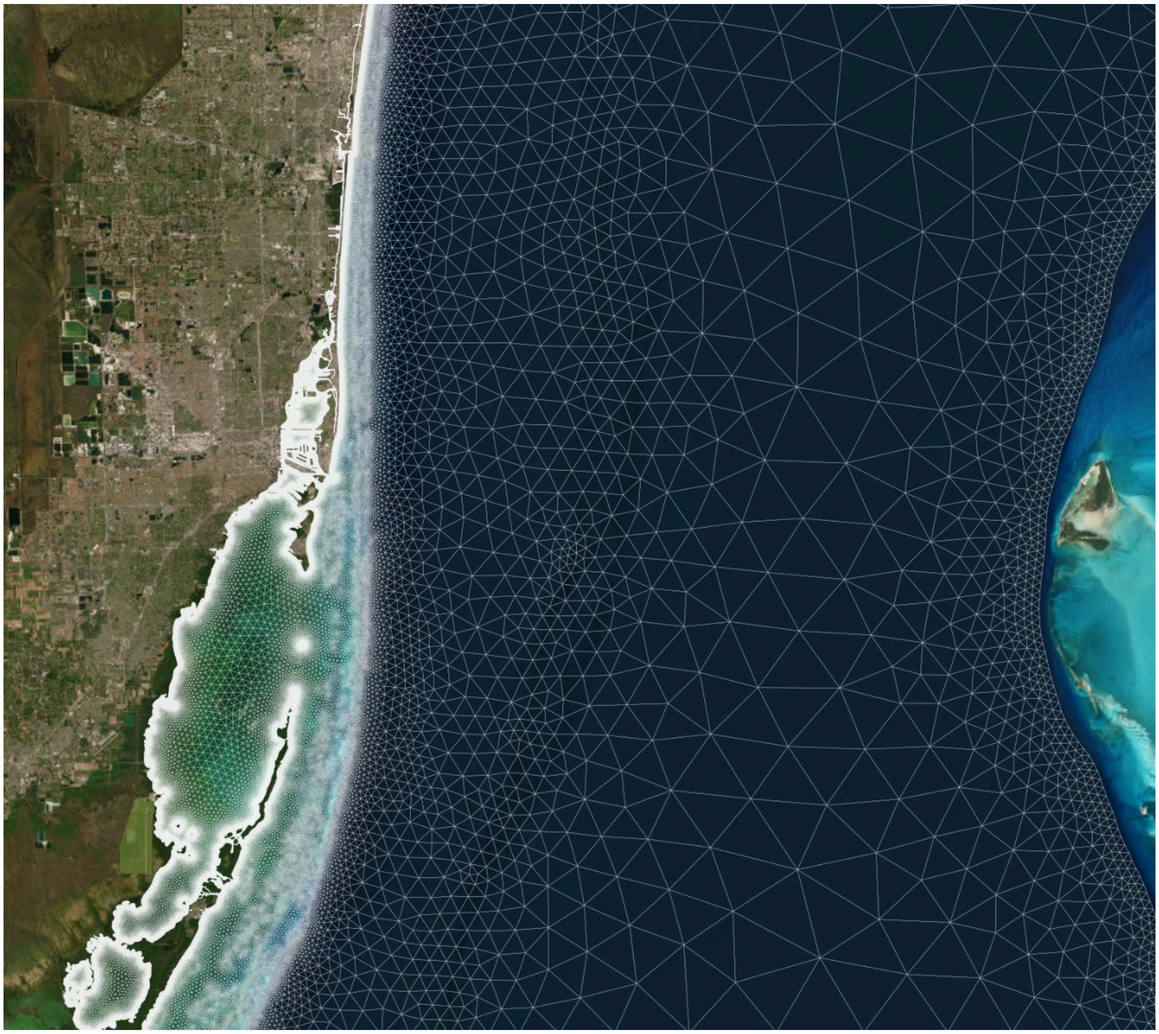
Hydrographic connections of inland water to diseased corals and water quality sites in SE FL



Hydrographic connections of inland water to diseased corals and water quality sites in SE FL

Final Report

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Acknowledgements

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Management Summary (300 words or less)

This report investigates the hydrographic connections between inland water sources and the incidence of coral diseases, specifically Stony Coral Tissue Loss Disease (SCTLD), on reefs in Southeast Florida. Using the high-resolution ocean model SLIM, the study simulated the dispersal of seven key analytes present in inland water released from four main inlets: Government Cut, Baker's Haulover, Port Everglades, and Hillsboro. These analytes include nitrite, nitrate, total nitrogen, orthophosphate, total phosphorus, silicate, and total suspended solids. The study period spanned from September 2018 to August 2021, providing a comprehensive view of seasonal variations and their impact on nearby coral reefs.

The findings indicate that inland water plumes, particularly from Government Cut, have a substantial footprint, impacting most of the reefs in the Coral ECA and extending south of the inlet into Biscayne Bay. The data revealed that nutrient loads from these inlets, especially during the wet season, could influence the incidence of SCTLD on nearby reefs. Government Cut was identified as the largest source of pollutants, contributing to higher concentrations of harmful analytes in the reef areas. This impact was more pronounced during periods of high rainfall and increased inlet flow rates, underscoring the seasonal nature of the problem.

This modeling approach aids in identifying the primary sources of harmful analytes, which is crucial for targeted coral disease mitigation strategies. By understanding the pathways and impact of these nutrients, management efforts can be more effectively directed. The study highlights the importance of managing inland water quality to protect coral reefs and suggests that efforts should focus on mitigating runoff during the wet season to reduce SCTLD impact.

The outcomes of this project will be incorporated into ongoing coral disease response efforts. These efforts aim to improve understanding of the scale and severity of the coral disease outbreak on Florida's Coral Reef, identify primary and secondary causes, and recommend management actions to remediate disease impacts and restore affected resources. This research provides essential insights that lay the groundwork for effective management actions to mitigate coral disease and promote reef resilience.

Executive Summary (max 1 page)

Coral reefs in Southeast Florida are experiencing significant declines due to Stony Coral Tissue Loss Disease (SCTLD), which is exacerbated by environmental factors such as nutrient pollution. This study aims to understand the hydrographic connections between inland water sources and diseased coral reefs to inform better management strategies. Utilizing the multiscale ocean model SLIM, the research simulated the dispersal of nutrients from four major inlets in Southeast Florida: Government Cut, Baker's Haulover, Port Everglades, and Hillsboro. Data on flow rates and water quality were sourced from the South Florida Water Management District's DBHydro database. The model accounted for seasonal variations and complex coastal interactions to estimate nutrient loads and their impact on coral reefs.

The results revealed that the nutrient loads from the inlets, particularly during the wet season, could influence SCTLD incidence on nearby reefs. Government Cut was identified as the largest source of pollutants, with a notable impact extending both north and south of the inlet. The study suggests a correlation between nutrient concentrations and SCTLD lesions, especially during periods of high rainfall and increased inlet flow rates. These findings highlight the importance of managing inland water quality to protect coral reefs. The model provides a detailed understanding of how nutrients from inland sources are transported to reefs, offering valuable insights for targeted intervention strategies. The seasonal variations in nutrient loads suggest that management efforts should focus on mitigating runoff during the wet season to reduce SCTLD impact.

Based on these insights, several recommendations are proposed. Further studies should identify specific sources of nutrient pollution contributing to SCTLD. Extending the temporal and geographical scope of monitoring is crucial to capture recent trends and additional inlets. Moreover, developing an operational forecasting system to predict water quality conditions in real-time would aid in proactive management. This study provides crucial insights into the hydrographic dynamics affecting coral reefs in Southeast Florida. By identifying key nutrient sources and their impact on SCTLD, it lays the groundwork for effective management actions to mitigate coral disease and promote reef resilience.

Table of Contents

1. INTRODUCTION

Spatiotemporal patterns of coral diseases on reefs are driven by a complex array of environmental, anthropogenic, and host-specific factors that affect pathogen virulence and host susceptibility (Work et al. 2008, Williams et al. 2010). As coral coverage continues to decline worldwide (Hughes et al. 2017, Williams & Graham 2019), identifying disease drivers will be key to designing effective local mitigation strategies and prioritizing disease intervention resources to minimize the loss of coral (Maynard et al. 2015). In southeast Florida, stony coral tissue loss disease (SCTLD) has decimated coral populations and persists in the endemic region on highly and intermediately susceptible species (Hayes et al 2022, Toth et al 2023). Monthly monitoring of *Orbicella faveolata* colonies showed that disease incidence varies temporally, with total infections highest during warm, wet season, and lowest in the dry season (Walker et al. 2022). Effective disease interventions that halt lesion progression have provided the unique opportunity to explore spatiotemporal patterns of SCTLD incidence. Spatial and temporal statistical models were created to investigate the relationship of monthly SCTLD incidence on 37 large coral colonies (> 2 m diameter) to various abiotic environmental drivers (e.g., depth, seawater temperature, nutrient concentrations) and human drivers (e.g., density of septic tanks, outflow from the Inlet Contributing Areas (ICA), and distance to offshore outfall locations) over 34 months. Five predictors explained 60.6% of the model variation in the number of SCTLD lesions over time: mean temperature in the 90 days prior (36.7%), mean rainfall in the 90 (9%) and 30 (6.9%) days prior, the number of Hot Snap events in the 60 days prior (5.7%), and flow out of the ICA inlets over the previous 7 days (2.3%). Analyses of reef water quality sites found that inlet flow, rainfall, and wind predictors explained 79% and 55% of the overall variation in Orthophosphate and Nitrate concentrations, respectively. These results suggest that SCTLD incidence is exacerbated seasonally by excessive nutrients during increased rainfall and inlet flow rates in high temperatures (Walker et al. 2023).

After identifying empirical links between inland water and nutrients and disease on the reef, the next steps were to use these data to identify the main nutrient sources. Thus, the Second-generation Louvain-la-Neuve Ice-ocean Model (SLIM) was implemented to simulate the release of nutrients (or some other pollutant) from the inlets and evaluate their connectivity to the neighboring reefs using Eulerian tracers and to backtrack Lagrangian particles from reef sites to identify their potential source. SLIM is an unstructured-mesh hydrodynamic model that simulates flows from the river to the coastal ocean. It relies on complex numerical methods to achieve a high accuracy, even for very complex coastlines and bathymetry. Similar modeling has been done in Florida to estimate larval connectivity and SCTLD transport (King et al 2023; Dobbelaere et al 2020). However, the previous models were not built to adequately model inland waters entering the ocean.

Project Goals and Tasks:

The goal of this work was to apply the multiscale ocean model SLIM to evaluate the connectivity between SE FL inlets and the neighboring reefs to determine the inland source of high nutrient water causing the increased concentrations in the reef water quality surveys and SCTLD incidence on large *Orbicella faveolata* colonies.

Specific tasks were the following:

1. Simulating the fine-scale details of the ocean dynamics near inland water inlets and over coral reefs with the new SLIM setup from Sep 2018 to Aug 2021, for which we had disease incidence observations.

2. Simulating inland water plumes from the four main inlets (Government Cut, Baker's Haulover, Port Everglades, and Hillsboro) in Miami-Dade and Broward counties by considering the non-continuous release dynamics of the nutrients/pollutants in the coastal environment.

3. Estimating coral reef exposure time to inland water plumes, i.e., how long the inland plumes stay over the reefs to develop heat maps highlighting the reefs that were most exposed to the inland water plumes.

4. Identifying the inland water sources that could be responsible for observed SCTLD infections to neighboring coral populations. SCTLD infection histories from the large coral monitoring were used to run a *backward-in-time* inland water plume simulation starting from the coral at the time the infection was first observed (or some days before that date) and then track the causative plume backward to identify its potential origin.

The outcomes of this project will be incorporated into an on-going coral disease response effort, which seeks to improve understanding about the scale and severity of the coral disease outbreak on Florida's Coral Reef, identify primary and secondary causes, identify management actions to remediate disease impacts, restore affected resources, and ultimately prevent future outbreaks.

Priorities Addressed & Reef Management Application:

This project addresses many long-standing SEFCRI LBSP management priorities (projects 18, 28, 29) and Our Florida Reefs recommended management actions (N-71, N-97, S-28, S-104) as well as the 2023 SCTLD Research Priorities 2 and 3, and the Resilience Action Plan for Florida's Coral Reef (2021-2026) goal 1 objectives 1 and 3.

This information will allow managers like Florida's Coral Reef Coordination Team supporting the South Florida Ecosystem Restoration Task Force to plan and prioritize actions to mitigate and reduce nutrients (or other pollutants) in the source water reaching and impacting the reefs.

2. METHODS

2.1. ICA flow rates and water quality data

The South Florida Water Management District's DBHydro monitoring stations and database collects hydrologic, meteorologic, hydrogeologic and water quality data and is the source of historical and up-to-date environmental data for the 16-county region covered by the District. Using this database, estimates of water flow from individual Inlet Contributing Areas (ICAs) to the inlet mouth were calculated (Fig. 1). A sub-set of the DBHydro monitoring stations that independently captured the full extent of the flow within each ICA were identified. Stations that were upstream or downstream from each other, and therefore were artificially inflating summed flow values, were identified using a map of the flow channel paths throughout the ICAs and one of each pair removed (sensu et al. 2022). Through this iterative pairwise process, 20 stations were identified for inclusion in the analyses and used to generate flow data for each ICA across the entire project period.

Using the 20 selected stations, we sourced all flow data and calculated the time difference between each row grouped by the station. On average, most stations reported a flow rate every 2 min, however, this was highly variable through time, (minimum time was as fast as 1 sec, maximum was several days or even weeks if a station went down). To account for this, we binned the data into 5-min intervals and calculated mean flow for each interval for each station to give an overall mean flow rate per 5-min interval for each ICA inlet over the project time period.

The water quality data used for this analysis were from a joint NOAA-Florida Department of Environmental Protection (FDEP) assessment program (Whitall et al 2019). The period of record used for this analysis was Sep 1, 2018, to Sep 1, 2021. To analyze water quality data at the reefs themselves, only water collected using Niskin bottles at the depth of the reef (not surface waters) were included in this analysis. The sampling protocol involved starting sample collection as far into the ebb tide as possible and at a minimum of two to three hours after the peak high tide. Sampling equipment was rinsed with deionized water three times between sites and then three times with site water once on site. Field clean equipment blanks were collected (at least one per day and at least one per 20 samples collected). Analytical chemistry was performed via standard methods. Post-processing was applied to address the relatively larger numbers of values below the method detection limits (Flynn 2010). A detailed description of the water quality data, including methods, temporal and spatial patterns, and data interpretation, can be found in Whitall et al. (2019) and Whitall and Bricker (2021). Using these water quality data, we calculated the estimated nutrient loads for each ICA so we could apportion how much was coming out of each inlet (see timeseries of flow rate and analyte load at Government Cut inlet in Fig. 2). We did this by using the data from the four centroid inlet sites (GOC002, BAK020, PEV040 and HIL050) - see section 2.3).

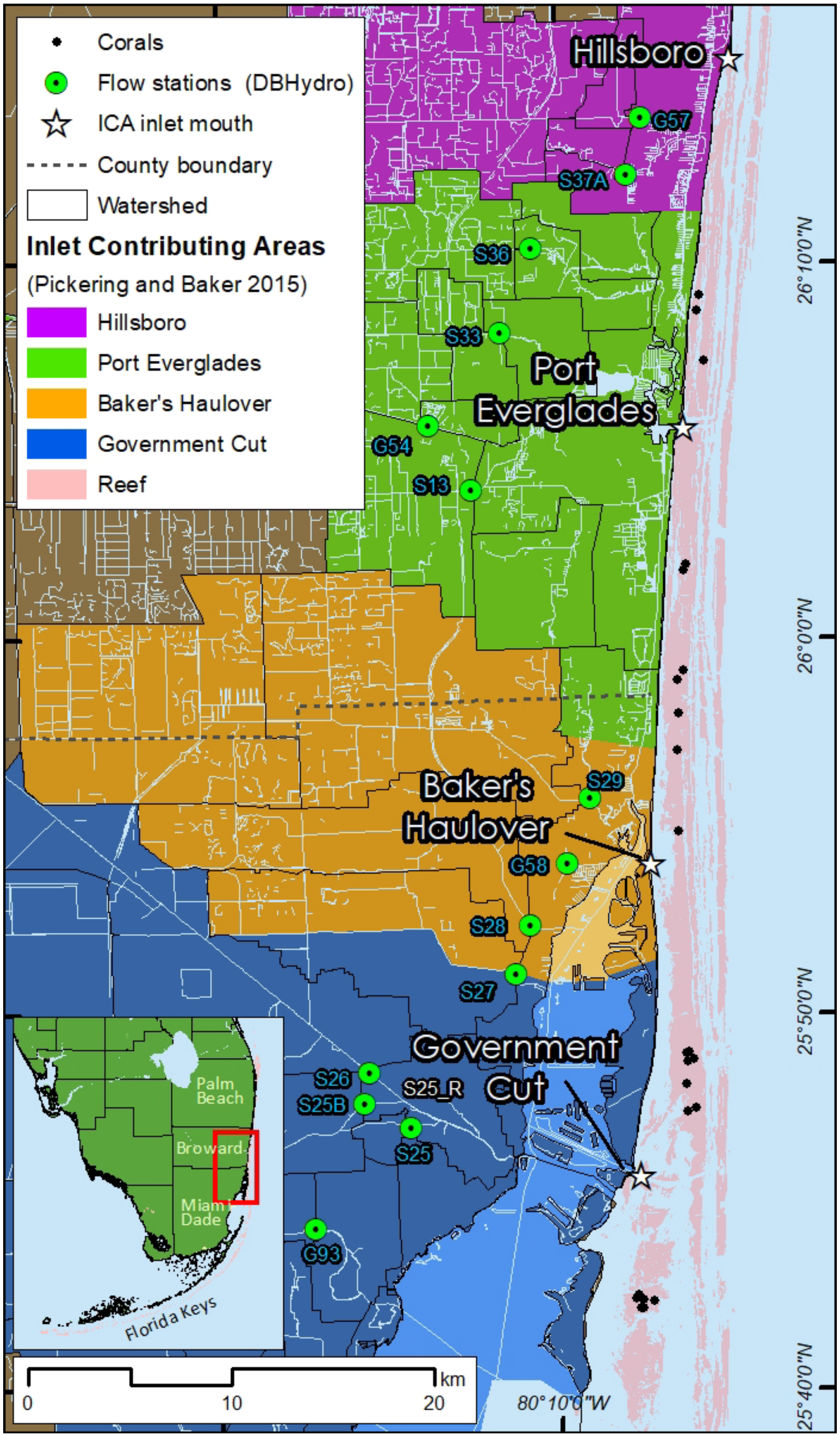


Figure 1. Map of the project area depicting the Inlet Contributing Areas, DBHydro flow stations, the inlet mouths, and large corals.

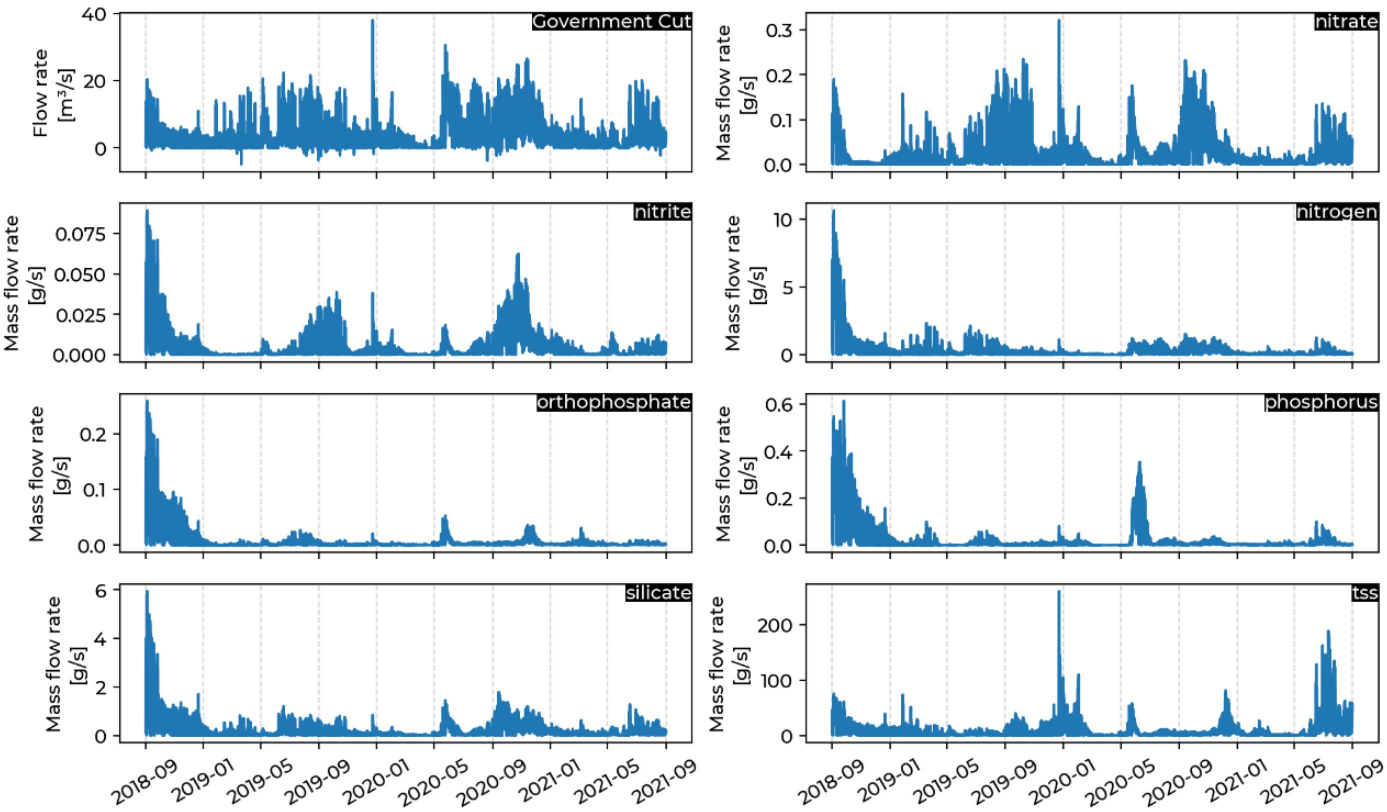


Figure 2. Time series of flow rates and estimated mass flow rates of the different analytes at Government Cut inlet.

2.2. Hydrodynamic modeling

We simulated the ocean circulation along East Florida's coastline with the multiscale ocean model , which has already been extensively applied and validated in Florida's coastal waters (Frys et al., 2020; Dobbelaere et al., 2020; Dobbelaere et al., 2022). Here, we considered an area of interest situated between Florida and the Bahamian Banks, and between 25.2°N and 27.5°N (Fig. 3). The Government Cut, Baker's Haulover, Port Everglades, and Hillsboro ICA's inlets were included in the area of interest as open boundaries through which water flow and analytes could enter in the model domain. SLIM uses an unstructured mesh whose resolution can be locally increased to accurately represent fine-scale flow features, such as those produced near the inlets and over the nearshore and offshore coral reefs. The mesh was generated with GMSH (Geuzaine & Remacle, 2009) using the Python package seamsh. The model resolution reached 25 m around the inlets, 50 m along the coastlines, 100 m over the coral reefs, and a few km further offshore, in the Florida Straits (Fig. 3). The model bathymetry was obtained by combining data from NCEI Coastal Relief Model (3 arcseconds) and NCEI Continuously Updated Digital Elevation Model (1/9 arcseconds). Reef polygons were extracted from FWC's unified reef map. The model was forced with winds from ECMWF-ERA5, large-scale currents (including tides) from HYCOM-GoM and processed DBHydro flow rates at the inlet boundaries. The model was run between September 1, 2018, and September 1, 2021, with hourly exports of the simulated sea surface elevation and currents.

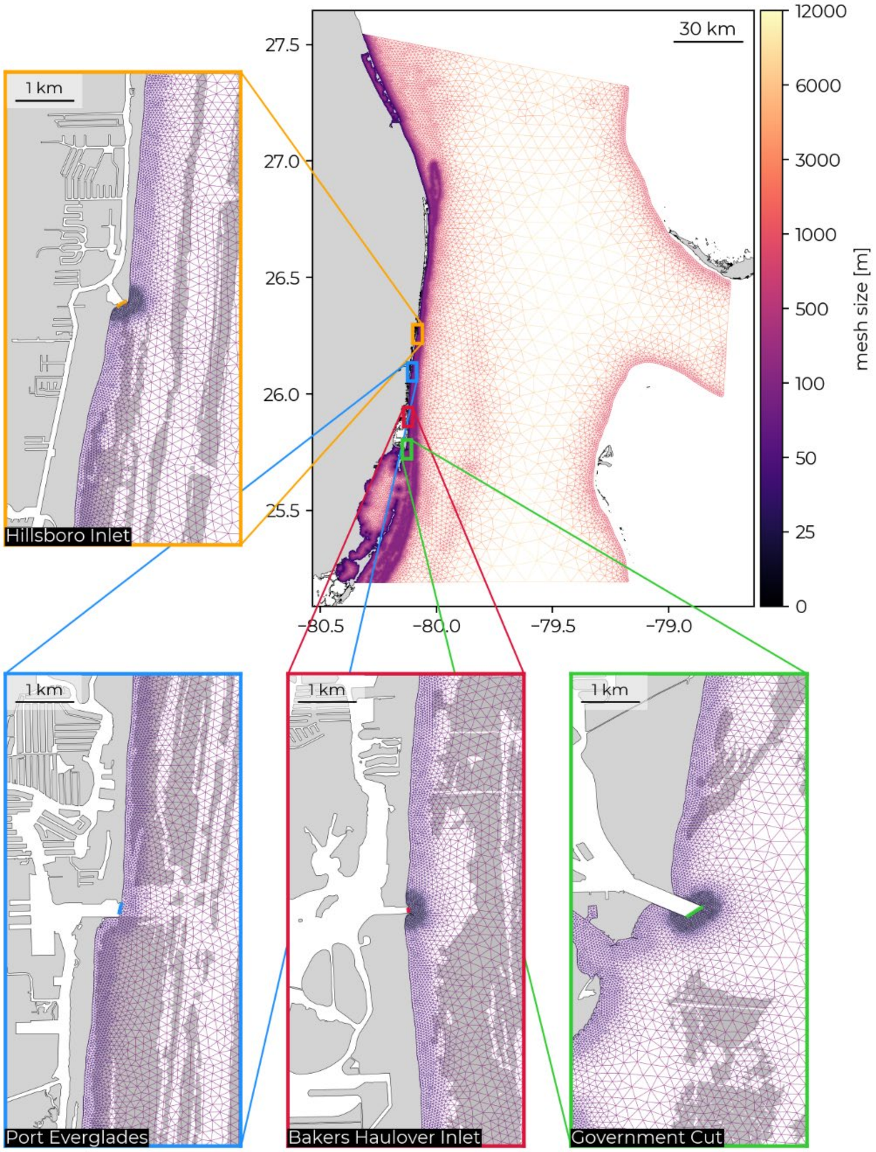


Figure 3: Model mesh and close-up views near the four ICA inlets, where the model resolution reaches 25 m. The inlet open boundaries where flow rates and analyte loads were imposed are highlighted with thick colored lines. The land is shown in light grey and reef polygons in dark grey.

2.3. Inland water plume dispersal

As a first step, we used the modeled currents to simulate the dispersal of inland water plumes of an unspecified pollutant from the four primary inland water inlets: Government Cut, Baker's Haulover, Port Everglades, and Hillsboro. Our inland water dispersal model employs a Lagrangian approach, representing the plume as a collection of inland water parcels transported by ocean currents and dispersed by oceanic turbulence. This method is well-suited for localized pollutant sources such as inlets. The model is inspired by the Particle Tracking Model (PTM) developed by the U.S. Army Corps of Engineers (USACE, MacDonald et al., 2006). All the simulations were run with a time step of 450 seconds. The number of particles released from each inlet was proportional to the flow rate at this inlet, with a maximum of 200 particles per release over a time step.

As a second step, we considered a more thorough decomposition of the inland water plumes into 7 specific analytes for which we had load measurements at each inlet. These were nitrite, nitrate, total nitrogen, orthophosphate, total phosphorus, silicate and total suspended solids (TSS). Mass of each analyte was attributed to each particle based on the analyte concentration measured at the inlet. The total mass of analyte released during a given time step of the simulation was obtained by multiplying the flow rate (in m^3/s) at the inlet by the analyte concentration (in $g/m^{3)}$ and the time step duration (in *s*). This total mass (in *g*) was then divided equally between all the particles released during that time step. The instantaneous analyte concentration within a given mesh element was then computed by dividing the total mass of analyte in the element by its volume, obtained as the product of the element are by the simulated water height in the element. This concentration was also computed over reef polygons to estimate coral reef exposure to the analytes released at each of the inlets. Reef polygons were extracted from the coral and hardbottom layer of the Unified Reef Map (FWC-FWRI, 2017) and intersected with 500 m × 500 m grid.

2.4. Reefs' inland water exposure time

The simulated inland water plumes, both for a generic pollutant and for the different water quality analytes, was then used to estimate the exposure of nearshore reefs to pollution originating from inland sources. To achieve this, we overlaid a 500 m × 500 m grid on the sea surface above the coral reefs and calculated the number of Lagrangian inland water parcel trajectories intersecting each grid element during each month of the three-year period that we simulated. By dividing the number of trajectories crossing each grid element in each month by the total number of trajectories originating from inland sources during that time, we generated a probability map. This map indicates the likelihood of each grid element being impacted by inland water from inland sources during that month. We have previously employed a similar approach to estimate Qatar's coastal infrastructures vulnerability to oil spills (*Anselain et al., 2023*). The resulting heat maps highlight reefs most exposed to inland water plumes and indicate the seasonal variability of this exposure

2.5. Backtracking

Finally, we used a backtracking approach to pinpoint the inlets most likely responsible for discharging inland water that adversely affected the monitored large corals prior to the observation of new SCTLD lesions. We continuously released particles at the location of the large corals during the 10 days preceding the observation of new lesions. This seeding period was chosen as it matches the characteristic infection time for SCTLD obtained from both modeling and transmission experiments (*Dobbelaere et al, 2020*). We then simulated the dispersal of these particles backward in time over a 25-day period. This duration was selected as it is sufficiently long to allow for particles to travel to the southernmost inlet at Government Cut (see Fig. A1 in Appendix). We then computed the cumulative number of particles inside each mesh element during each model time step. This value was normalized to obtain a probability density function for the presence of particles in the mesh elements during the simulation. We then computed the probability for particles to originate from each inlet by integrating this probability density function on all elements within 500 m of each inlet.

Alternatively, the impact of inland water plumes from each inlet on the reef sites has also been evaluated by computing the analyte concentration time series at the reef sites. These time series were interpolated from the concentration fields described in section 2.3.

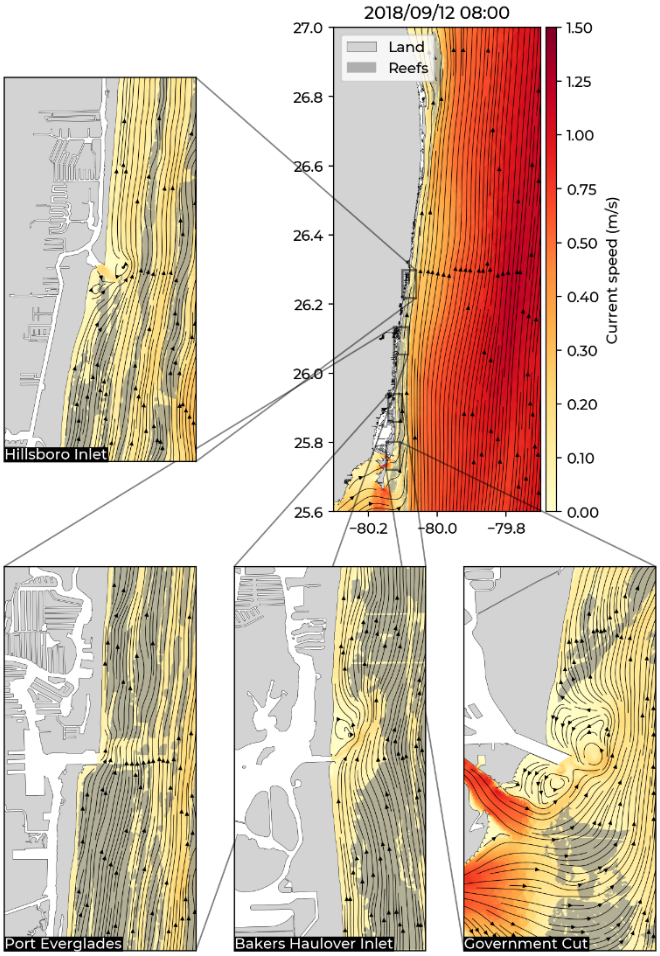
3. RESULTS

The simulated ocean circulation patterns along East Florida's coastline are predominantly northward under the influence of the Florida Current (Fig. 4). The primary northward ocean circulation is however influenced by tidal currents, which introduce oscillatory dynamics that can alter the flow direction, occasionally causing it to reverse and move southward. Additionally, this northward circulation is affected by the passage of (sub)mesoscale baroclinic eddies, which induce meandering in the Florida Current and can further influence changes in its direction. In addition to these two physical processes, the ocean currents interact with the coral reefs along the coast. As those reefs are shallower and have a higher rugosity than the sandy seabed, they tend to slow down and deflect the ocean currents. All these changes and variability in the ocean circulation patterns in turn affect the dispersal of inland water plumes originating from the four inlets. While they tend to move north, they can also be flushed southward and hence affect reefs not directly downstream of the inlets.

The footprint of each inlet can be assessed for each of the analytes present in the inland water. For the sake of illustration, we only show here the results for nitrogen but the same has been done for the other six analytes for which we had load measurements at each inlet (see Appendix). We computed the mean nitrogen concentration over both the wet (May to October) and dry (November to April) seasons over the 3-year period that we simulated (Fig. 5, top and middle panels). While the analyte plumes extend mostly north of each of the source inlets, they also have a non-negligible southern footprint that extends over tens of kilometers. This is particularly the case for Government Cut and Baker's Haulover inlets whose inland water plumes clearly intrude into Biscayne Bay.

Government Cut and Baker's Haulover also discharge the largest amount of pollutants leading to inland water plumes with a higher analyte concentration. As these two inlets are further the southernmost, they have the most detrimental effect on the marine environment. When comparing wet and dry seasons, we observe that inland water plumes generally have a larger analyte concentration during the wet season. This is again particularly the case for Government Cut and Baker's Haulover (Fig. 5, bottom panels).

When looking more specifically at the analyte concentration over each reef, we see that Government Cut's inlet not only has the largest footprint in terms of surface area but also exhibits the highest concentration of inland water over the reefs across that area (Fig. 6). This is due to both its southern location and its highest pollutants load. While Government Cut, Baker's Haulover and Port Everglades inlets predominantly impact reefs north of the inlets, analyte concentrations from Hillsboro's inlet are largest over reefs south of the inlet.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Reefs
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Current speed (m/s)
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Hillsboro Inlet
Port Everglades
Bakers Haulover Inlet
Government Cut

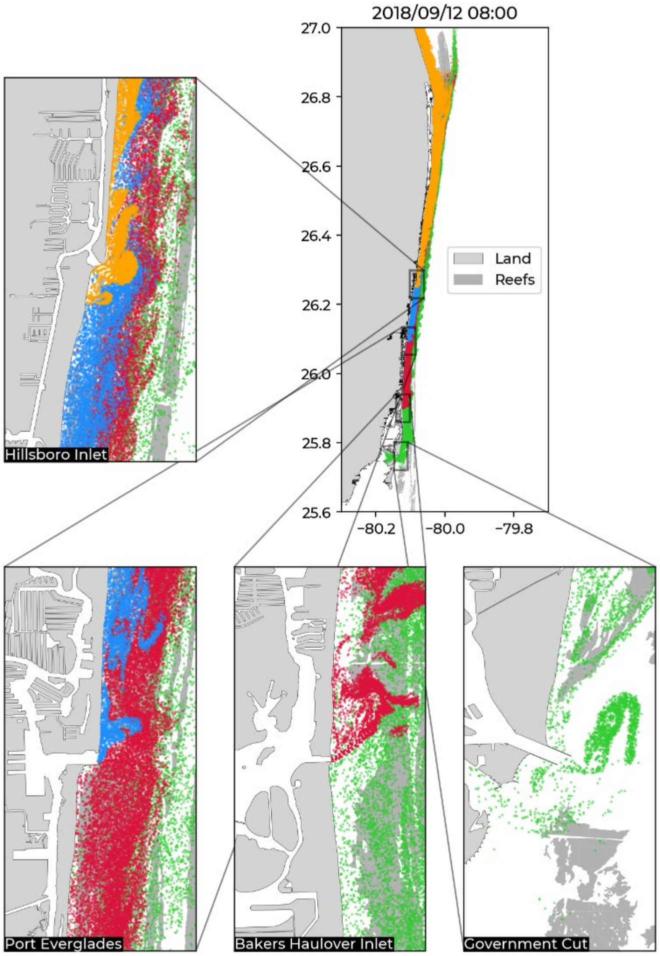

Figure 4: Snapshot of the simulated currents near the inlets (top) and the position of the pollutant particles released from the different inlets (bottom). The land is shown in light gray and coral reefs in darker gray. This illustrates how the flow rates at the inlets and small-scale eddies are captured by the model.

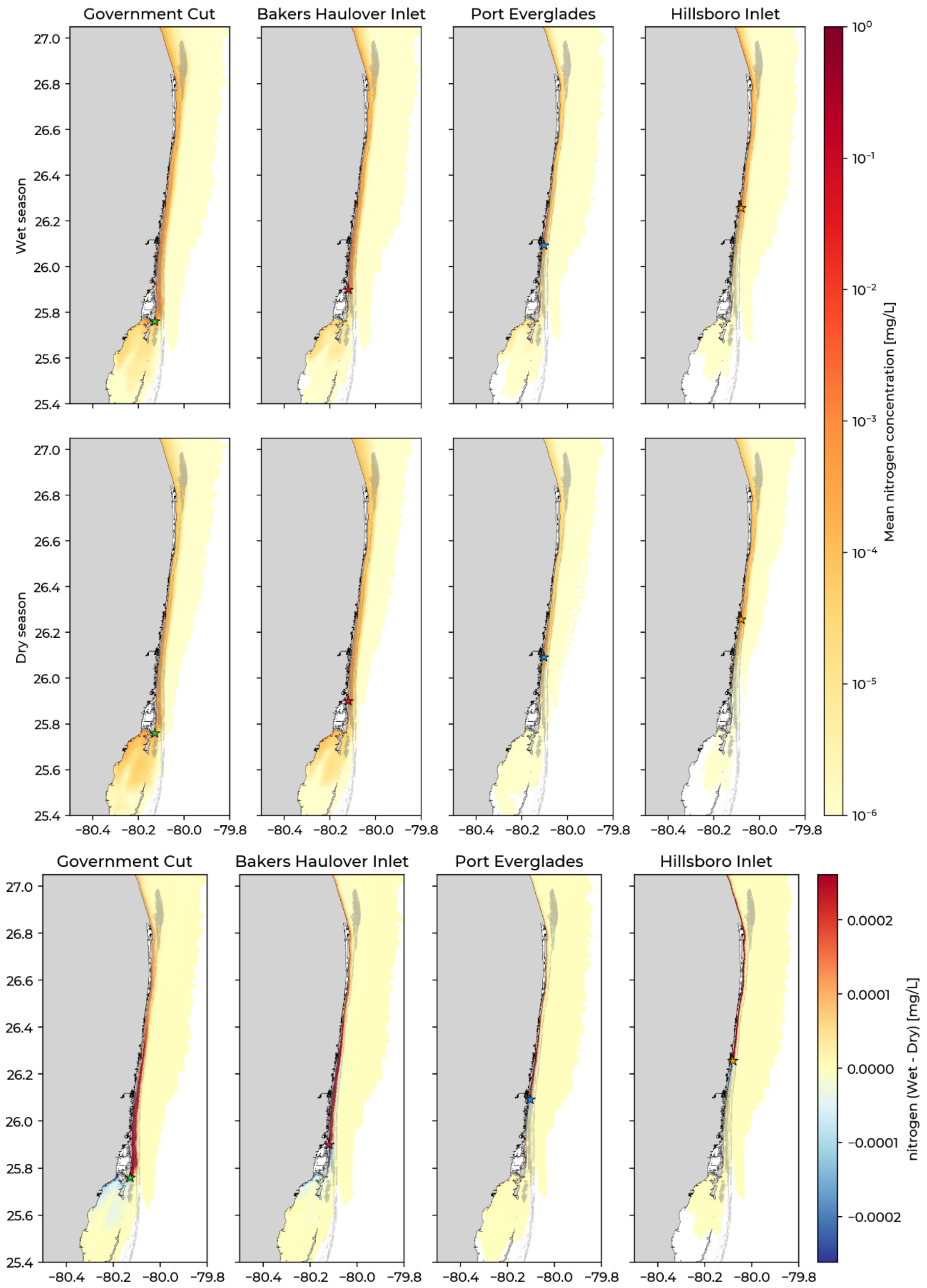

Figure 5: Seasonal mean concentration of nitrogen originating from the different inlets for the wet (top panels) and dry seasons (middle panels). The difference in concentration between wet and dry seasons is shown in the bottom panel.

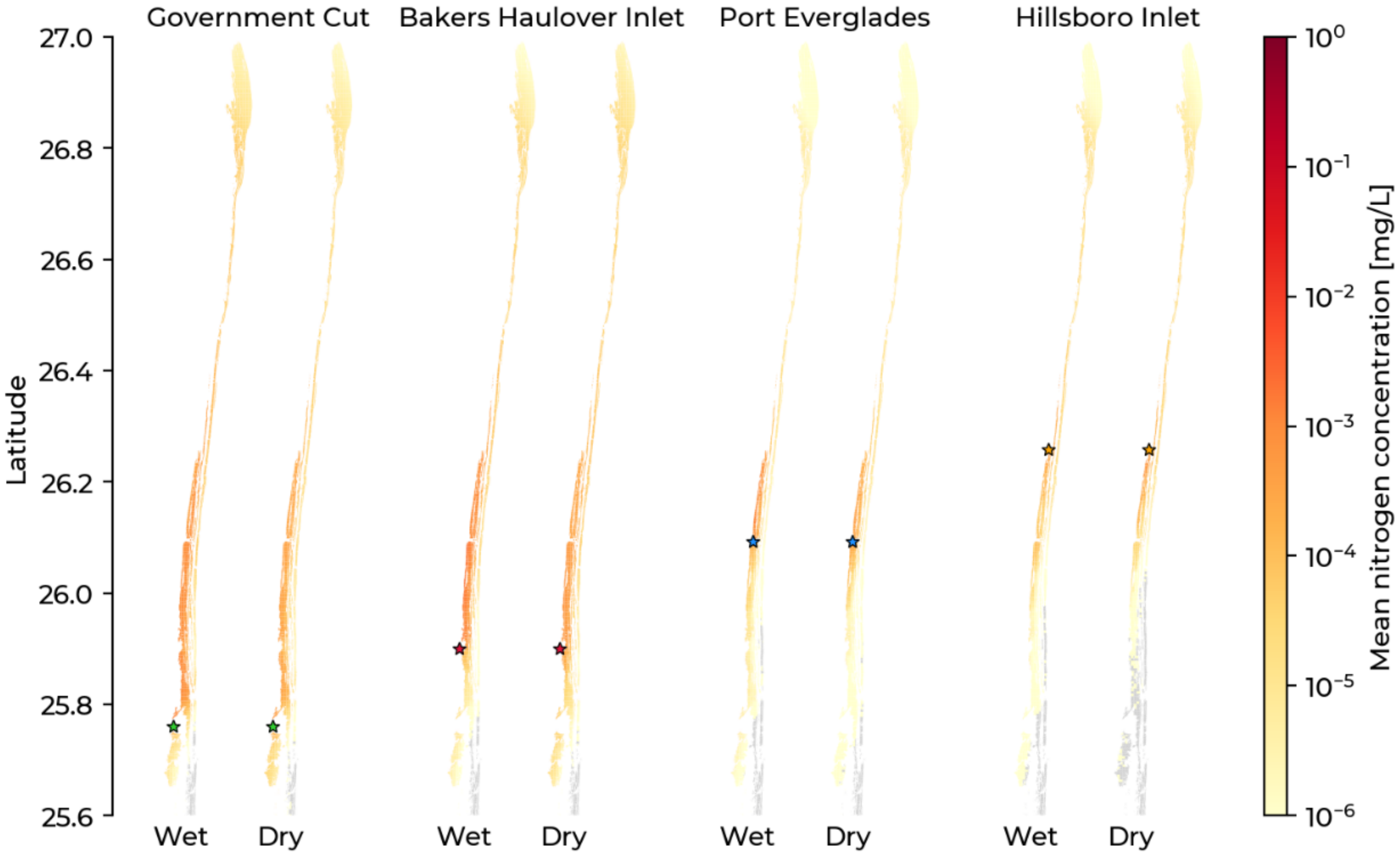

Figure 6: Seasonal mean concentration of nitrogen coming from the different inlets over the reefs.

For all the large corals where disease lesions were observed, we conducted backtracking simulations to identify the contributing inland water inlets. These reef sites are ordered from south to north along the y axis in the four panels of Fig. 7. Each panel represents an inlet, with its latitude highlighted by a dashed line on the y-axis. As Government Cut is the most southern inlet, it had an impact on almost all the diseased reef sites. The other inlets, being further north, had a more limited impact, which further decreased with increasing inlet latitude. It is, however, noteworthy that all inlets could impact reefs located south of the inlet, which again shows that the ocean circulation along East Florida's coastline is not a mere conveyor belt transporting disease agents northward. It however remains that Government Cut inlet had the largest detrimental effect, followed by Baker's Haulover and then Port Everglades. For Government Cut, the probability of the inlet being a source of inland water impacting the reefs often exceeded 10%, which was much less frequent for the other inlets. Moreover, a seasonal variation was observed in these probabilities, with higher values typically occurring during the wet season, except for November and December 2020, which recorded unusually high probabilities.

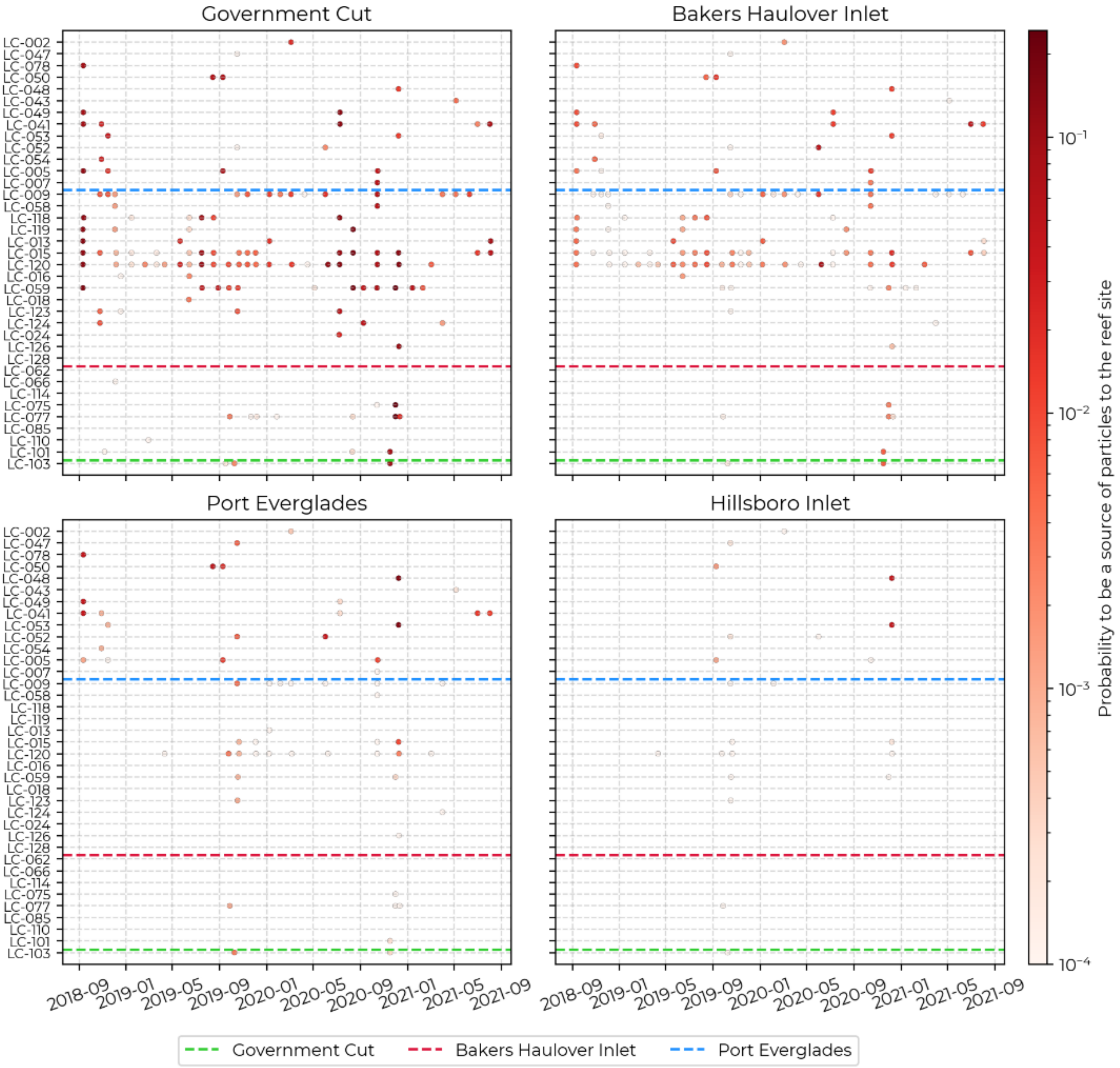

Figure 7: Probability for each inlet to be a source of particles that reached the reef monitoring sites during the 10 days preceding the observation of new SCTLD lesions. The sites on the y-axis are ordered from south to north, the points correspond to the dates and locations of observation of new lesions and their color indicate the probability for particles to originate from the different inlets. The latitudes of the different inlets are indicated by colored dashed lines.

While the backtracking simulations indicate which inlets were the source of inland water impacting a reef during the few weeks preceding disease observations, we also derived a complete timeseries of analyte concentrations on reefs where disease signs were observed. These timeseries were derived from the forward simulations initiated at each inlet and cover the entire 3-year simulated period. They indicated the concentration of each of the 7 analytes originating from each of the 4 inlets. As an illustration, we show the time series of nitrite concentration at reef LC-005 for the 4 source inlets (Fig. 8). As reef LC-005 is among the northernmost reefs where disease lesions were observed (see Fig. 7), it was impacted by inland water from all 4 inlets. Interestingly, Government Cut, the inlet located the furthest away, contributed the most at the beginning of the 3-year period. Afterwards, Bakers Haulover and Port Everglades inlets had a larger impact, while the contribution of Hillsboro Inlet remained very small throughout the entire study period.

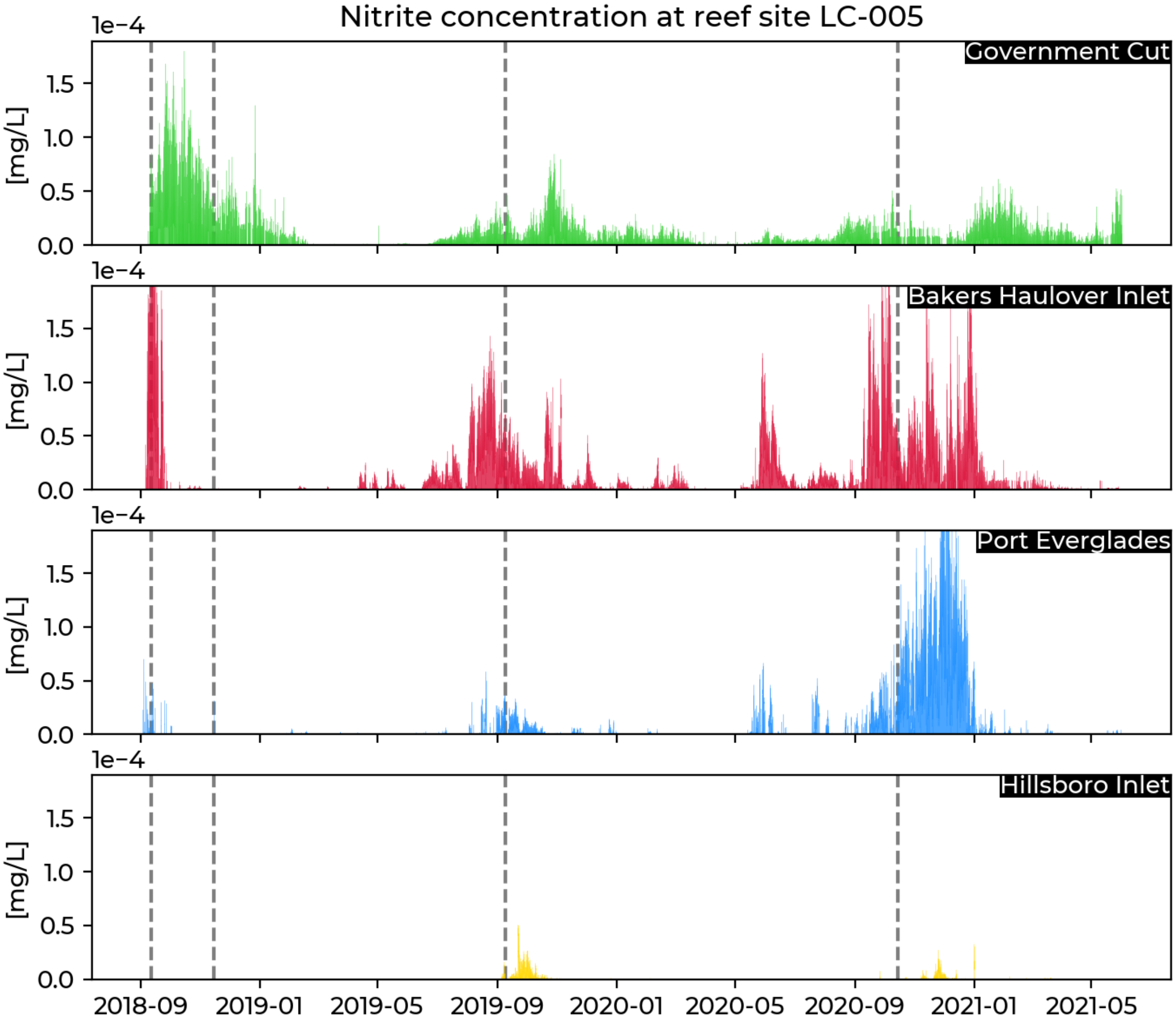

Figure 8: Time series of modeled nitrite concentration over reef site LC-005. Dotted lines correspond to the observation dates of new lesions.

4. DISCUSSION

The study has highlighted several features of the ocean circulation patterns near inland water inlets and their environmental impacts on coral reefs. First, it was found that these circulation patterns are highly irregular, influenced by a combination of tides, mesoscale eddies, and interactions with topography. These factors collectively shape the inland water dispersal patterns, resulting in environmental footprints that do not merely extend northward as might be inferred from the Florida Current alone. Seasonal variations in flow rate and analyte load further modulate these footprints.

By considering these diverse factors, we identified the reefs most affected by the four inland water inlets. Additionally, a preliminary assessment was conducted to explore the relationship between reef exposure to inland water analytes and SCTLD occurrence. This involved tracing the inland water sources affecting diseased reefs and analyzing the analyte concentration timeseries for these reefs over three simulated years. The goal was to determine if disease occurrences were preceded by peaks in analyte concentration.

Moving forward, several steps are essential to build on these findings:

Statistical Inference Analysis: A thorough statistical analysis is needed to assess the correlation between changes in water quality over the reefs and the occurrence of SCTLD. This analysis should be enhanced by incorporating other variables, such as ocean temperature, to provide a more comprehensive understanding of the disease dynamics.

Extended Analysis: The time window of the analysis should be extended to the present day to capture recent trends and patterns. Additionally, the geographic scope should be broadened to include other inland water inlets, particularly those in the northern part of the ECA and in the Florida Keys. This expanded analysis will help in identifying new hotspots and understanding broader impacts.

Operational Forecasting System: On a longer term, we should pave the way for an operational forecasting system to provide real-time water quality forecasts at the scale of individual reefs. This system would utilize real-time data on flow rate and analyte loads to predict water quality conditions. Inspiration can be drawn from existing models such as the Chesapeake Bay Environmental Forecast System, adapting similar methodologies to the unique conditions of Florida Coral Reef.

These steps will not only enhance our understanding of the interactions between inland water inputs and coral reef health but also provide actionable insights for conservation and management efforts.

Data availability

All the data produced during this project is available on the following ftp site: geo10.elie.ucl.ac.be (username: NOVA, password available from the authors of this report).

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5. APPENDIX

5.1. Plume arrival time to the reefs

For each inlet, we estimated the time needed for inland water plumes to reach the reefs. Overall, that duration was always smaller than the 25-day backtracking simulation duration, hence justifying the choice for that duration. As an illustration, it did not exceed 13 days in September 2020 for all four inlets (Fig. A1).

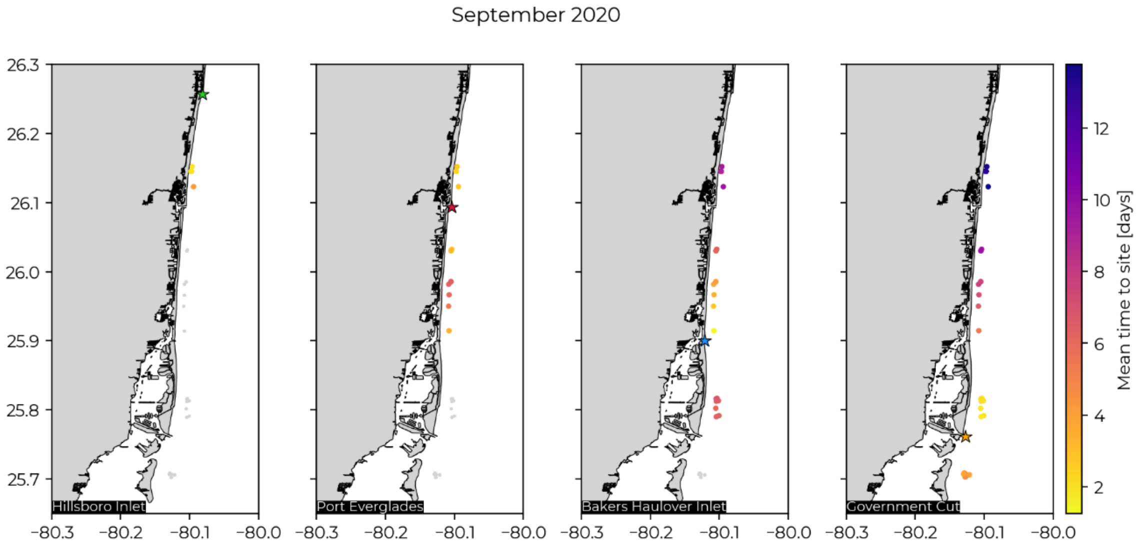

Figure A1: Monthly-averaged time needed for an inland water plume originating from each of the four inlets to reach the surrounding reefs.

5.2. Mean analyte concentrations

Here we provide the mean analyte concentration for both the wet (May to October) and dry (November to April) seasons, and the difference between them, over the 3-year simulated period for nitrate (Fig. A2), nitrite (Fig. A3), orthophosphate (Fig. A4), phosphorus (Fig. A5), silicate (Fig. A6) and TSS (Fig. A7).

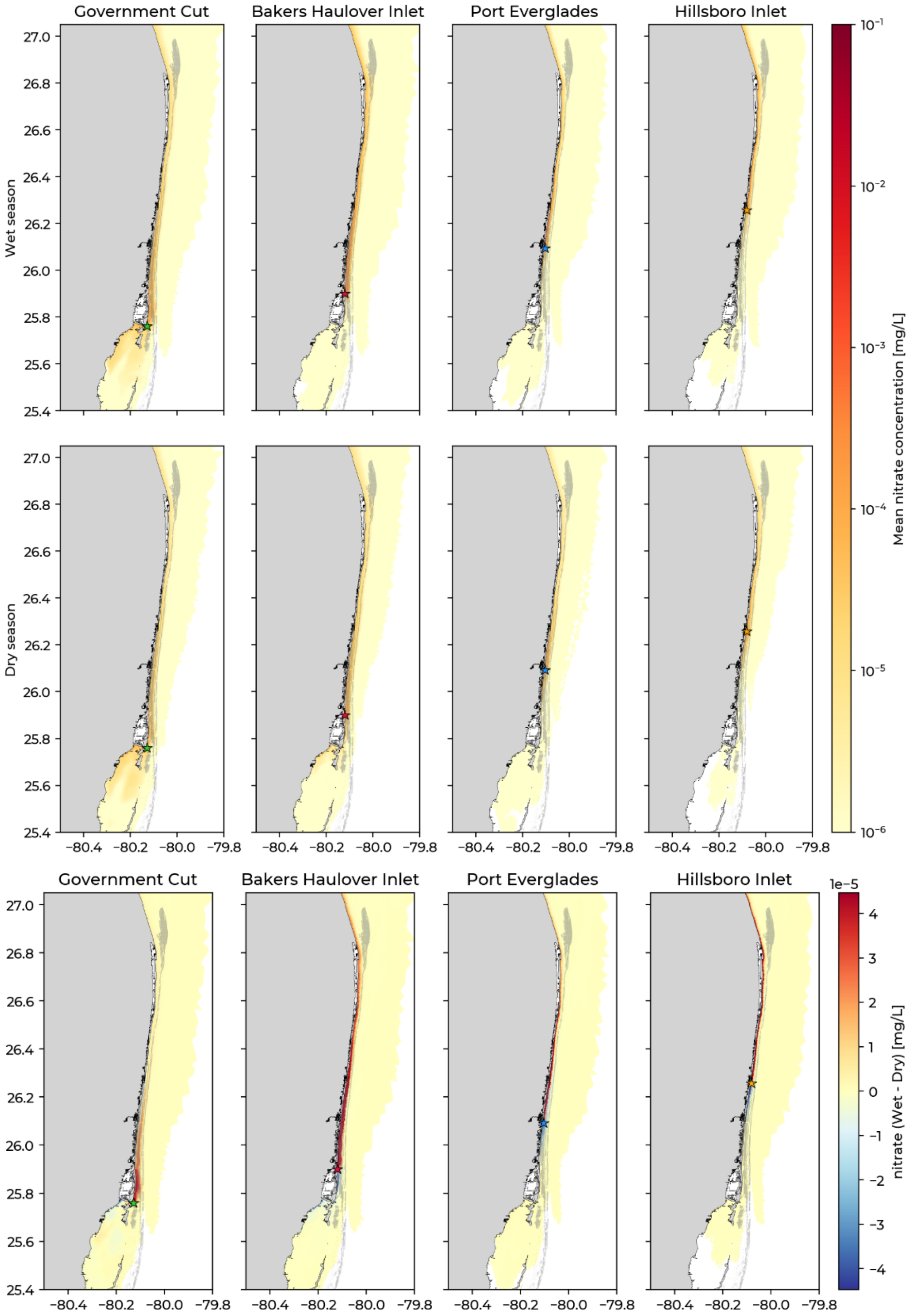

Figure A2: Seasonal mean concentration of nitrate coming from the different inlets for the wet (top panels) and dry seasons (bottom panels). The difference in concentration between wet and dry seasons is shown in the bottom panel.

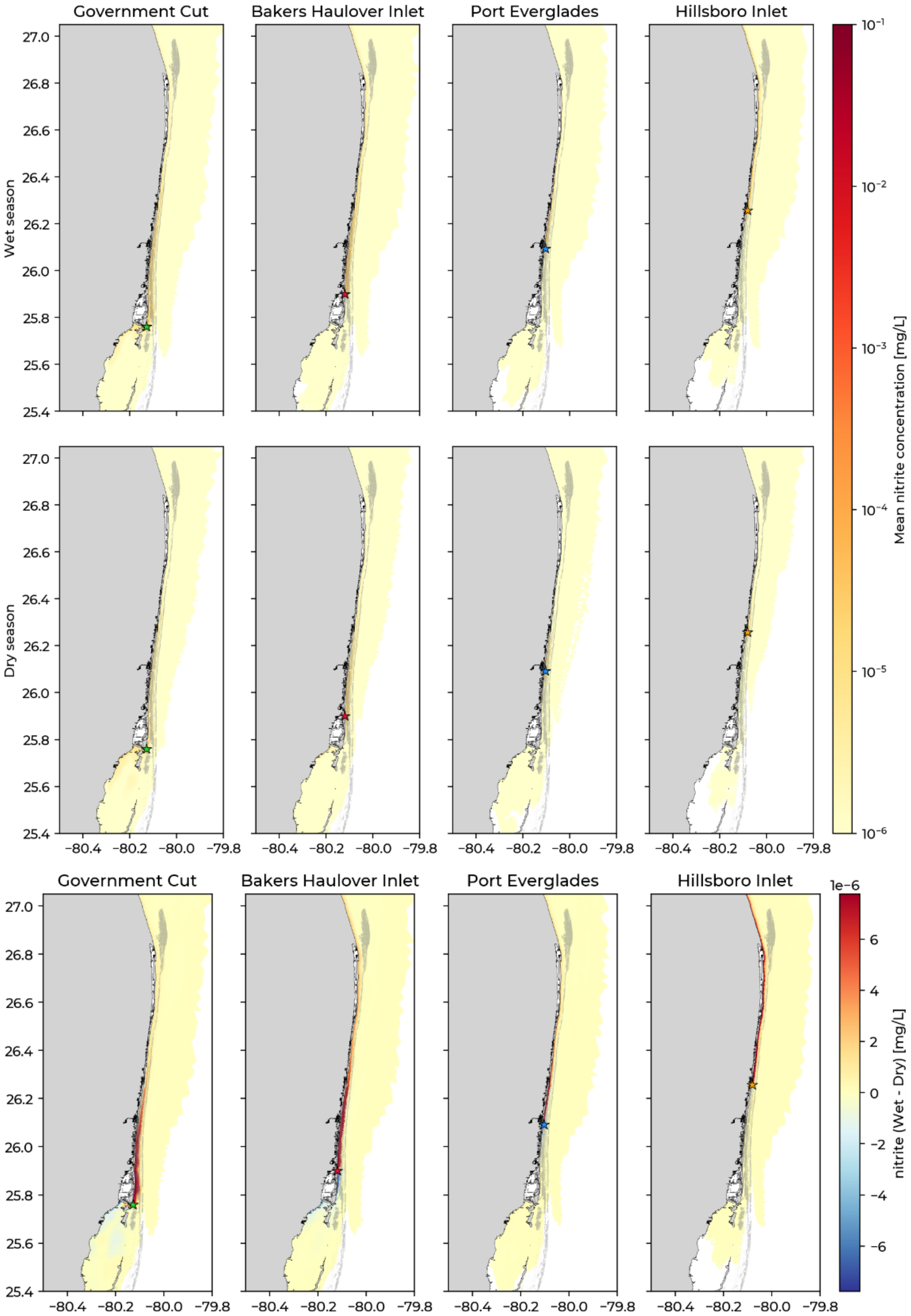

Figure A3: Seasonal mean concentration of nitrite coming from the different inlets for the wet (top panels) and dry seasons (bottom panels). The difference in concentration between wet and dry seasons is shown in the bottom panel.

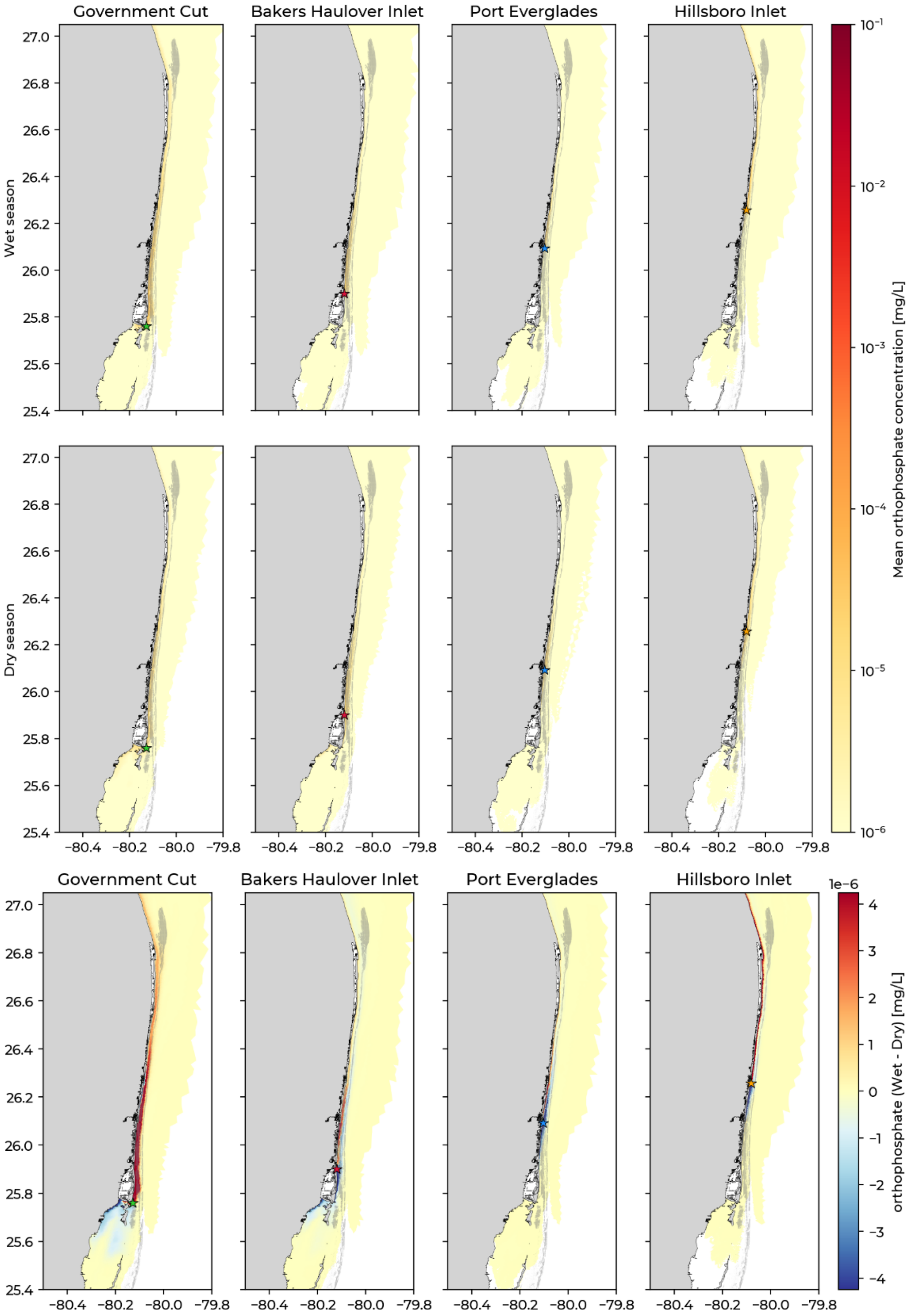

Figure A4: Seasonal mean concentration of orthophosphate coming from the different inlets for the wet (top panels) and dry seasons (bottom panels). The difference in concentration between wet and dry seasons is shown in the bottom panel.

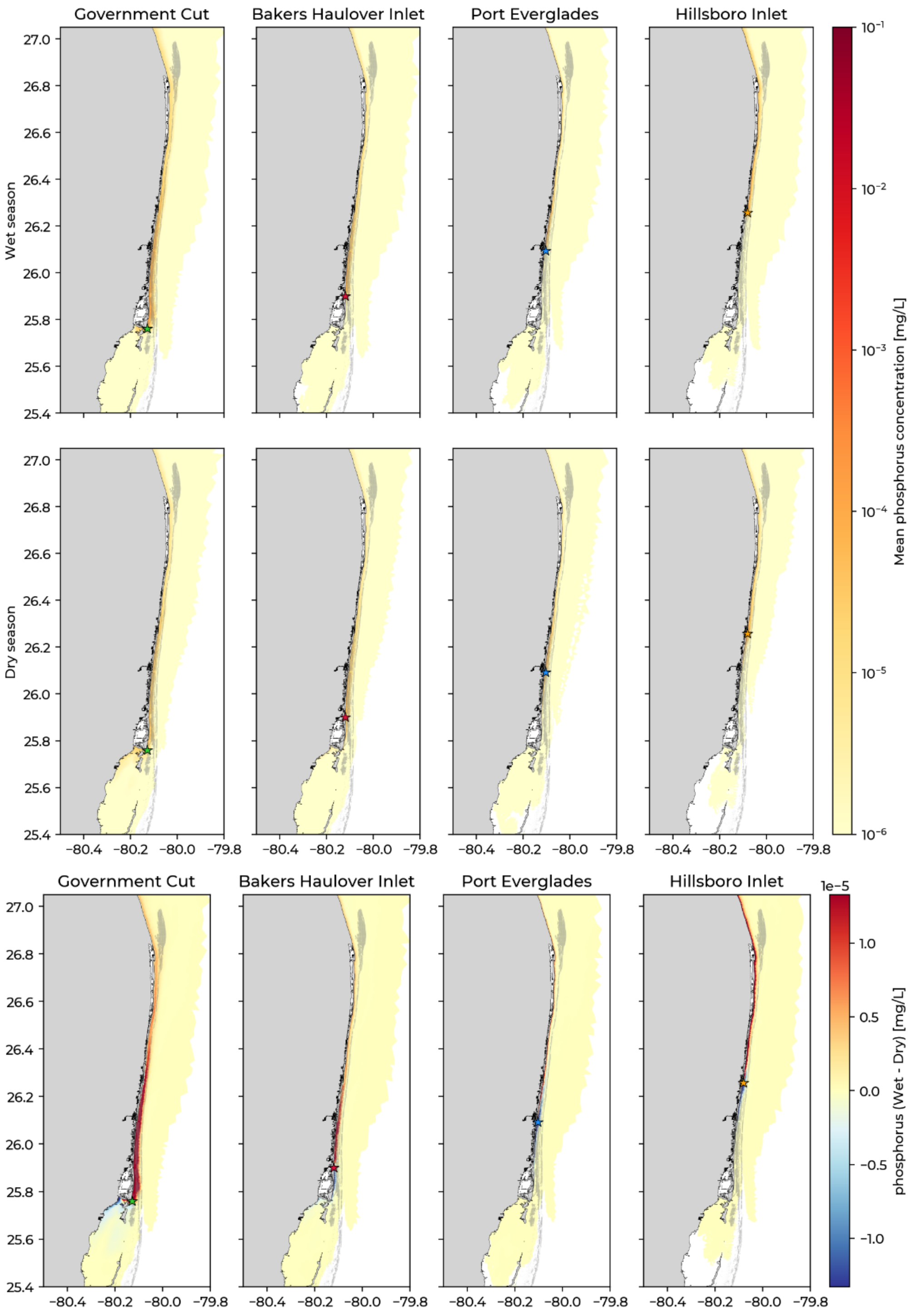

Figure A5: Seasonal mean concentration of total phosphorus coming from the different inlets for the wet (top panels) and dry seasons (bottom panels). The difference in concentration between wet and dry seasons is shown in the bottom panel.

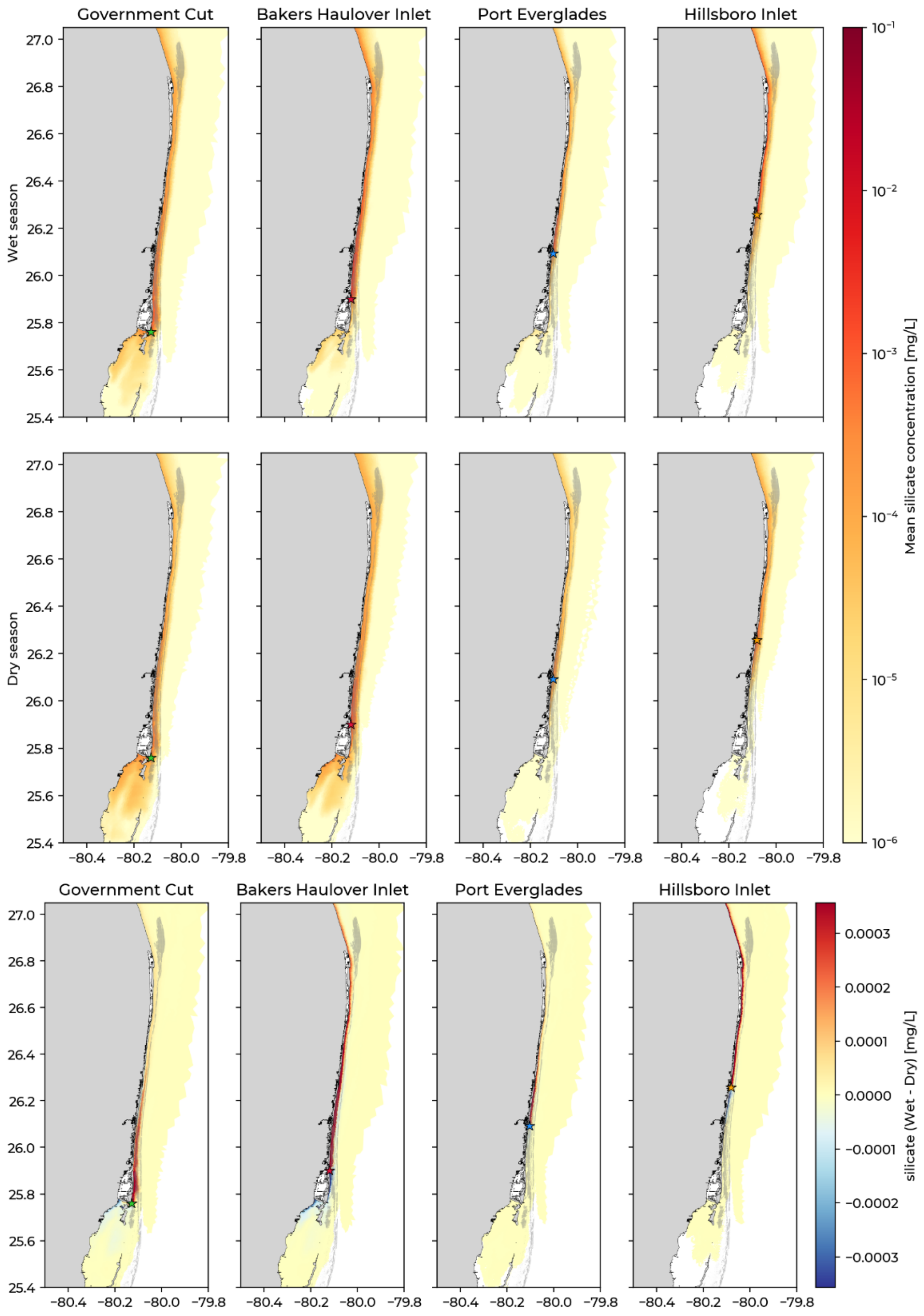

Figure A6: Seasonal mean concentration silicate coming from the different inlets for the wet (top panels) and dry seasons (bottom panels). The difference in concentration between wet and dry seasons is shown in the bottom panel.

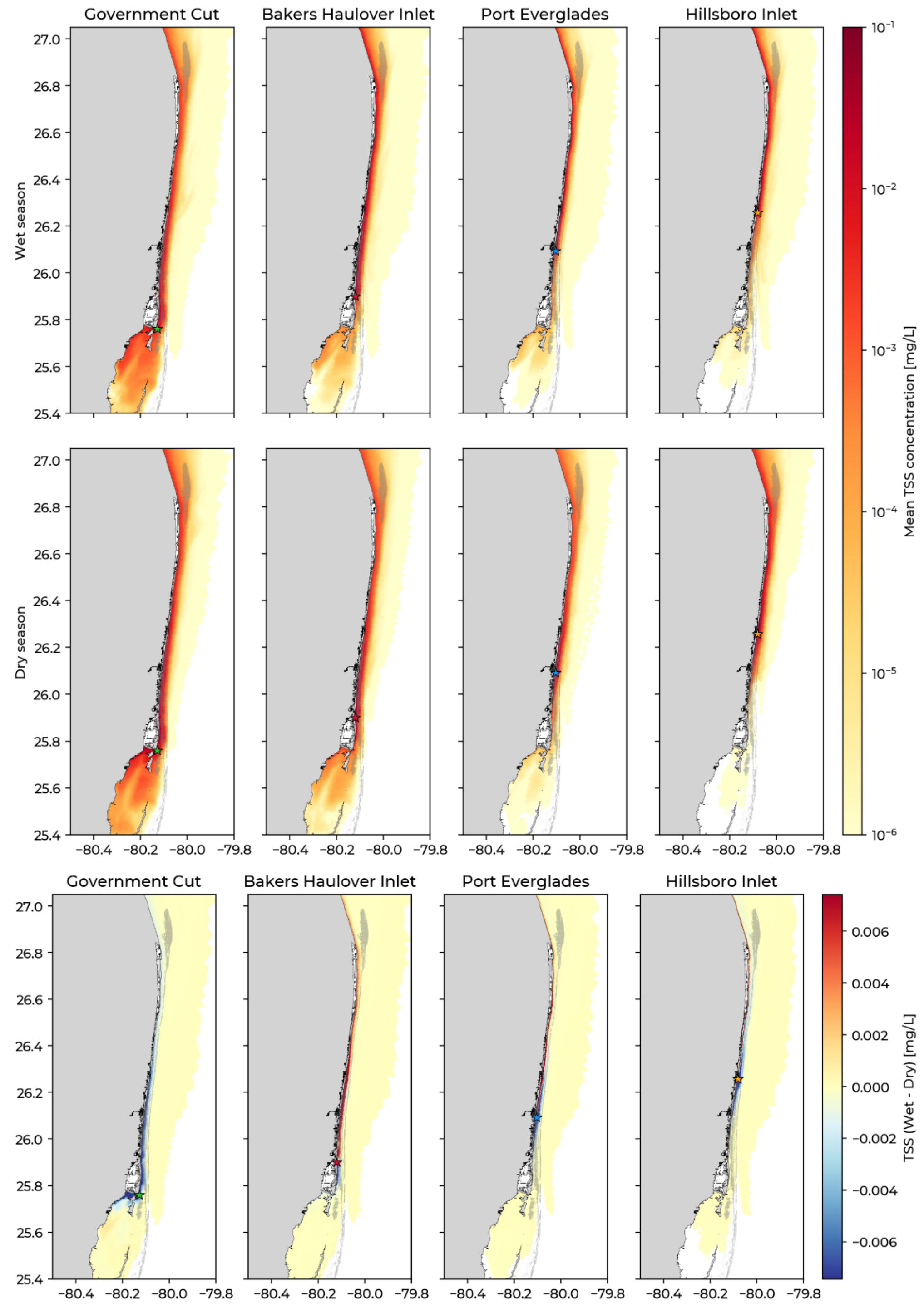

Figure A7: Seasonal mean concentration of total suspended solids (TSS) coming from the different inlets for the wet (top panels) and dry seasons (bottom panels). The difference in concentration between wet and dry seasons is shown in the bottom panel.