-information-sargassum> (accessed on 20 November 2025).
10. Perera-Valderrama, S.; Conruyt, G.; Rossin, L.; Petit, A.; Singh-Clarke, T.; Corbin, C. Strengthening Regional Cooperation: The Role of the Cartagena Convention in Addressing the *Sargassum* Inundations Challenge in the Wider Caribbean. *Harmful Algae* **2026**, *151*, 103028. [CrossRef] [PubMed]
11. United States Environmental Protection Agency. *Sargassum* Inundation Events (SIEs): Impacts on Aquatic Life and Associated Ecosystems. Available online: <https://www.epa.gov/habs/sargassum-inundation-events-sies-impacts-aquatic-life-and-associated-ecosystems> (accessed on 20 November 2025).
12. Resiere, D.; Valentino, R.; Nevière, R.; Banydeen, R.; Gueye, P.; Florentin, J.; Cabié, A.; Lebrun, T.; Mégarbane, B.; Guerrier, G.; et al. *Sargassum* Seaweed on Caribbean Islands: An International Public Health Concern. *Lancet* **2018**, *392*, 2691. [CrossRef] [PubMed]
13. Teyssier, M.; Desrosiers, C.; Hellio, C.; Kerninon, F. Assessing *Sargassum* Pressure on Coastal Habitats Using a Spatial and Temporal Approach at the Territorial Scale. *Ecol. Indic.* **2025**, *171*, 113211. [CrossRef]
14. Resiere, D.; Mehdaoui, H.; Florentin, J.; Gueye, P.; Lebrun, T.; Bateau, A.; Viguier, J.; Valentino, R.; Brouste, Y.; Kallel, H.; et al. *Sargassum* Seaweed Health Menace in the Caribbean: Clinical Characteristics of a Population Exposed to Hydrogen Sulfide during the 2018 Massive Stranding. *Clin. Toxicol.* **2021**, *59*, 215–223. [CrossRef]
15. Rodríguez-Martínez, R.E.; Gómez Realí, M.Á.; Torres-Conde, E.G.; Bates, M.N. Temporal and Spatial Variation in Hydrogen Sulfide (H₂S) Emissions during Holopelagic *Sargassum* spp. Decomposition on Beaches. *Environ. Res.* **2024**, *247*, 118235. [CrossRef]
16. SENKO Co., Ltd. *SP-SGT-P Replaceable Single Gas Detector Datasheet*; SENKO: Osan-si, Republic of Korea, 2025.
17. Silva, T.M.; Waked, D.; Bastos, A.C.; Gomes, G.L.; Closs, J.G.V.; Tonin, F.G.; Rossignolo, J.A.; do Valle Marques, K.; Veras, M.M. A Custom, Low-Cost, Continuous Flow Chamber Built for Experimental *Sargassum* Seaweed Decomposition and Exposure of Small Rodents to Generated Gaseous Products. *Heliyon* **2023**, *9*, e18787. [CrossRef] [PubMed]
18. Kwak, N.; Tsameret, S.; Mc Intyre, B.; Sobhanian, M.; Diaz-Brunet, D.; Bi, C.; Solo-Gabriele, H.; Li, J. Quantification of Sulfur Compound Emissions from *Sargassum* Strandings. *Mar. Pollut. Bull.* **2026**, *225*, 119262. [CrossRef] [PubMed]
19. Jouanno, J.; Almar, R.; Muller-Karger, F.; Morvan, G.; van Tussenbroek, B.; Benshila, R.; Marchesiello, P.; Appeaning Addo, K. Socio-Ecological Vulnerability Assessment to *Sargassum* Arrivals. *Sci. Rep.* **2025**, *15*, 9998. Available online: <https://www.nature.com/articles/s41598-025-94475-3> (accessed on 2 November 2025). [CrossRef]
20. Madinair.fr. Surveillance Continue H₂S et NH₃. Available online: <https://www.madinair.fr/surveillance-continue-sargasses> (accessed on 2 November 2025).
21. ENVEA. *ENVEA Cairnet Autonomous Networks of Sensor-Based Mini-Stations Datasheet: Air Quality Monitoring Systems*; ENVEA: Poissy, France, 2025. Available online: https://envea.global/wp-content/uploads/2025/01/envea_cairnet_air-quality-networks-sensor-based-mini-stations_en-2.pdf (accessed on 2 November 2025).
22. Interreg Caribbean. Interreg Caribbean SARG'COOP. Available online: <https://interreg-caraibes.eu/sargcoop> (accessed on 30 November 2025).
23. CMAS: *Community Modeling and Analysis System C-TOOLS*, version 5.1; Community Modeling and Analysis System: Chapel Hill, NC, USA, 2025. Available online: <https://cmascenter.org/c-tools/> (accessed on 2 December 2025).
24. Isakov, V.; Barzyk, T.M.; Smith, E.R.; Arunachalam, S.; Naess, B.; Venkatram, A. A Web-Based Screening Tool for near-Port Air Quality Assessments. *Environ. Model. Softw.* **2017**, *98*, 21–34. [CrossRef]
25. CMAS: *Community Modeling and Analysis System C-PORT Research Grade Screening Tool*, version 5.1; Community Modeling and Analysis System: Chapel Hill, NC, USA, 2025. Available online: <https://cmascenter.org/c-tools/c-port.cfm> (accessed on 2 December 2025).
26. Resiere, D.; Kallel, H.; Florentin, J.; Banydeen, R.; Compton, K.; Gueye, P.; Mehdaoui, H.; Nevière, R. *Sargassum* Seaweed in the Caribbean: A Major Public Health Problem Still Unsolved. *J. Glob. Health* **2023**, *13*, 03017. [CrossRef]
27. NIOSH *Occupational Exposure Banding E-Tool*, version 1.1; Centers for Disease Control and Prevention: Atlanta, GA, USA, 2026. Available online: <https://wwwn.cdc.gov/Niosh-oeb/Resource/Calculator> (accessed on 7 January 2026).
28. Hu, C.; Barnes, B.B.; Qi, L.; Gower, J.F.R.; Jiao, J.; Xie, Y. Monitoring Pelagic *Sargassum* in the Atlantic Ocean from Space: Principles and Practices. *Harmful Algae* **2025**, *144*, 102840. [CrossRef]
29. León-Pérez, M.C.; Reisinger, A.S.; Gibeaut, J.C. Spatial-Temporal Dynamics of Decaying Stages of Pelagic *Sargassum* spp. along Shorelines in Puerto Rico Using Google Earth Engine. *Mar. Pollut. Bull.* **2023**, *188*, 114715. [CrossRef]

30. Uribe-Martínez, A.; Berriel-Bueno, D.; Chávez, V.; Cuevas, E.; Almeida, K.L.; Fontes, J.V.H.; van Tussenbroek, B.I.; Mariño-Tapia, I.; de los Ángeles Liceaga-Correa, M.; Ojeda, E.; et al. Multiscale Distribution Patterns of Pelagic Rafts of Sargasso (*Sargassum* spp.) in the Mexican Caribbean (2014–2020). *Front. Mar. Sci.* **2022**, *9*, 920339. [CrossRef]
31. Arellano-Verdejo, J.; Santos-Romero, M.; Lazcano-Hernandez, H.E. Use of Semantic Segmentation for Mapping *Sargassum* on Beaches. *PeerJ* **2022**, *10*, e13537. [CrossRef]
32. Iporac, L.A.; Hatt, D.; Bally, N.; Castro, A.; Cardet, E.; Mesidor, R.; Olszak, S.; Duran, A.; Burkholder, D.; Collado-Vides, L. Community-Based Monitoring Reveals Spatiotemporal Variation of Sargasso Inundation Levels and Morphotype Dominance across the Caribbean and South Florida. *Aquat. Bot.* **2022**, *182*, 103546. [CrossRef]
33. Rutten, J.; Arriaga, J.; Montoya, L.D.; Mariño-Tapia, I.J.; Escalante-Mancera, E.; Mendoza, E.T.; van Tussenbroek, B.I.; Appendini, C.M. Beaching and Natural Removal Dynamics of Pelagic *Sargassum* in a Fringing-Reef Lagoon. *J. Geophys. Res. Oceans* **2021**, *126*, e2021JC017636. [CrossRef]
34. Banydeen, R.; Rejaudry Lacavalerie, M.; Savoyen, L.; Monthieux, A.; Jean-Laurent, M.; Florentin, J.; Radouani, F.; Mehdaoui, H.; Resiere, D.; Neviere, R. Sargassum Inundations and the Risk of Hypertension Disorders Among Pregnant Women Living in the French Caribbean Island of Martinique. *Int. J. Environ. Res. Public Health* **2024**, *21*, 1612. [CrossRef]
35. *ArcGIS Pro*, version 3.6.0; Environmental Systems Research Institute: Redlands, California, USA, 2025.
36. Dawson, N.; Fischer, J.; Kuhn, M.; Pasotti, A.; Mhugent; Rouzard, D.; Bruy, A.; Sutton, T.; Dobias, M.; Pellerin, M.; et al. *Qgis/QGIS*, version 3.44.5; Open Source Geospatial Foundation: Beaverton, OR, USA, 2025.
37. National Centers for Environmental Information (NCEI). Available online: <https://www.ncei.noaa.gov/> (accessed on 7 December 2025).
38. US EPA. *Meteorological Processors and Accessory Programs, AERMET*, version 24142; US EPA: Washington, DC, USA, 2025. Available online: <https://www.epa.gov/scram/meteorological-processors-and-accessory-programs> (accessed on 4 December 2025).
39. Hijmans; Robert, J. *Second-Level Administrative Divisions, Martinique, 2015*; Stanford Digital Repository, 2018; University of California Berkeley Museum of Vertebrate Zoology: Berkeley, CA, USA; International Rice Research Institute: Laguna, Philippines, 2015. Available online: <https://purl.stanford.edu/pz383ny7457> (accessed on 7 December 2025).
40. Grant, R.; Boehm, M.T. Emissions of H₂S from Hog Finisher Farm Anaerobic Manure Treatment Lagoons: Physical, Chemical and Bio-Logical Influence. *Atmosphere* **2022**, *13*, 153. [CrossRef]
41. United States Environmental Protection Agency. *Development of Emissions Estimating Methodologies for Lagoons and Basins at Swine and Dairy Animal Feeding Operations*; EPA: Washington, DC, USA, 2012.
42. Chang, J.; Hanna, S. Air Quality Model Performance Evaluation. *Meteorol. Atmospheric Phys.* **2004**, *87*, 167–196. [CrossRef]
43. Kumar, A.; Luo, J.; Bennett, G.F. Statistical Evaluation of Lower Flammability Distance (LFD) Using Four Hazardous Release Models. *Process Saf. Prog.* **1993**, *12*, 1–11. [CrossRef]
44. ANSES. *Sargassum Seaweed: Limit the Exposure of Residents and Workers to Hydrogen*. Available online: <https://www.anses.fr/en/content/sargassum-seaweed-limit-exposure-residents-and-workers-hydrogen-sulphide> (accessed on 13 December 2025).
45. Jin, D.; Wang, A.; Dalton, T. Economic Impacts of Sargassum Events in Puerto Rico, USVI, and Coastal Florida. *Harmful Algae* **2025**, *150*, 102996. [CrossRef] [PubMed]
46. CARICOOS. *Sargassum Tracker*. Available online: <https://www.caricoos.org/sargassum> (accessed on 14 December 2025).
47. CoastWatch. Caribbean and Gulf of America Regional Node—Weekly *Sargassum* Inundation Risk (SIR v1.4). Available online: <https://cwcgom.aoml.noaa.gov/SIR/> (accessed on 14 December 2025).
48. University of South Florida, College of Marine Science. Optical Oceanography Laboratory. Available online: <https://optics.marine.usf.edu/index.html> (accessed on 14 December 2025).
49. CLS. *SAMtool: Detection and Monitoring of Sargassum*; CLS Datastore Ocean & Water: Ramonville-Saint-Agne, France, 2026.
50. United States Environmental Protection Agency. Management Methods for *Sargassum* Inundation Events (SIEs). Available online: <https://www.epa.gov/habs/management-methods-sargassum-inundation-events-sies> (accessed on 14 December 2025).
51. U.S. Fish and Wildlife Service. *Endangered Species Act of 1973*; U.S. Fish and Wildlife Service: Falls Church, VA, USA, 1973; pp. 1531–1544.
52. Lajara, F.G.R.; Samten, K. (Ligocsicnarf89) English: Sargasso in Playa Punta Tuna, Maunabo. Available online: [https://commons.wikimedia.org/wiki/File:Sargasso_in_Playa_Punta_Tuna_\(2025\)-1.jpg](https://commons.wikimedia.org/wiki/File:Sargasso_in_Playa_Punta_Tuna_(2025)-1.jpg) (accessed on 17 December 2025).
53. Google Maps. *Composite Screen Capture Image of Martinique in C-PORT*; Satellite map. Google: Mountain View, CA, USA, 2025. Available online: <https://ctools.its.unc.edu/ctools/cport/> (accessed on 1 December 2025).

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