PRELIMINARY ASSESSMENT OF SURFACE WATER CLARITY CHANGES IN KEY WEST DURING THE COVID19 ANTHROPAUSE

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SUMMARY OF FINDINGS

While the Anthropocene encompass the period since the beginning of significant human impact on the atmosphere, biosphere and hydrosphere, the recently named Anthropause is characterized by a substantial slowdown in human activity due to the COVID19 pandemic (Rutz et al. 2020). This slowdown has driven changes of environmental conditions around the world (Rutz et al. 2020; Forti et al. 2020; Manenti et al. 2020), fostering research programs to evaluate its impact (https://www.bio-logging.net). Preliminary evaluation of these changes suggest that air quality improves significantly in cities around the world, water pollution and noise are cut-down, and greenhouse gas emissions also decline (Rume and Didar-Ul 2020). In this context the slow-down has the potential of reverting or abating the effects of the Anthropocene.

There have been countless reports of improving water clarity during the COVID19 shut-down, and the ban on cruise-ship traffic in Key West, but no hard data has been presented to back-up those statements. We have attempted to detect changes in water quality during the COVID19 shutdown from measurements performed by Florida International University the last 25+ years in the Florida Keys National Marine Sanctuary and from data gathered by MODIS instruments onboard Aqua and Terra satellites provided by University of South Florida Optical Oceanography Lab. We used turbidity and water clarity as water quality indexes, two quantifiable properties amenable of detection by the human eye, which would relate to citizens perception. Additionally we used a “first-responder” water quality index, dissolved oxygen, to complement the assessment of changes in water quality.

We began by comparing the ShutDown period against a 25-year Baseline spanning from 1995 to 2019, and testing the changes with two different statistical procedures, conventional ANOVA tests and Welch's approach for ANOVA. We contrasted the median and the mean from the Baseline to those of the Shutdown. As shown in Figure I for Box-and-Whisker method, median turbidity in surface waters south of Key West during the ShutDown, was significantly lower than the median of the previous 25 years (green arrow), while median dissolved oxygen concentrations were higher during 2020 and Kd was lower. Bottom waters in reef samples also had lower median turbidity and Kd, and higher DO, but the differences with the median of previous years were not statistically significant (blue arrows). All those changes are signs of water quality improvements with respect to median Baseline.

Tests contrasting the mean of parameters between Baseline and Shutdown (Fig I; MINITAB Welch's) was even more dramatic. Mean for turbidity, Kd, and DO for surface and bottom waters in reef sites were all significantly different (meaning better) from those of the Baseline (green arrows in Fig i). Mean turbidity in surface waters north of Key West was lower during the ShutDown, while DO in bottom waters was higher. Mean DO in surface waters and Kd of the water column did not change from Baseline to 2020, for northern stations.

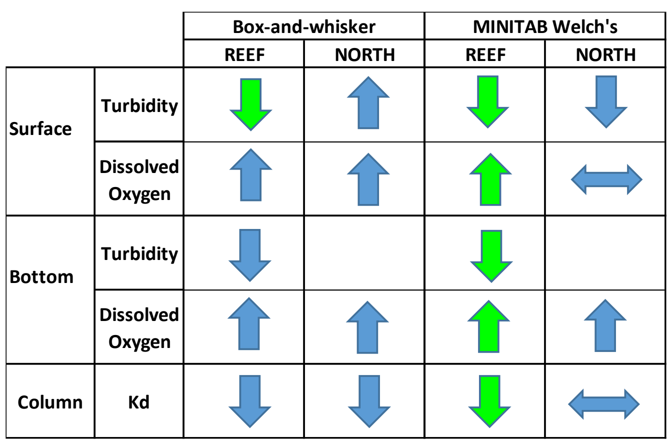

Figure i: Summary of changes in turbidity, DO, and Kd in surface and bottom waters of the Reef and North of Key West areas.

MODIS data to compare and test differences between pre-shutdown (2019-Feb 2020) and COVID-ShutDown (March 2020-Dec 2020) indicate that most stations in reef waters experienced drops in Kd (#275, #276, #280, #281) and/or turbidity (#275, #276, #278, #281) in 2020 as compared to 2019. Breaks in the mean function derived from Rodionov test were statistically significant.

Waters south of Key West, during year 2020 were among the less turbid waters in the last 25 years, together with 2012, 2013 and 2015. Kd was low, but similar to several previous years. Turbidity and Kd in waters in Garrison Bight and Man of War Bay, north of Key West, are not different from most previous years. In all instances, magnitude of changes were very small, underscoring the sensitivity of these ecosystem to even very small changes. What is interesting is that small improvements in turbidity and Kd swiftly cascade into observable changes in water quality perceived by Keys neighbors, and surely by the rich biota of the Florida Keys National Marine Sanctuary.

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INTRODUCTION

While the Anthropocene encompass the period since the beginning of significant human impact on the atmosphere, biosphere and hydrosphere, the recently named Anthropause is characterized by a substantial slowdown in human activity due to the COVID19 pandemic (Rutz et al. 2020). This slowdown has driven changes of environmental conditions around the world (Rutz et al. 2020; Forti et al. 2020; Manenti et al. 2020), fostering research programs to evaluate its impact (https://www.bio-logging.net). Preliminary evaluation of these changes suggest that air quality improves significantly in cities around the world, water pollution and noise are cut-down, and greenhouse gas emissions also decline (Rume and Didar-Ul 2020). In this context the slow-down has the potential of reverting or abating the effects of the Anthropocene.

Since March 2020, when the pandemic shutdown was imposed, Key West residents began to observe improvements in water clarity. Experiencing these beneficial environmental changes cascaded into the inception of a strong social movement aiming to preserve what their followers interpret as environmental gains brought about by the shutdown. This report summarizes a preliminary evaluation of water clarity changes in waters around Key West, Florida Keys, since March 2020, when the shutdown due to COVI19 began. Florida International University, under contract with the Environmental Protection Agency, is responsible for the execution of the Water Quality Monitoring Project (WQMP) for the Florida Keys National Marine Sanctuary, as part of the Water Quality Protection Program. The Sanctuary extends in a NE to SW direction from offshore Biscayne Bay to Dry Tortugas National Park (some 340 kilometers). There are 112 active monitoring stations in the Sanctuary (Fig 1), where water samples are collected, and water properties are measured every quarter (http://serc.fiu.edu/wqmnetwork/FKNMS-CD/), including waters surrounding Key West.

This study is a preliminary evaluation of differences in selected water quality parameters between year 2020 and the previous 24 years. The parameters selected for evaluation are physical-chemical properties of waterbodies that respond rapidly to imposing conditions (Briceño and Boyer 2009). We will discuss first, the long-term data from FIU monitoring program, and later a preliminary look at remote sensing data derived for the same FIU localities south of Key West.

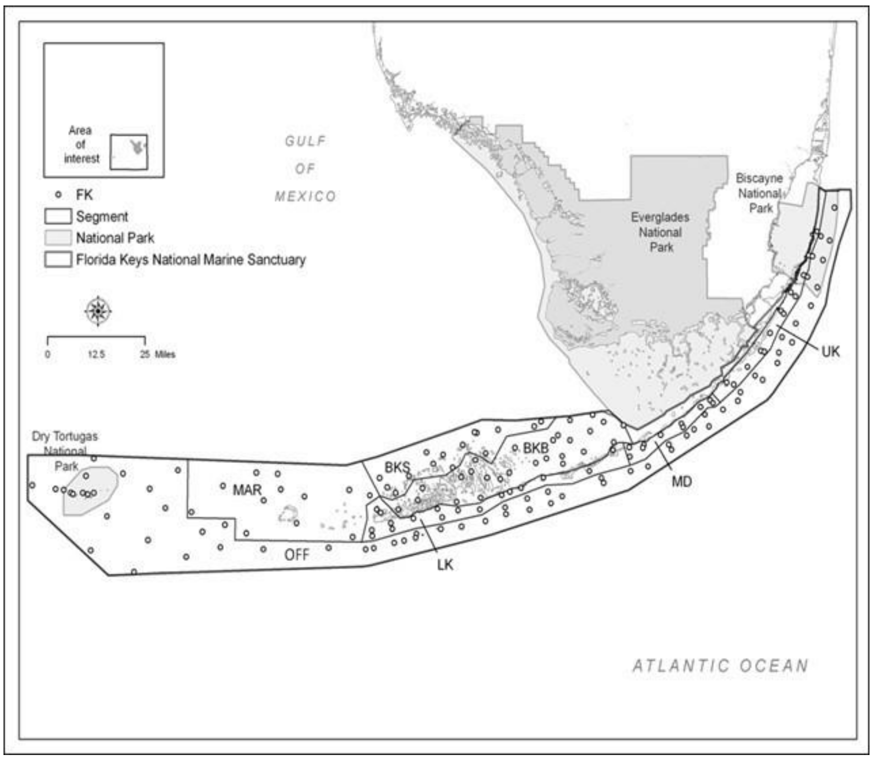


Figure 1: *Map of FKNMS showing segments derived from biogeochemical data: OFF=Offshore; MAR=Marquesas; BKS=Back Shelf; BKB= Back Bay; LK= Lower Keys; MK= Middle Keys; UK= Upper Keys*

STUDY AREA

In order to assess potential water quality changes since the beginning of the Anthropause, we selected data from a series of WQMP monitoring stations around Key West. Five stations (white sites in Fig 2) located on the Atlantic side south of Key West, and two stations to the north of Key West (yellow sites in Fig 2). Stations to the extreme south (#276 and #280) overlie mostly coral barrier-reefs areas (reef-track) and are characterized by their extremely low nutrient concentrations and high clarity (low turbidity). Stations #275, #278 and #281 are in the Hawk Channel, between the reef-track and the keys. Bottom in the channel contains sandy bottom, and reef patches. Those waters are characterized by low nutrient concentrations and a little higher turbidity than reef samples. Both, reef-track and Hawk Channel samples are so similar that we bundled them together as a group (Reef area) for the purpose of this study.

Figure 2. *FIU active monitoring stations near Key West. White stations to the south overlie coral reefs (Reef Area). Yellow stations are in Garrison Bight (#317) and Man of War Harbor Bay (#316), north of Key West (North Area). Light blue line is approximate track of navigation channel*

Finally, stations north of Key West (North area sites; yellow in Fig 2) display moderate to high turbid, and are relatively richer in nutrients and chlorophyll-a, due to the impacts from nearby urban centers and contributions from the Gulf Shelf. There are no stations located in the navigation channel, and the closest site (station #278) is one mile west of the southern extension of the channel (Fig 2).

DATA SOURCES

Data for this study comes from two sources. First, the Florida Keys National Marine Sanctuary (FKNMS) Water Quality Monitoring Project (WQMP) executed by FIU, and second, remote sensing data from the Virtual Buoys Project at University of South Florida's Optical Oceanography Laboratory (https://optics.marine.usf.edu/projects/vbs.html). FIU's monitoring entails both, field measurements of physical-chemical properties of the water column, and the collection and chemical analysis of water samples. Data was downloaded from FIU's Water Quality Monitoring Network website http://serc.fiu.edu/wqmnetwork/FKNMS-CD/.

METHODS

Field Measurements

The period of record for field measurements of water quality parameters was from March 1995 to December 2020 (25.5 years), which included 102 quarterly sampling events. Variables used for this study included dissolved oxygen, turbidity and light attenuation coefficient. Given the shallow depth of #316 and #317, there is no bottom turbidity data for those sites. Field measurements were made with a Seabird SBE 19 and a Lamotte 2020 turbidity meter. The vertical light attenuation coefficient for downward irradiance (K_d, m^{-1}) was calculated at 0.5 m intervals from photosynthetically active radiation (PAR) and depth data using the standard exponential equation (Kirk 1994) and averaged over the station depth. The LICOR PAR sensor uses a diffusive sphere and filters to create nearly uniform sensitivity to light between 400 and 700 nm, which closely corresponds to light used by most terrestrial and aquatic plants and algae.

Statistical analysis

We have tested the hypothesis that water quality has changed significantly during the Anthropause on the coral reefs south of Key West, and to the north of Key West. Levels of surface and bottom turbidity (TURB), dissolved oxygen (DO), and light attenuation coefficient (Kd) during the COVID19 shut down, were compared to baselines of the same water quality indexes, calculated for the period 1995-2019. Comparison was primarily with box-and-whisker plots. The box-and-whisker plot is a simple but powerful statistic as it shows the median, range, the data distribution as well as serving as a graphical, nonparametric Analysis of Variance (ANOVA).

The example in Figure 3 highlights the components of box-and-whisker plots. Turbidity data from two sites, A and B, are compared with box-and-whisker plots. In a box-plot, the center horizontal line of the box is the median of the dataset (the median is the value separating the higher half from the lower half of a data sample). The top and bottom of the box are the 75^{th} and 25^{th} percentiles, and the upper and lower ends of the whiskers are the 95^{th} and 5^{th} percentiles, respectively. The notches indicate the span of the confidence interval for the median. When notches overlap, the median of the comparing distributions are not significantly different at a given confidence level, here established as 5%. The software package used for the Box-and-Whisker statistical calculations was StatView®.

An additional ANOVA tests to complement/validate StatView box-plot results was performed with MINITAB 19® statistical software. This verification was necessary because of the substantial differences in sample size and differences of variance, between pre-Anthropause and Anthropause, for which conventional One-Way ANOVA used by StatView is not very reliable.

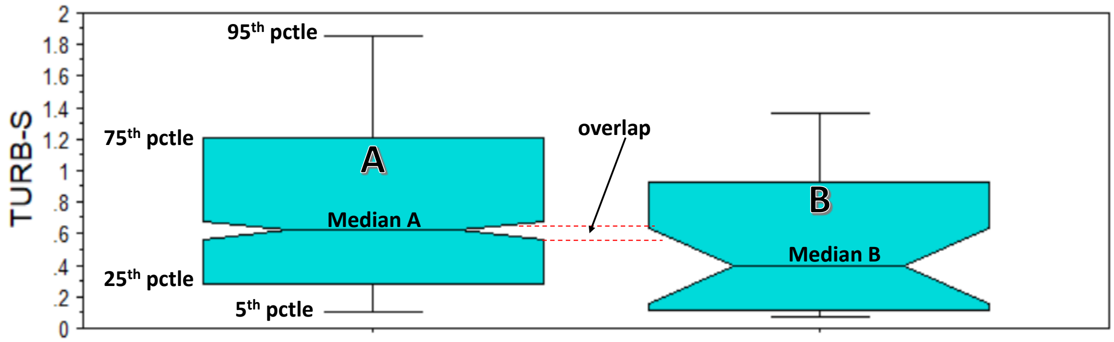


Figure 3: *Example of Box-plot. Center horizontal line is the median of the data, the top and bottom of the box are the 75^{th} and 25^{th} percentiles, and the upper and lower ends of the whiskers are the 95^{th} and 5^{th} percentiles. In this example the notches overlap, indicating the median of the comparing distributions are not significantly different*

PRESENTATION & DISCUSSION OF RESULTS

The dataset was subdivided into two periods for comparison, Baseline and ShutDown. Baseline includes all measurements performed since inception of the monitoring program in 1995 until December 2019 (24 years). ShutDown corresponds to all those measurements done since March 2020, when the shutdown began, until December 2020.

Reef area

Figure 4 show the distribution of values for each period for Turbidity (TURB-S), dissolved oxygen (DO-S), and temperature (TEMP-S) in surface waters, as well as light attenuation coefficient (Kd), for the overall water column. As seen in Figure 4, the median (horizontal line within box) for the ShutDown distributions south of Key West do not match those of the Baseline, suggesting some deviation in 2020 from the "normal" of the previous 24 years. Median turbidity in 2020 was lower than the median of previous years in surface and bottom waters. Confidence interval (notches) for the median turbidity in surface waters do not overlap, indicating the difference with Baseline is statistically significant. That would explain the generalized perception of the citizens of Key West that waters were cleaner (less turbid) since the shutdown began. Bottom turbidity was lower than Baseline in 2020, but the difference is not statistically significant.

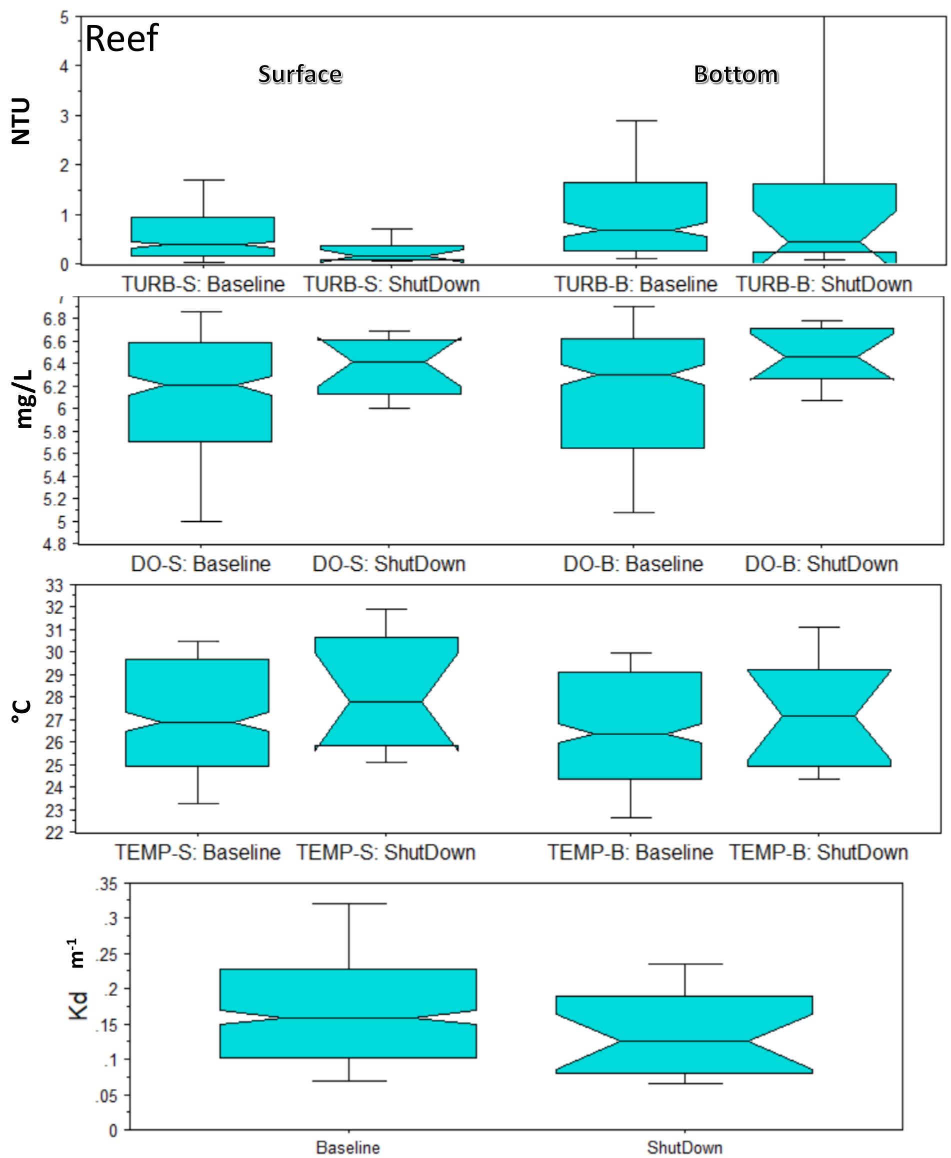


Figure 4: *Box-plots of turbidity (TURB-S, NTU), light attenuation coefficient (Kd; m^{-1}), dissolved oxygen (DO-S, mg L^{-1}) and temperature (°C) for surface and bottom waters in reef areas south of Key West.*

Likewise, median Kd for the ShutDown is smaller than the Baseline median, indicating clearer waters during 2020. That said, Figure 4 also shows that the notches of the distributions for Kd in Baseline and ShutDown overlap, indicating that the differences are not statistically significant at the 5% level of confidence. Simply put, Kd medians are different, but differences are not statistically significant at this confidence level. This is a good example of a very common statistical statement that becomes a conundrum for audiences not familiar with statistics.

Median dissolved oxygen concentrations in the reef area during 2020 were higher than those of the Baseline (Fig 4), and the notches of the distributions overlap, meaning that medians of dissolved oxygen concentration since the shutdown are higher than those from the previous 24 years of Baseline, but the differences are not statistically significant. That is an interesting result, given that higher oxygenation is a sign of water quality improvement. Indeed a sign not detected with the naked eyes of the community, as is turbidity.

Dissolved oxygen concentration in water is a function of temperature. The higher the temperature the lower the dissolved oxygen content. Therefore, we needed to verify if the increase in oxygen concentration was potentially due to the shutdown or it was just caused by a decline in temperature. Figure 4 shows that the median temperature in 2020 was higher than the Baseline median. In other words, DO should have declined during the ShutDown if only controlled by a rise in temperature, but it did not. On the contrary, median DO increased while median temperature increased too. This apparent disparity suggests that another factor different from temperature (the shutdown?), may have driven such an increase in DO, beyond and above the effects of higher temperature.

In summary for the reef area, when compared to previous years, median turbidity in surface and bottom waters was lower in 2020 than before; median dissolved oxygen was higher, while Kd was lower. All of those differences point toward an improvement in water quality in 2020 with respect to median conditions during the Baseline. The only statistically significant change was that of the decline in surface turbidity.

North Area

Stations in the North area are located in Garrison Bight (#317) and Man of War Harbor Bay (#316), north of Key West. These stations belong to the LOWER KEYS water type (Briceño and Boyer 2013), with higher nutrient, chlorophyll-a (CHLA) and Kd than reef waters. They are different statistical populations. Both station receive an important contribution from the Gulf Shelf and their nutrient concentrations and Kd are rather similar.

Box-and-whisker plots for Baseline and ShutDown for the northern area are in Figure 5. Surface turbidity, was slightly higher in 2020 than before, but the difference with the Baseline is non-significant (notches overlap). Likewise, Kd is slightly lower but the difference is not statistically significant. Dissolved oxygen is a little higher in surface and bottom waters in year 2020, but differences with Baseline are non-significant. Finally, the slightly higher temperature during the ShutDown is non-significant.

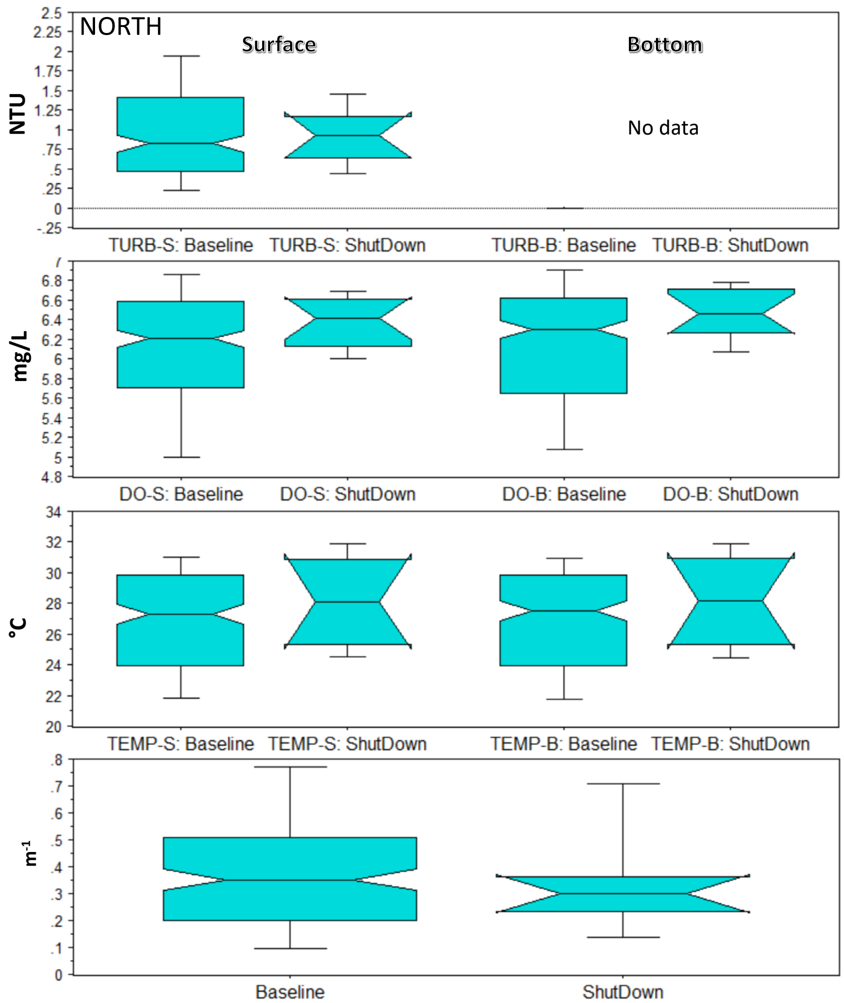


Figure 5: *Box-plots of turbidity (TURB-S, NTU), light attenuation coefficient (Kd; m^{-1}), dissolved oxygen (DO-S, mg L^{-1}) and temperature (°C) for surface and bottom waters north of Key West (Garrison Bight and Man of War Bay).*

MINITAB ANOVA Tests

An additional ANOVA tests to complement/validate StatView box-plot results was performed with MINITAB 19® statistical software. This validation is necessary because the substantial differences in sample size between Baseline (98 sampling events) and ShutDown (four sampling events) as well as differences in variance, for which conventional One-Way ANOVA is not totally reliable. MINITAB 19's ANOVA uses Welch's approach (Welch 1951; Moder 2010), which does not assume or require that the statistical samples have equal variances. Furthermore, Welch's test performs well with unequal variances, disregarding the sample sizes. This test is performed on the mean, not the median as with the box-plots.

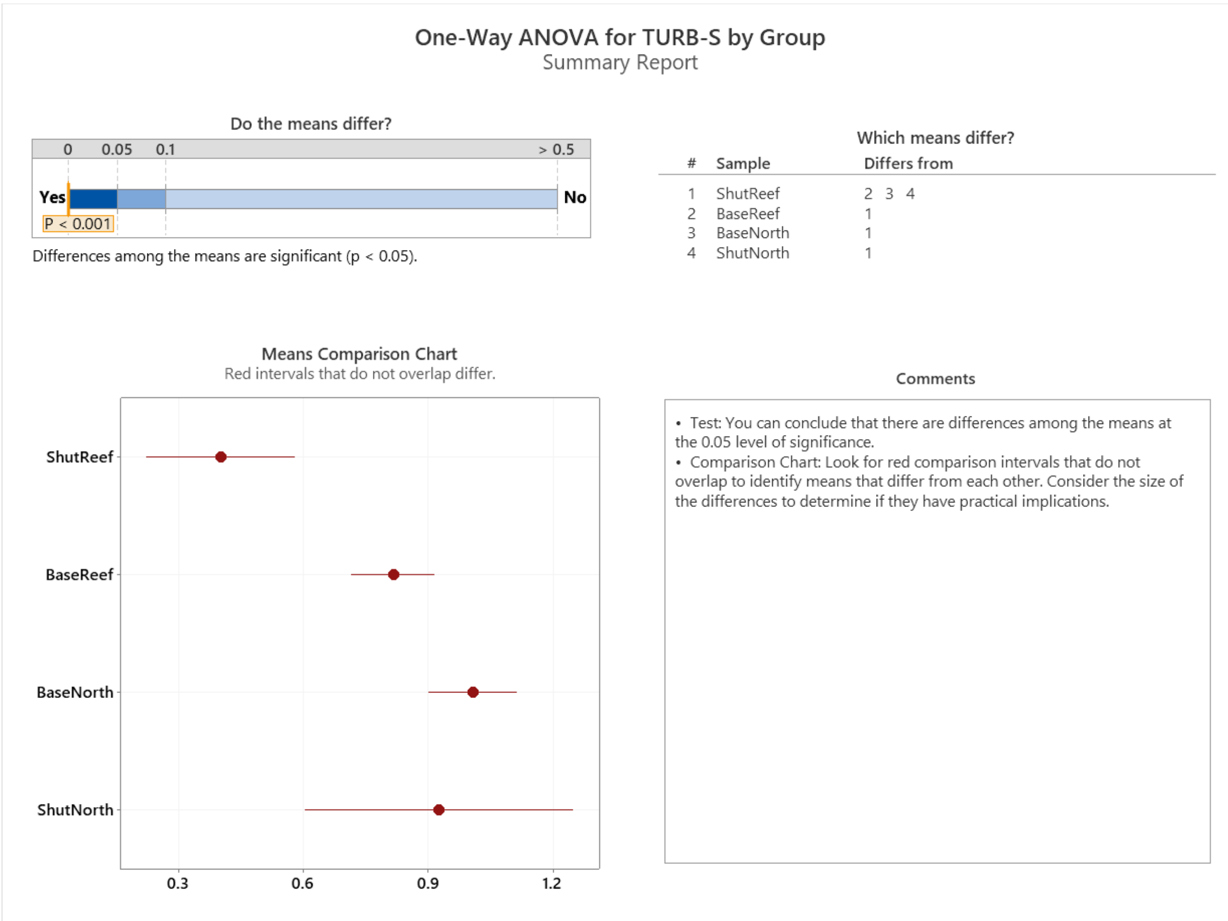
As shown in Table 1, surface mean turbidity during ShutDown (0.40 NTU) in the Reef area is significantly smaller than that during Baseline (0.81 NTU), and the confidence intervals do not overlap, so the difference is statistically significant. Mean surface turbidity in the north area are very similar for Baseline and ShutDown and their confidence intervals overlap. In summary surface turbidity declined significantly in reef areas during the shutdown, but there were not significant changes in turbidity in stations north of Key West.

Results for Kd (Table 2) indicate that for the reef area, mean Kd during Baseline (0.21 m^{-1}) was significantly higher than mean Kd during the shutdown of year 2020 (0.13 m^{-1}), suggesting water clarity improvements. Changes in Kd north of Key West were not statistically significant during Baseline and ShutDown.

Finally, Table 3 shows the results of the MINITAB 19 ANOVA test for mean dissolved oxygen. There was a statistically significant increase in dissolved oxygen in reef stations, but no change was observed in sites north of Key West.

In summary, Box-and-Whisker ANOVA on the median and MINITAB ANOVA test on the mean lead to similar conclusions regarding direction of changes from Baseline to shutdown periods. Significant declines in turbidity and light attenuation (Kd), and increase in dissolved oxygen in reef sites, but not statistically significant changes in sites to the north in Garrison Bight and Man of War Harbor.

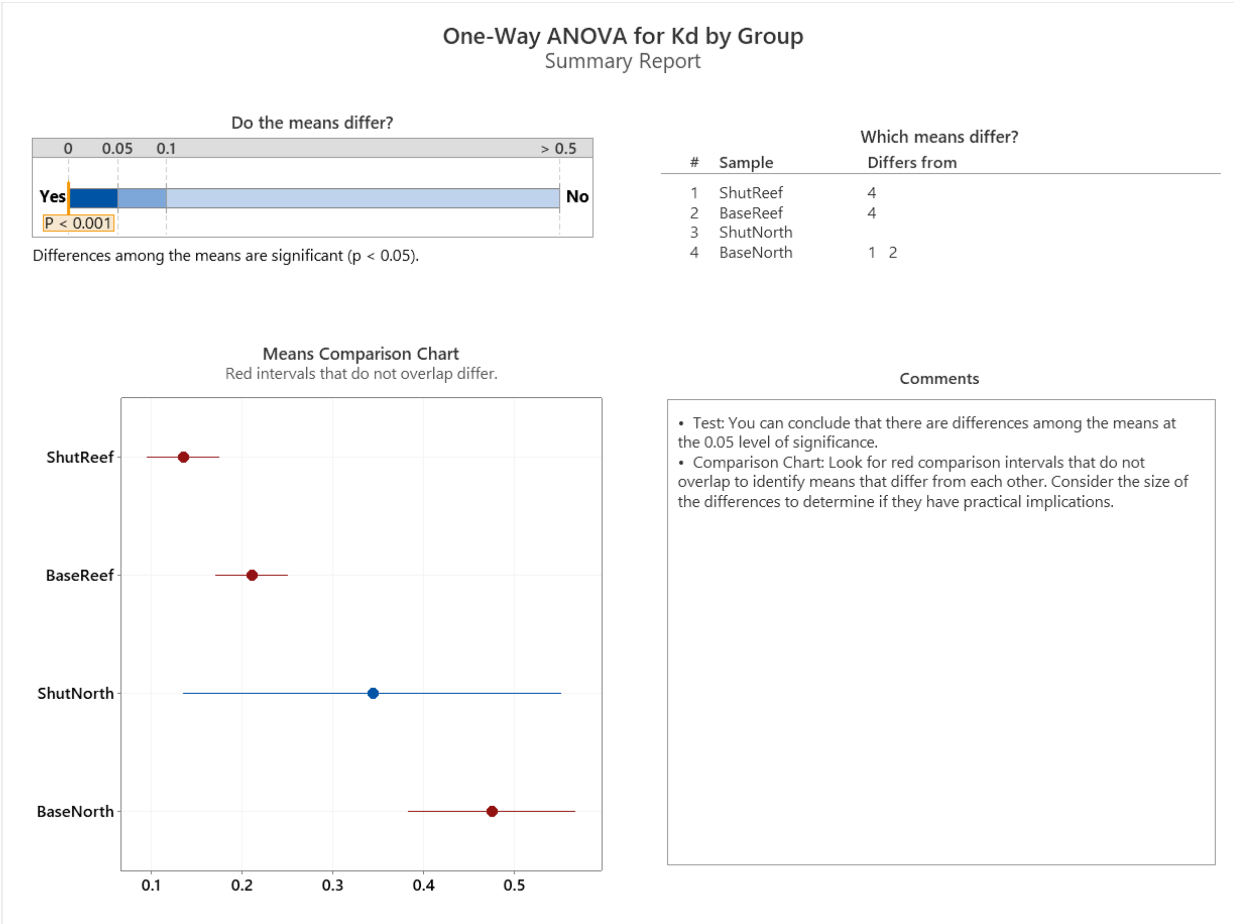
Table 1: *Results of ANOVA tests for Turbidity*



Statistics

Group	Sample Size	Mean	Standard Deviation	Individual 95% CI for Mean
BaseNorth	193	1.0085	0.75002	(0.90198, 1.1149)
BaseReef	475	0.81573	0.93630	(0.73131, 0.90014)
ShutNorth	8	0.92625	0.37355	(0.61395, 1.2385)
ShutReef	20	0.40225	0.43461	(0.19885, 0.60565)

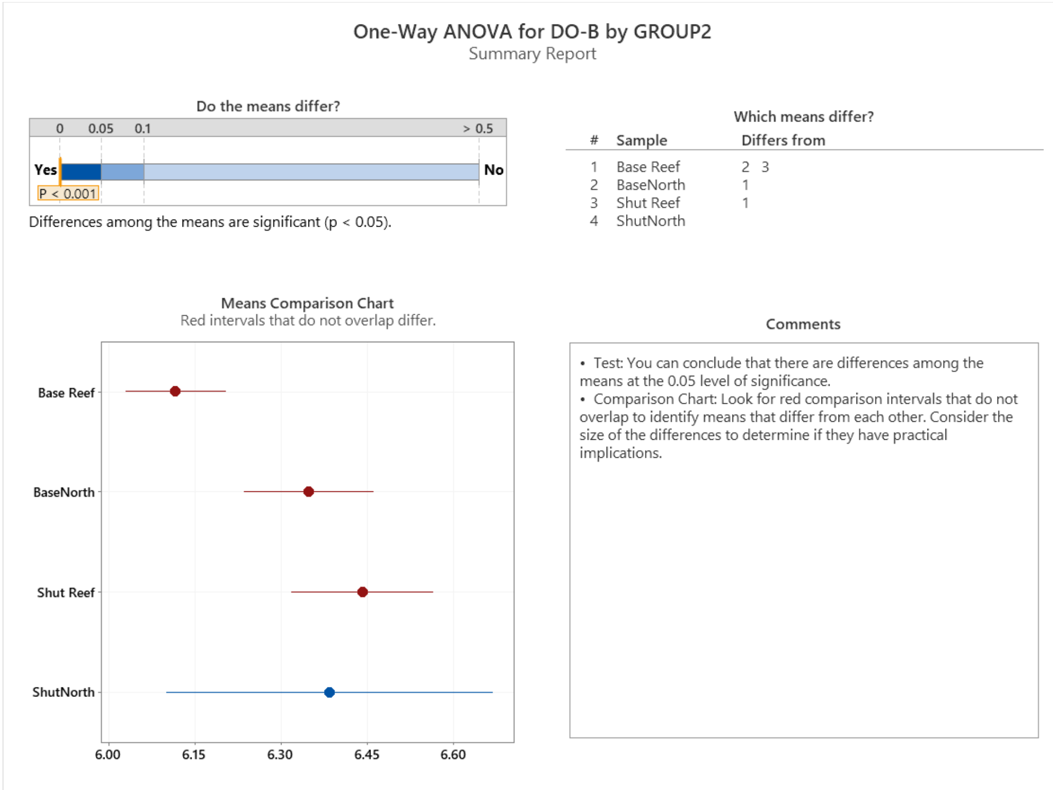
Table 2: *Results of ANOVA tests for Kd*



Statistics

Group	Sample Size	Mean	Standard Deviation	Individual 95% CI for Mean
BaseNorth	148	0.47544	0.65423	(0.36917, 0.58172)
BaseReef	416	0.21022	0.30017	(0.18129, 0.23915)
ShutNorth	8	0.34355	0.22329	(0.15687, 0.53022)
ShutReef	20	0.13454	0.06502	(0.10411, 0.16497)

Table 3: *Results of ANOVA tests for Dissolved Oxygen*



Statistics

GROUP2	Sample Size	Mean	Standard Deviation	Individual 95% CI for Mean
Base Reef	470	6.1170	0.76189	(6.0479, 6.1860)
BaseNorth	190	6.3485	0.89039	(6.2211, 6.4759)
Shut Reef	20	6.4420	0.30386	(6.2998, 6.5842)
ShutNorth	8	6.3836	0.32656	(6.1106, 6.6566)

Seasonal comparisons

Trying to understand the observed changes in a time framework, we explored seasonal changes between Baseline and ShutDown periods given that monitoring data in the Florida Keys is collected quarterly, roughly corresponding to Winter (Dec-Feb), Spring (Mar-May), Summer (Jun-Aug) and Fall (Sep-Nov).

We tested Baseline and ShutDown for Reef sites each season. Overall, data do not show seasonality for turbidity or Kd, and DO describes a seasonal patterns as follows: Summer < Fall < Spring < Winter. Temperature displays a pattern opposite to that of DO. Median turbidity is lower during ShutDown in all seasons (Table 4), but significantly lower only during spring. Median Kd is also lower in all seasons, and not statistically significant in any. Likewise, median dissolved oxygen and median temperature were higher in 2020, but the only significantly higher median was that of temperature in the summer. North of Key West seasonal changes between Baseline and ShutDown were not significant for any season.

Table 4. Summary of direction of water quality changes and their significance

		WINTER	SPRING	SUMMER	FALL	Comments
REEF	Turbidity	↓	↓	↓	↓	All changes in right direction. Only Spring was significant
	Dissolved Oxygen	↑	↑	↑	↑	All changes in right direction. Only Spring was significant
	Kd	↓	↓	↓	↓	All changes in right direction. None was significant

Annual variability

From the analysis discussed in this report so far, some improvements in water quality seem to have occurred during the shutdown as compared to median and mean conditions during the Baseline, especially in waters overlying the coral reefs. We compared the distributions of annual measurement since inception of the monitoring program in 1995, to verify if such changes were exclusive of the shutdown year. We plotted annual data for each station (Fig 6) and we observed that along the 25 years of monitoring, in several occasions conditions have been similar to those of year 2020. As shown in Figure 6, during 2020 water turbidity and Kd at sites south of Key West, have been among the lowest in 25 years.

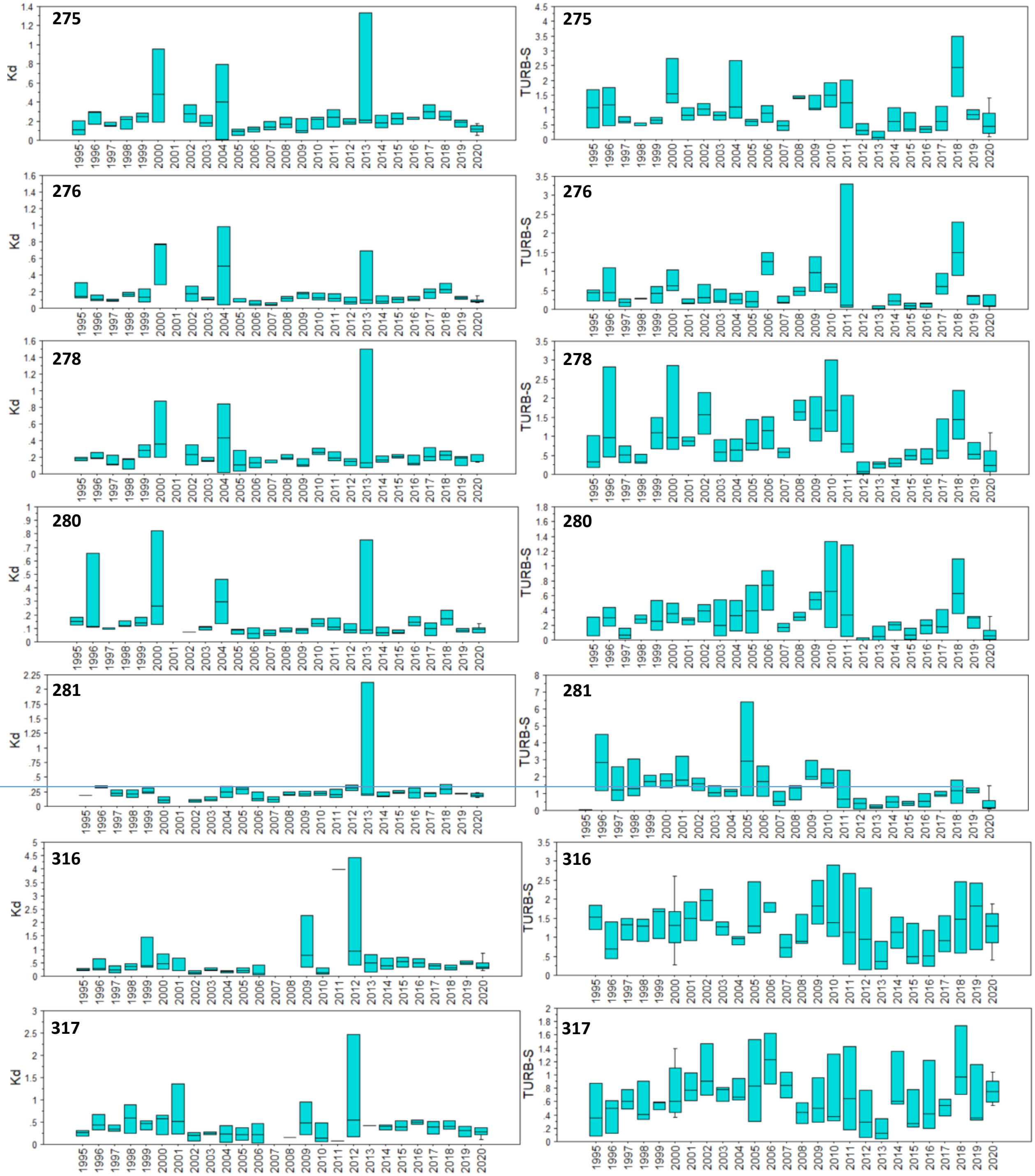


Figure 6: Annual comparison of turbidity and Kd, in waters around Key West since 1995. Year 2020 is among the lowest for turbidity and Kd, especially in the reef area (stations #275, #276, #278, #280 and #281). Turbidity and Kd at stations #316 and #317 are not especially different from other years since 1995.

Long-term trend

Changes from 2019 to 2020 around Key West must be framed within the general variability of long-term changes region wide. The annual reports published by FIU for the Water Quality Monitoring Program for the Florida Keys National Marine Sanctuary provide such a regional long-term framework. Briceño and Boyer (2020) indicate that during the last 25 years the greatest increases in DO occurred on the Atlantic side of the Keys, Marquesas, and in some inshore areas on the Bay side (Fig 7). Likewise, water column turbidity (cloudiness) declined throughout the FKNMS during the 25 year period (beneficial trend), especially around the Marquesas. These changes also cascaded into a decline of the light attenuation coefficient Kd, and an increase in light reaching the bottom, benefitting benthic communities.

Waters around Key West are in an extremely dynamic environment. It is the site of mayor interaction of the Gulf Shelf, the Florida Current and the islands chain, as can be seen in Figure 7. Those regional players may blur local changes very easily.

In order to downscale those regional trends to Key West surroundings, we performed regression analysis for surface and bottom turbidity and DO, as well as Kd along the complete period of record for stations #275. #276, #278, #280, #281, #316 and #317 (Fig. 2) to gain insight on those long term trends. An example of the detailed tests performed on the time series is in Figure 8 and a summary of results for all studied sites is on Figure 9. Most surface turbidity has declined over the last 25 years south of Key West, but the drop has not been statistically significant. North of Key West surface turbidity has increased long-term but without statistical significance, either.

Likewise, bottom turbidity has increased south of Key West except at #281 where it declined. Again, these changes have no statistical significance. Dissolved oxygen, on the other hand, has increased at all stations in surface and bottom waters. Those DO changes have been statistically significant for stations south of Key West, in coral reef waters. In summary, as expected, those local changes follow very closely the regional pattern of change.

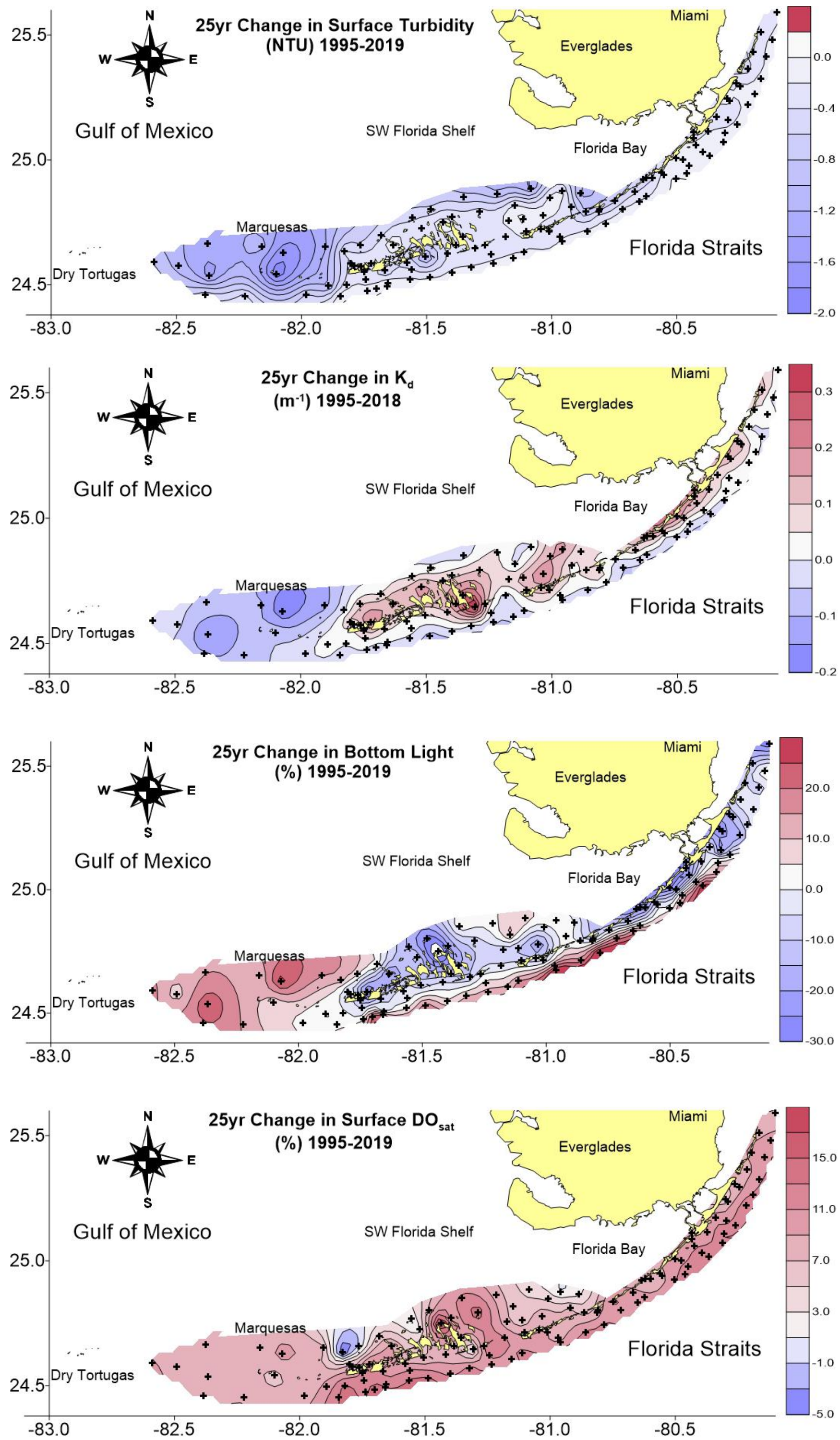


Figure 7. *Total change in turbidity, light attenuation coefficient Kd, Bottom light and DO saturation, in surface waters of the Florida Keys National Marine Sanctuary the last 25-year period.*

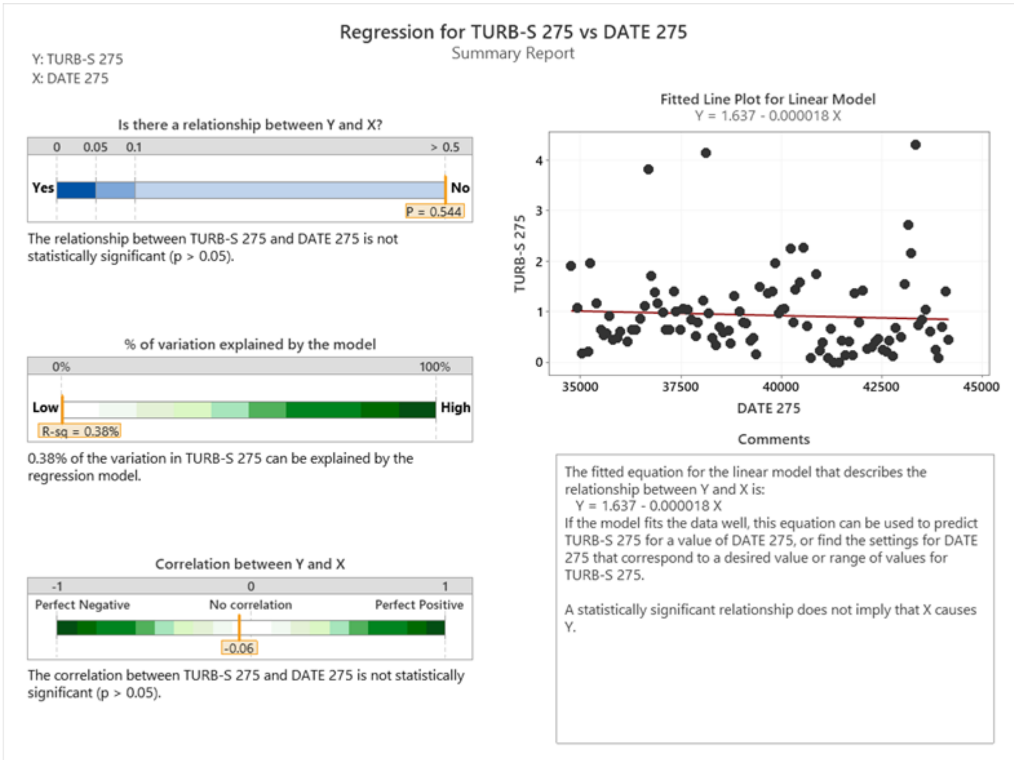


***Figure 8:** Regression analysis for long-term trend of surface turbidity at station #275*

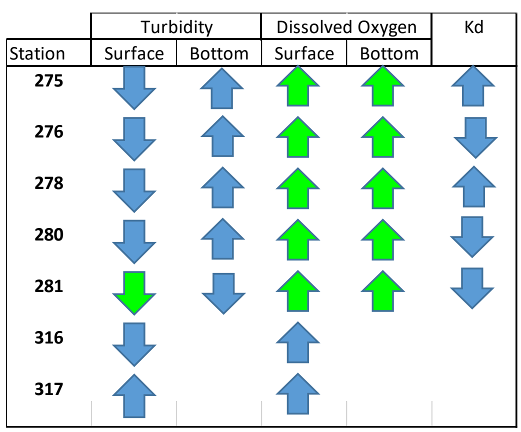


***Figure 9:** Tendency of 1995-2020 long-term trends at each study site. Arrow up= increase; arrow down=decline; green=significant; blue=non-significant*

Remote Sensing Data

Given that FIU monitoring is done quarterly we have had only four sampling events at each station during the shutdown, which is a very small statistical sample. In order to increase the observations through sampling frequency we resorted to remote sensing data from the MODIS instrument (Moderate Resolution Imaging Spectroradiometer) onboard the Aqua and Terra satellites. Those satellites provide view of the entire Earth's surface every 1-2 days. We selected data extraction sites at the same reef locations as FIU monitoring stations during 2019 and 2020 and an additional virtual buoy close to the Port of Key West (St 01) where no FIU site exists (Fig 9). Remote sensing data come from the Virtual Buoys Project at University of South Florida's Optical Oceanography Laboratory (https://optics.marine.usf.edu/projects/vbs.html) kindly provided by Dr. Brian Barnes.

Figure 9. *Location of virtual buoy stations for data extraction from MODIS data.*

This initial assessment with virtual buoy data for this specific area was done only with data for 2019 and 2020. Remote sensing data comes from MODIS instruments onboard satellite platforms. Extracted data include Remote Sensing Reflectance at 645 nm (Rrs_645), used as a proxy for in-water turbidity, and Kd_488, as a proxy for the multispectral diffuse attenuation coefficient (Kd) derived from MODIS/Aqua measurements and validated against in situ Kd(488) data (Hu et al 2004, 2013; Chen et al. 2010; Barnes et al 2013). Virtual buoys if located in clear waters, usually need water columns deeper than 5 m (~16.5 ft) to avoid signal contamination by bottom reflectance. Therefore, water depth hinders the possibility of retrieving water column data in shallower waters close to Key West.

Comparing Remote Sensing and FIU Field Data

First, we compared remote sensing time series with the available quarterly sampling data from FIU monitoring program for 2019 and 2020 (Fig 10). Diagrams of Figure 10 indicate:

- There is in general very good agreement between FIU Kd and USF estimates from MODIS modkd_488
- Initial Rrs_645 units are “per steradians” and values were converted to turbidity using Chen et al (2010) equation as follows:
    - **turbidity = 1203.9 × Rrs(645)^1.087**
- Transformed values are within the range of FIU’s measured data (Fig 10), despite not being collected on the same date.

In summary, satellite-derived data seems to match within the margins of acceptable error those of the field measurements. Next would be to compare changes from 2019 to 2020 in satellite-derived proxies for Kd and turbidity.

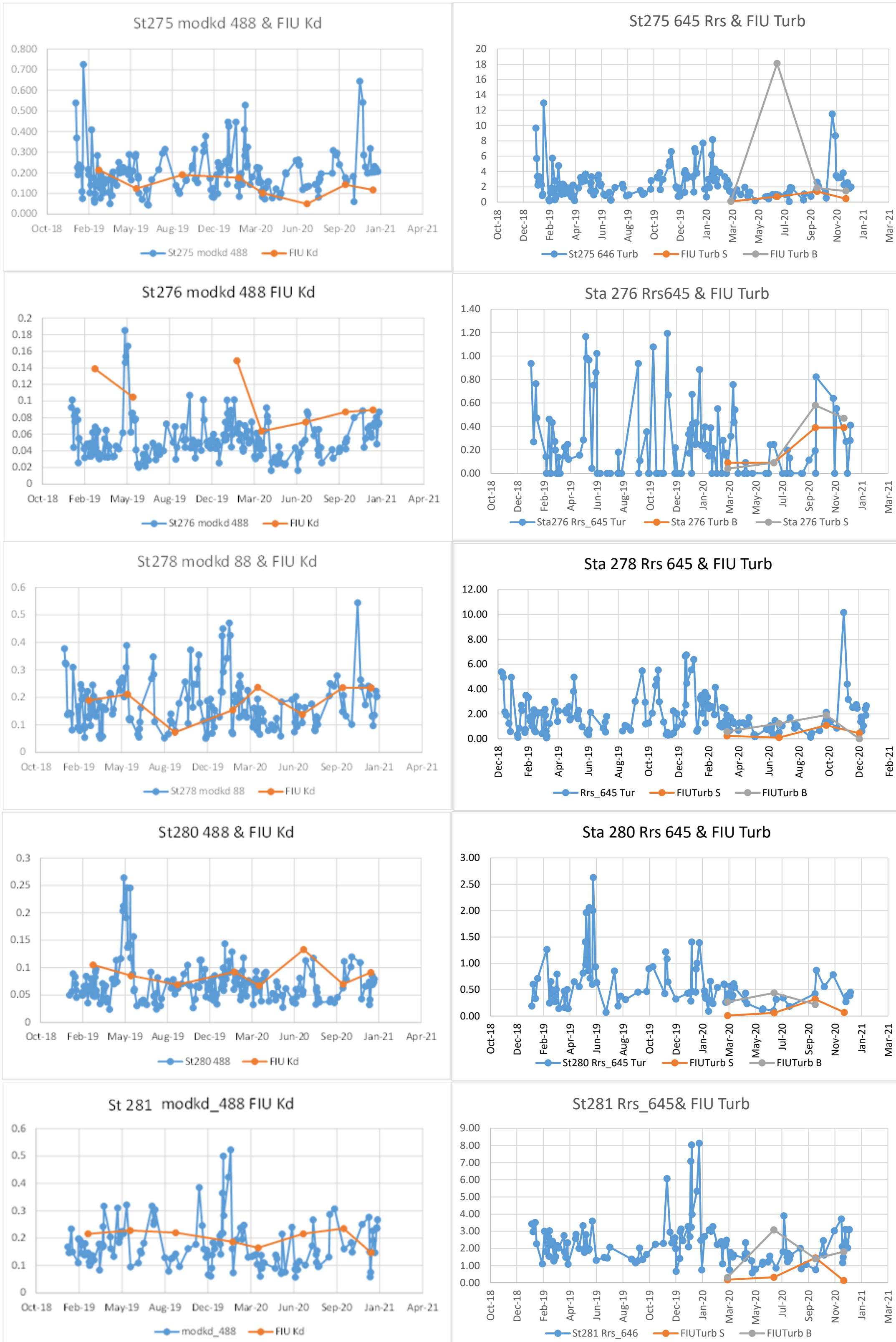


Figure 10. Comparison of remote sensing derived Kd (modkd_488) and turbidity (Rrs_654) with FIU field measurements. We plotted lines connecting points, only to help visualization.

We explored changes in the remote sensing time-series and tested differences between pre-shutdown (2019-Feb 2020) and COVID-ShutDown (March 2020-Dec 2020) using the regime-shift detection method of Rodionov (2004; https://www.beringclimate.noaa.gov/regimes/).

Results shown in Fig 11 indicate:

- **Station St01:** There were no significant changes in 2020 with respect to 2019 in Kd or turbidity. Perhaps the incomplete time series does not allow for clear discrimination, if it existed.
- **Station St275:** There was a drop in modkd at station 275 starting in Jan 2020 and lasting until October. Likewise, there was a drop in turbidity from Jan to Oct 2020.
- **Station St276:** Kd and turbidity at Station 276 experienced declines in April 2020 and extending to October 2020
- **Station St278:** From January to December 2020, Kd at station 278 stayed about the average of 2019 when multiple changes occurred. Turbidity dropped in March and stayed low until October 2020
- **Station St280:** Kd at Station 280 was lowest from April to early October 2020, but turbidity in 2020 was high as compared to most of 2019
- **Station St281:** Kd at station 281 clearly dropped from March to September 2020, and turbidity followed suit starting in January 2020, and remaining low until late December 2020.

Most stations show drops in Kd (#275, #276, #280, #281) and/or turbidity (#275, #276, #278, #281) in 2020 as compared to 2019. Breaks in the mean function derived from Rodionov test are statistically significant. Two additional comments are necessary. First, in some instances (stations #275, #278 and #281), the drop seems to begins in Jan 2020 before the onset of shutdown, but after detailed observation of the data, it is clear the drops started in March 2020 and the shift to January is an artifact of the regime-shift software (Fig 11). Second, declines of turbidity and Kd from 2019 to 2020 as observed from MODIS data occurred, but their magnitude was small in the studied reef stations.

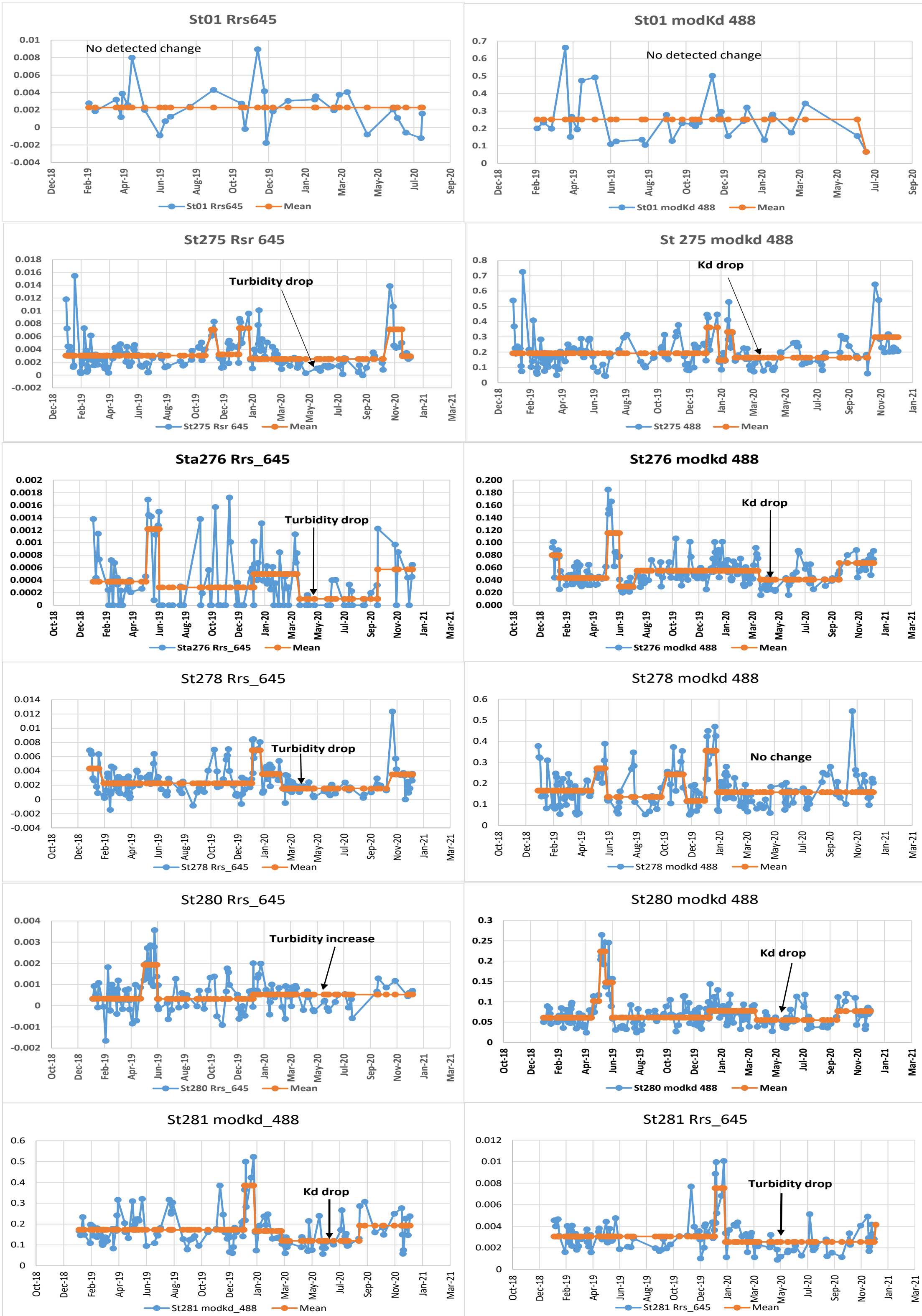


Figure 11. Regime-shift (Rodionov 2005) for satellite-derived Kd (modKd_488) and turbidity (Rrs_645) from virtual buoy sites on FIU reef stations.

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