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Effect of COVID-19 Anthropause on Water Clarity in the Belize Coastal Lagoon

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The Coronavirus disease 2019 (COVID-19) pandemic halted human activities globally in multiple sectors including tourism. As a result, nations with heavy tourism, such as Belize, experienced improvements in water quality. Remote sensing technologies can detect impacts of "anthropauses" on coastal water quality. In this study, moderate resolution imaging spectroradiometer (MODIS) satellite data were employed along the Belizean coast to investigate impacts of the COVID-19 shutdown on water quality. The attenuation coefficient at 490 nm, $K_d(490)$, was used as an indicator of water quality, with a lower $K_d(490)$ indicating increased water clarity. Four Coastal Management Zones were characterized by marine traffic as high traffic areas (HTAs) and two as low traffic areas (LTAs). Monthly composites for two periods, 2002–2019 (baseline) and 2020 were examined for $K_d(490)$. For months prior to the COVID-19 shutdown in Belize, there was generally no significant difference in $K_d(490)$ ($p > 0.05$) between 2020 and baseline period in HTAs and LTAs. Through the shutdown, K_d was lower in 2020 at HTAs, but not for LTAs. At the LTAs, the $K_d(490)$s observed in 2020 were similar to previous years through October. In November, an unusually active hurricane season in 2020 was associated with decreased water clarity along the entire coast of Belize. This study provides proof of concept that satellite-based monitoring of water quality can complement *in situ* data and provide evidence of significant water quality improvements due to the COVID-19 shutdown, likely due to reduced marine traffic. However, these improvements were no longer observed following an active hurricane season.

Keywords: diffuse attenuation coefficient, moderate resolution imaging spectroradiometer, remote sensing, water quality, marine traffic, Belize Barrier Reef Reserve System, water clarity

INTRODUCTION

The Central American nation of Belize is home to the Belize Barrier Reef Reserve System, the largest barrier reef system in the northern hemisphere and a World Heritage Site (UNESCO, 1996; Cherrington et al., 2010, 2020). Belize's reef system is approximately 250 km in length, 963 km^2 in area, and is located 0.5-80 km offshore between Mexico and Guatemala's borders (Gischler and Hudson, 2004; Baumann et al., 2019; Claudino-Sales, 2019). This reef system contains hundreds of reef patches which developed during the Holocene (Gischler and Hudson, 2004; Eckert et al., 2019). Belize's coral reefs support high levels of biodiversity (Young, 2008), and provide essential ecosystem services such as coastal protection and fisheries (Hoegh-Guldberg et al., 2007), and important economic revenue as tourism is a primary contributor to the economy (Murray, 2020). Since 1998, the main use for Belize's reefs has been identified as tourism and thus the nation must continuously monitor tourism impacts in order to prevent the degradation of the reefs and preserve Belize's competitiveness in ecotourism markets (Gibson et al., 1998; Diedrich, 2007).

The Coronavirus disease 2019 (COVID-19) pandemic caused shifts in the environment and climate due to global lockdowns resulting in a reduction of social and economic activities (Bar, 2020; Rume and Islam, 2020). On March 23, 2020, a mandatory quarantine was placed on Ambergris Caye within Belize followed by a countrywide state of emergency (SoE) declared on March 30, 2020 (Government of Belize Press Office, 2020b; United Nations, 2020a). To limit the spread of COVID-19, Belize closed their borders to international travelers by closing land borders and its international airport (Government of Belize Press Office, 2020a). On October 1, 2020, the reopening phase of Belize's international airport began while expecting 140 travelers on its first day (Government of Belize Press Office, 2020c).

Tourism has declined on a global scale, which can have devastating impacts on local and regional economies. Other observed impacts include a reduction of anthropogenic footprint on natural ecosystems (Bar, 2020). Remote sensing datasets are especially well-positioned to assess these changes by providing a mechanism to observe larger scale responses to these declines in human activity, often referred to as the "anthropause" (Rutz et al., 2020). This is especially important in data-scare regions such as Belize. For example, Landsat-8, Sentinel-2, Sentinel-3, and moderate resolution imaging spectroradiometer (MODIS) have been used to evaluate changes in air quality emissions (Wang and Christopher, 2003; Gupta et al., 2006; Mishra et al., 2021), water clarity (Barnes et al., 2013; Zheng et al., 2016; Kuhn et al., 2019), and coastal/ocean productivity (Ho et al., 2017; Astuti et al., 2018; Caballero et al., 2020). A variety of satellites have been used for impact assessment such as Landsat-8 (Nanda et al., 2020; Patel et al., 2020; Yunus et al., 2020), PlanetScope (Niroumand-Jadidi et al., 2020), Sentinel-2 (Braga et al., 2020; Garg et al., 2020), Sentinel-3 (Cherif et al., 2020; Mishra et al., 2020), and MODIS (Gaiser et al., under revision). Multiple studies report reductions in air, water, and noise pollution due to global lockdown orders. Within the hydrosphere, rivers (Dutta et al., 2020; Garg et al., 2020; Patel et al., 2020), lakes (Yunus et al., 2020), lagoons (Braga et al., 2020; Niroumand-Jadidi et al., 2020), and coastal regions (Cherif et al., 2020; Mishra et al., 2020) experienced improvements in water quality with decreases in turbidity, pollution, and pathogens. Improvements in water quality were attributed to reductions in industrial discharges, boat traffic, and public interactions in general. These anthropogenic activities tend to increase water column turbidity and sediment resuspension in the near-shore environments and diminish water quality in the lagoon. Here, we hypothesize that the COVID-19 lockdowns and the subsequent decline in tourism and marine traffic will improve the water clarity in the Belizean coast, namely near major ports and tourist regions.

To test the hypothesis, we used satellite datasets, model produced runoff and precipitation outputs, and marine traffic data conjunctively to investigate the impacts of the COVID-19 pandemic on coastal water quality in Belize. Using the vertical diffuse attenuation coefficient [$K_d(490)$] as the primary indicator of water quality, we compared the monthly variations in water clarity in 2020 to that observed from 2002 to 2019.

METHODS

Study Area and High and Low Marine Traffic Areas

Belize is located between Mexico and Guatemala with approximately 280 km of coastline. The climate is tropical with high humidity occurring from June to October. Belize is also on the western side of "Hurricane Alley" with tropical storms and hurricanes appearing from June to November (Morales-Vela et al., 2000). Most of Belize's major cities, towns, tourist centers, and residential properties are located along the coast. The Belizean coastal lagoon is classified as a Case-1 waters like other Caribbean coastal waters (Alvain et al., 2005; Mishra et al., 2005b, 2007; Shi and Wang, 2010) as well as being oligotrophic in nature (Gómez, 2014; Mélin and Vantrepotte, 2015). In addition, multiple studies operate under the knowledge and understanding of these water being oligotrophic (Mendoza et al., 2009; Contreras-Silva et al., 2020; Correa-Ramirez et al., 2020; Guimarais et al., 2021) which is necessary for the development and flourishing of corals (Warne et al., 2005; Guimarais et al., 2021). The Belizean coast hosts multiple diverse ecosystems including coral reefs, mangroves, and seagrasses (Cherrington et al., 2010; Baumann et al., 2016; Verutes et al., 2017; Sweetman et al., 2019; Helmuth et al., 2020) which not only attract tourists but also play an integral role in mitigating coastal erosion and impacts from tropical storms (Cooper et al., 2009). Though these ecosystems contribute millions of United States dollars to Belize's economy (Cooper et al., 2009), industries such as tourism, fisheries, real estate, and agriculture stand to threaten the very ecosystems that allow them to operate (Verutes et al., 2017). Tourism season in Belize takes place during in dry, winter months from November to April (Renaud, 2020).

Belize's Integrated Coastal Zone Management Plan (ICZMP) divides its coast into nine regions based on biological, geographical, economic, and administrative characteristics

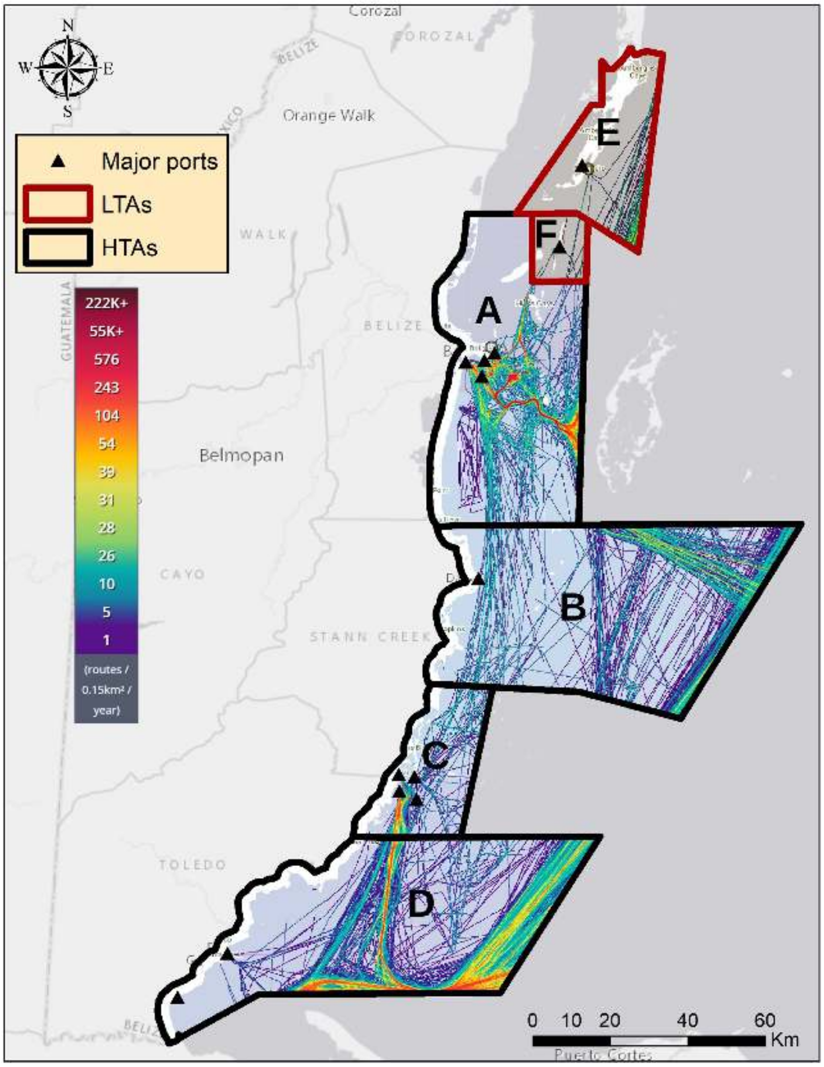

FIGURE 1 | Belize Coastal Zones, Major Ports, and Marine Traffic Density. Six coastal areas were used in this study: **(A)** Central Region, **(B)** South Northern Region, **(C)** South Central Region, **(D)** Southern Region, **(E)** Ambergris Caye, and **(F)** Caye Caulker. Areas **(A–D)** are denoted as high traffic areas (HTAs) and E & F as low traffic areas (LTAs). Each zone is filled with 2019 marine traffic density maps where the color of each line corresponds to the number of routes/0.15 km^2/year.

(Coastal Zone Management Authority and Institute [CZMAI], 2016). Six of these nine regions were characterized as high and low traffic areas (HTAs and LTAs, respectively) based on a 2019 marine traffic density map assumed to depict typical traffic patterns prior to COVID-related lockdowns (**Figure 1**). The four HTAs comprise the Central Region which includes Belize City (A), South Northern Region which includes Dangriga (B), part of South Central Region containing Placenia, Big Creek, and Harvest Caye (C), and the Southern Region containing Punta Gorda and Barranco (D). The two LTAs are to the north, at Ambergris Caye (E), and Caye Caulker (F).

High Traffic Areas

Belize City is the largest city within the Belize District (17.5046° N, 88.1962° W) and is home to the nation's principal port (Belize City Council, 2020). The Port of Belize Limited is located on the south side of Belize City and is responsible for containerized and break bulk cargo (Belize Port Authority, 2020b). Other major port facilities in Belize City include Puma Energy Bahamas SA for bulk fuel import, Fort Street Tourism Village, a water taxi terminal operated by the Belize Border Management Agency (BMA), Radisson Fort George, and Old Belize port.

Dangriga is a town in southern Belize and the capital of Stann Creek District (16.9696° N, 88.2315° W). Though the Commerce Bight port 1.5 miles south of Dangriga is currently not operational (Belize Port Authority, 2020a), Dangriga is known as "the cultural capital of Belize" and is a popular tourist location (Belize.com, 2020).

Placencia is located on the Placencia Peninsula (16.5212° N, 88.3713° W) on the southeast coast of Belize within the Stann Creek District and is rapidly growing in tourism (Wells et al., 2014; Renaud, 2020). Just south of the Stann Creek District in the Toledo District is the Port of Big Creek, the nation's second major port (7 News Belize, 2020), responsible for banana exports, crude oil tank farming, and sugar storage (Port of Big Creek, 2020). South of both Big Creek and Placencia and a mile off the coast is Harvest Caye, a private island developed for tourism by a Miami-based Norwegian Cruise Line (Renaud, 2020). Belize City and Placencia are two major coastal cities which have experienced coral growth declines (Baumann et al., 2019) and mangrove clearings (Cherrington et al., 2010).

Punta Gorda (16.0989° N, 88.8095° W) and Barranco (16.0011° N, 88.9186° W) are both towns located in the southernmost region of Belize located in the Toledo District. Punta Gorda is the capital of the Toledo District and is home to the Punta Gorda Port (Belize Port Authority, 2020c). The Port of Barranco is a very small port in the town of Barranco (FleetMon, 2020).

Low Traffic Areas

San Pedro is a town in the southern part of Ambergris Caye in the Belize District in northern Belize (17.9214° N, 87.9611° W). There is a water taxi terminal with six berths located in San Pedro under the Belize BMA (Belize Port Authority, 2020d).

Caye Caulker is a small island off the coast of Belize (17.7612° N, 88.0277° W) accessible by water taxis and small planes (CayeCaulker.org, 2020).

Satellite Images

The average vertical diffuse attenuation coefficient for downwelling irradiance at 490 nm, $K_d(490)$, was calculated in Google Earth Engine (GEE) from images collected from MODIS onboard the Aqua satellite. The images processed in GEE started from June 4, 2002 to July 31, 2020. The rest of the images for 2020 were downloaded from https://oceancolor.gsfc.nasa.gov/and ingested into GEE. All images were Level-3 daily images with a spatial resolution of 4 km and $K_d(490)$ was calculated using the NASA operational algorithm (Werdell and Bailey, 2005). The algorithm is a fourth-order polynomial between blue and green remote sensing reflectances (Rrs) and $K_d(490)$. The algorithm is based on two high quality bio-optical global datasets, the SeaWiFS Bio-Optical Archive and Storage System (SeaBASS) and the NASA bio-Optical Marine Algorithm Data (NOMAD) archives. Though the datasets encompass a broad range of water types and locations, certain oceanic regions remain underrepresented.

The NASA operational algorithm is as follows for the MODIS sensor:

$$K_d(490) = 10^{(-0.8813-2.0584x+2.5878x^2-3.4885x^3-1.5061x^4)} + 0.0166$$

where $x = \log_{10} \frac{Rrs(488)}{Rrs(547)}$. Beside numerous open ocean applications, MODIS-derived $K_d(490)$ products have also been used in turbid coastal water (Tomlinson et al., 2019), for coastal river plume characterization during high flow (López et al., 2013), and turbidity impacts on coral health (Freitas et al., 2019; Martínez-Castillo et al., 2020). Caribbean coastal waters are generally considered as Case-1 waters because thriving seagrass and reef habitats help reduce water column turbidity (Mishra et al., 2005a, 2007). The NASA operational algorithm for $K_d(490)$ has also been used specifically in coastal Caribbean regions (López et al., 2013; García-Sais et al., 2017; Vega Sequeda et al., 2017). A function was created to calculate $K_d(490)$ for each image and the newly calculated band was appended to the image collection. Monthly averages for $K_d(490)$ were calculated for the coast of Belize using a mean reducer for LTAs and HTAs and compared between 2020 and the baseline period. The number of pixels included in each monthly calculation was obtained through the count reducer which computes the number of non-null inputs. Percent difference maps of $K_d(490)$ were also created in GEE by filtering the images for each respective month of the year, taking the average for the years of 2002–2019 and 2020, and mapping the percent difference between the two time frames. A decrease in $K_d(490)$ indicates a decline in water clarity, generally associated with degradation in water quality, whereas an increase in $K_d(490)$ indicates an increase in water clarity, associated with an improvement.

Marine Traffic Data

Marine traffic data were obtained from the company MarineTraffic[1] for ports and anchorages in Belize from January 2020 to November 2020 (**Figure 2**). The data uses both Automated Identification System (AIS) data and data from satellite receivers. The data includes arrival and departure data for ports in Belize City, Belize City anchorage, Old Belize, Radisson Fort George, Placencia, Big Creek, Big Creek anchorage, Harvest Caye, San Pedro, and Caye Caulker. The company also detects port calls from Dangriga, Punta Gorda, and Barranco ports, but in 2020 there were no port calls detected through AIS or satellite data for these ports.

Runoff and Precipitation Models

Monthly time-averaged precipitation and runoff were calculated over Belize using NASA's Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) model from June 2002 to October 2020. MERRA-2 is a global atmospheric reanalysis produced by NASA's Global Modeling and Assimilation Office (NASA Global Modeling and Assimilation Office, 2020). For precipitation, the "total surface precipitation" variable was used (M2TMNXFLX v5.12.4) and for runoff, the "overland runoff including throughflow" variable was used (M2TMNXLND v5.12.4). The model outputs were extracted from NASA Giovanni[2].

Statistical Analysis

For each month of the year where data were available, data for each location for years 2002–2019 and for the year 2020 were grouped and tested for normality using histograms created in R (R Core Team, 2020). In no cases were both the previous years and 2020 found to be normal, so the Wilcoxon unpaired test was used to test the null hypothesis that there was no difference

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[1] marinetraffic.com

[2] https://giovanni.gsfc.nasa.gov/giovanni/

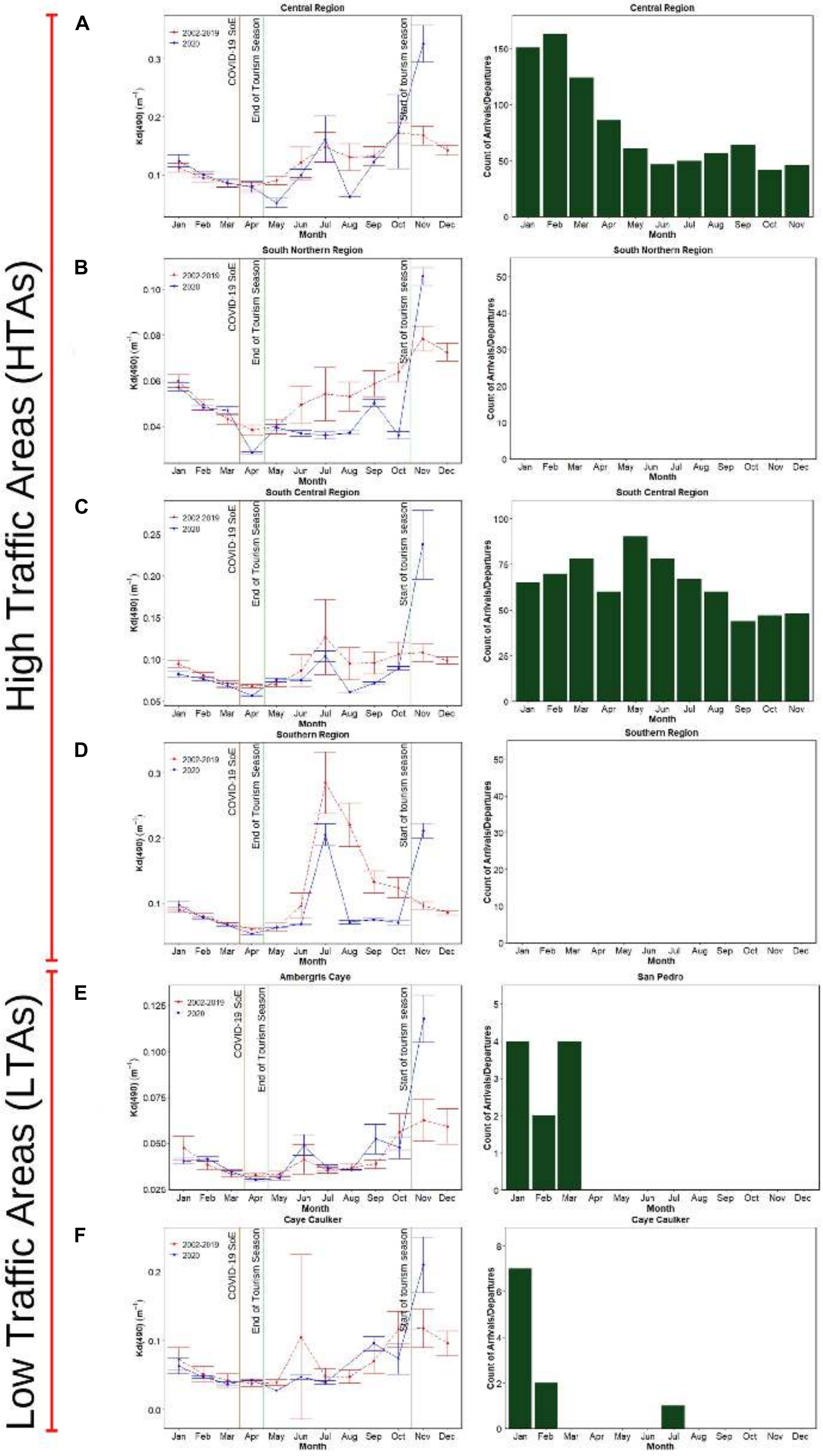

FIGURE 2 | K_d(490) Time Series Plots and 2020 Total Port Counts. The first vertical column of figures are plots of monthly K_d(490) values and standard deviations for the 2020 and 2002–2019 time periods. The orange vertical line marks the time of the COVID-19 SoE in Belize. The green lines represent the beginning and end of the tourist season in Belize. The second column of figures are total port counts for each month for 2020. Some ports did not have any port calls in 2020 through AIS or satellite data. Each lettered row of plots corresponds to the areas in **Figure 1**. **(A)** Central Region, **(B)** South Northern Region, **(C)** South Central Region, **(D)** Southern Region, **(E)** Ambergris Caye, and **(F)** Caye Caulker.

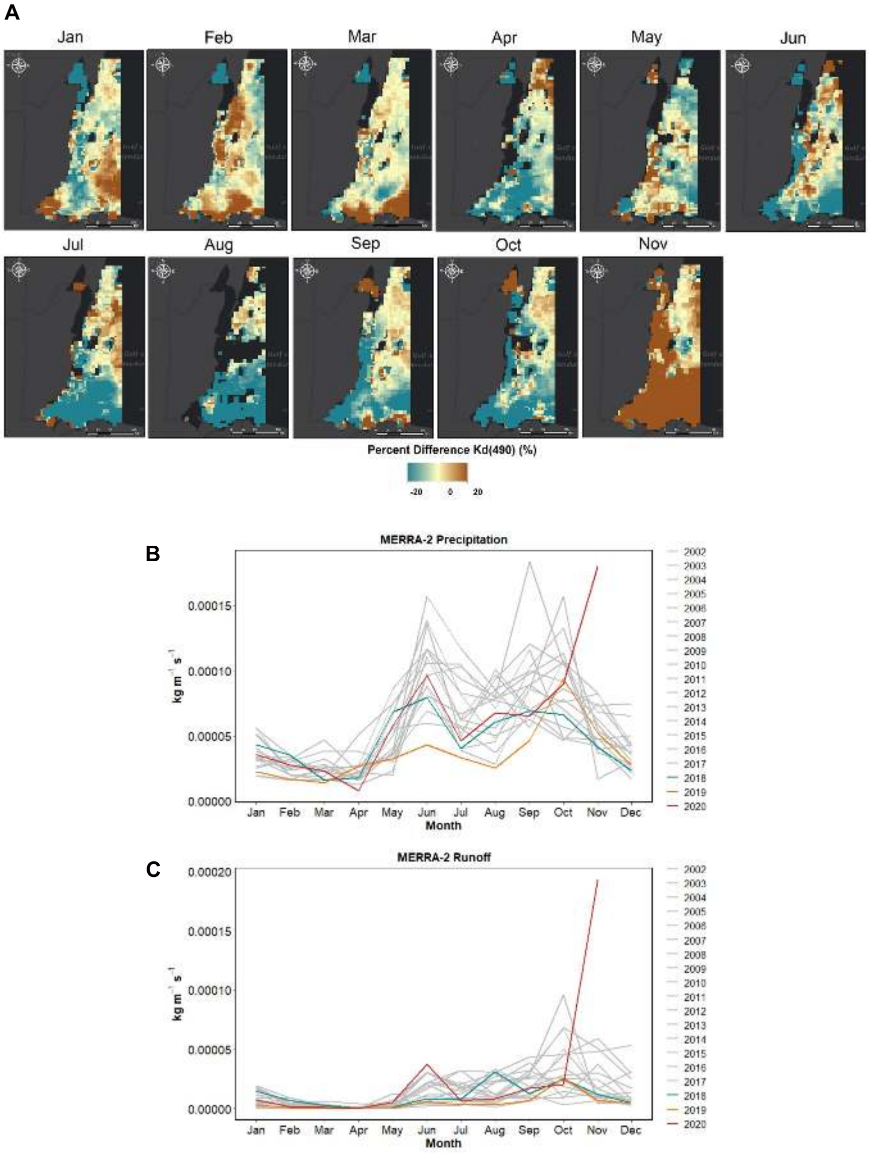

FIGURE 3 | Percent Difference K_d(490) Maps and MERRA-2 Model Outputs. **(A)** Monthly percent difference maps comparing 2020 K_d(490) values against those of the 2002–2019 (baseline) time period. **(B)** MERRA-2 precipitation output for the country of Belize from 2002 to 2020 in kg m^{-1} s^{-1}. **(C)** MERRA-2 runoff output for Belize from 2002 to 2020 in kg m^{-1} s^{-1}.

between 2020 and previous years. We computed means and standard deviation for both time periods.

RESULTS

At the start of 2020 prior to the Belize SoE COVID shutdown, the K_d(490) was consistently similar to that observed for previous years, with no significant differences observed for any location (**Figure 2**). However, the monthly K_d(490) maps show notable decreases in K_d(490) along the Belizean coast at HTAs following the initial lockdown orders in place on March 23, 2020 compared to the 2002-2019 average (**Figure 3A**). Following the SOE in April, 2020 data showed a lower K_d (indicating increased water clarity) compared to previous years in (most) HTAs, but not the LTAs. For example, for HTA-D, which includes Placencia, the average K_d(490) from 2002 to 2019 for the month of April was 0.068 m^{-1} (SD 0.002), while for 2020 the value was 0.057 m^{-1} (SD 0.001). In May of 2020, HTA-A, which includes Belize's most popular port, shows a K_d of 0.051 m^{-1} (SD 0.008) in 2020, compared to 0.090 m^{-1} (SD 0.008) for the years 2002–2019. See **Table 1** for the p-values for hypothesis testing for the difference between 2020 and previous years. While LTAs showed some differences in means, these tended to be smaller, and statistically significant differences were only observed at HTAs. For both HTAs and LTAs for the months of June and July, none of the

TABLE 1 | Wilcoxon test *p*-values for each month between K_d(490) values in 2020 versus 2002–2019 baseline for all regions.

Site	Coastal region	HTA/LTA	Wilcoxon test *p*-values										
			January	February	March	April	May	June	July	August	September	October	November
A	Central region	HTA	0.679	0.374	0.987	0.705	0.029*	0.895	0.651	0.269	0.982	0.067	0.006*
B	South Northern region	HTA	0.806	0.866	0.164	0.018*	0.429	0.988	0.479	0.250	0.83	0.006*	0.033*
C	South Central region	HTA	0.082	0.250	0.230	0.046*	0.165	0.359	-	0.113	0.004*	0.496	< 0.001*
D	Southern region	HTA	0.600	0.968	0.423	0.483	0.063	0.403	0.852	0.044*	0.009*	0.003*	< 0.001*
E	Ambergris Caye	LTA	0.131	0.021*	0.504	0.313	0.382	-	0.590	0.787	0.591	0.419	0.002*
F	Caye Caulker	LTA	0.567	0.353	0.481	–	–	–	–	–	0.162	0.178	0.009*

An asterisk is used to denote p-values less than 0.05. Orange highlighting indicates the K_d(490) in 2020 was lower than that in previous years. Green highlighting shows where K_d(490) was higher in 2020 than in previous years.

observed differences in means were significant, possibly due to the tourism season ending so no major differences in marine traffic would be expected.

Figure 3A shows the percent difference of K_d(490) between 2020 and previous years. A greater fraction of the coastal waters shows a decrease (blue) compared to previous years for the months of April through October. In November 2020, K_d(490) increases (brown) drastically across the entire coast. This increase coincides with a record-breaking hurricane season where Belize experienced impacts of Hurricanes Nana, Eta, Iota, and Tropical Storm Cristobal (Amandala Newspaper, 2020). **Figures 3B,C** show the precipitation and runoff for 2002 through 2020 of Belize. While month to month 2020 was not an atypical year for precipitation through the month of October, both precipitation and runoff were dramatically elevated for the month of November (**Figures 3B,C**).

Because K_d(490) incorporates both inorganic and organic components within the water column, we tested for correlations between *in situ* chlorophyll-a and MODIS-derived K_d(490). Using a dataset from 2018 and 2019, we saw no significant correlation between chlorophyll-a and K_d(490) after calculating the Spearman's rank order correlation coefficient following tests for normality using Q–Q plots and histograms (Spearman's rho = 0.34) (see **Supplementary Material**).

DISCUSSION

This preliminary study shows that MODIS K_d(490) data can be used to better understand spatiotemporal changes in water quality impacts associated with environmental disturbances. This is particularly important in locations where *in situ* data are limited and healthy ecosystems are essential to the local economy. Belize relies on robust tourist traffic to support the economy, and water clarity is critical for coral reef health (De'ath and Fabricius, 2010). Marine traffic due to both commerce and tourism have the potential to result in decreased water clarity through an increase in suspended solids. In addition, marine traffic is also shown to increase nutrient depositions which spurs phytoplankton growth (Zhang et al., 2021). For this site, chlorophyll-a and K_d(490) were not significantly associated, suggesting that K_d(490) is mainly attributed to sediment resuspension rather than algal particles. Nonetheless, the possible contribution of chlorophyll-a to MODIS K_d(490) at the study site needs further investigation, and future data collection should attempt to deconvolute their signals.

The COVID-19 shutdown in 2020, along with the availability of satellite data with an extended recorded (2002–2019), presented an opportunity to understand the impacts of tourism on water quality and subsequent effects on coral reef health in a data-scarce region. As shown in this work, the COVID-19 shutdown resulted in increased water clarity in areas along the Belizean coast with typically high marine traffic, while water clarity was similar in areas with typically low marine traffic during the tourism season. This finding, along with knowledge of the relationships between water clarity and reef health, provides insight on the role of commerce and tourism on the long-term sustainability of the northern hemisphere's largest barrier reef system. Additionally, this finding is similar to other studies that investigated COVID-19 impacts on turbidity, suspended particulate matter (SPM), and total suspended matter (TSM). Studies in India show a 15.9% decrease in SPM in a lake (Yunus et al., 2020), a significant reduction in the usual pre-monsoon phytoplankton content in coastal waters (Mishra et al., 2020), water quality index increase of 37% in the Yamuna River (Patel et al., 2020), and reductions in turbidity in the Ganga River (Garg et al., 2020) all with notable changes in April 2020. A couple of studies of the Venice Lagoon, which has high water traffic, found decreases of TSM (Niroumand-Jadidi et al., 2020) and increases in water clarity (Braga et al., 2020) during their lockdowns in March and April 2020.

One expected outcome of this study is a further collaboration with colleagues at the Coastal Zone Management Authority Institute, who is committed to the protection and sustainable management of coastal resources and the ICZMP. The ICZMP is an evidence-based set of policy recommendations that enable an improved understanding of how land management might impact coastal and marine resources (Coastal Zone Management Authority and Institute [CZMAI], 2016).

This work also observes substantial water clarity changes, e.g., anomalous coastal plumes, following the active hurricane season in 2020, an observation enabled by high-frequency, freely available satellite data such as MODIS. Hurricane events in November 2020 coincided with a significant decrease in water clarity compared with November during the baseline period (Aronson et al., 2000; Haines, 2019). Future work should include evaluating the changing climatology of hurricane events on corresponding plumes into the marine environment. Furthermore, it is critical that future work considers *in situ* datasets that would allow improved tuning of remote sensing based estimates of water quality as well as improved characterization of plume constituents. It has been observed that these Belize coastal plumes can be comprised of a variety of constituents, including sediments, agricultural runoff, and sewage (Maidens and Burke, 2005; Macintyre et al., 2009; Emrich et al., 2017; Wells et al., 2019), with Soto et al. (2009) observing a consistent year-to-year river plume occurrences with coral ecosystems (Soto et al., 2009). Though classified as oligotrophic, river plumes can often cause Caribbean waters to become mesotrophic (Warne et al., 2005; Torregroza-Espinosa et al., 2021). In Belize, New River is known to cause a decline in water quality affecting surrounding corals due to poor farming practices and deforestation (Espinoza-Avalos et al., 2009; Reyes et al., 2019). Corals in particular are highly sensitive to changing conditions and it is expected that agricultural runoff and water temperature increases may contribute to their declines (Baumann et al., 2019).

CONCLUSION

Remote sensing can be used to evaluate these coupled events and their spatial and temporal effects on coastal waters. This study observes an improvement in water clarity during COVID-19 shutdowns in Belize, followed by a decline in water clarity following an atypical, active hurricane season. Use of remote sensing is especially important for coastal waters, as populations rise and population density and development along the coasts continue to increase (Martínez et al., 2007; Glavovic, 2017; Elliott et al., 2019). Remote sensing of water quality holds great promise to improve detection of changes in water quality and ecosystem health in data-scarce locations impacted by development, tourism, or climate change, and may represent an asset for nations and entities seeking to set and advance toward the UN Sustainable Development Goals[3] (United Nations, 2020b). This study in particular is closely linked with SDG 14.1 (life in water). Satellite data can be used to extend ground-based monitoring programs to increase the temporal and spatial density of data. Future research will involve the use of match-ups between *in situ* and satellite data to further investigate long-term relationships between *in situ* water quality parameters such as chlorophyll-a and TSM and isolate any signal related to COVID-19 lockdowns.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

IC, JJ, DM, and CL wrote the manuscript. IC developed all scripts and performed the data processing and analysis with some guidance from BP. CL, DM, RG, and EC conceived the study. CL, JJ, and DM co-advised the research. CL, RG, and JJ acquired the funding. EC, MA, RG, AR, SF, AC, MR, and CE contributed to the development of the project and manuscript editing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.648522/full#supplementary-material

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[3] https://sdgs.un.org/goals/goal14

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