

Interactive comment on “The Relationship between Tropical Cyclone Activity, Nutrient Loading, and Algal Blooms over the Great Barrier Reef” by Chelsea L. Parker et al.

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Received and published: 2 May 2017

Response to Reviewers

Title: The Relationship between Tropical Cyclone Activity, Nutrient Loading, and Algal Blooms over the Great Barrier Reef
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MS No.: bg-2017-23

VALIDATION

We appreciate the concerns of the reviewers regarding the accuracy and reliability of the MODIS chlorophyll a data in the coastal region of the Great Barrier Reef (GBR). It is evident that validation of this dataset needs to be carried out.

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In response to these concerns, we have begun validation of the remotely sensed data product using chlorophyll a in situ measurements from NOAA cruise data measurement (the World Ocean Database, available at <https://www.nodc.noaa.gov/OC5/SELECT/dbsearch/dbsearch.html>). Importantly these NOAA cruises sample the GBR marine park and measurements capture Case 2 waters and allow for the validation of the MODIS product in these complex waters. Given the rarity of cruises, there were only 4 passages that crossed the GBR and coincided with available MODIS data in our 10-year study period.

Our initial validation aggregates all the available NOAA WOD data from our time period partitioned by times of TC presence (Figure 1) or absence (Figure 2). Both relationships demonstrate a significant positive correlation ($p < 0.05$) between the in situ and the remotely sensed product (Figure 1, 2). The MODIS data reasonably captures the trend in in situ measurements. Figure 1 begins to suggest that the MODIS product may be systematically underestimating surface chlorophyll a concentrations during times of TC presence. This new analysis suggests that the discussed signals and relationships between chlorophyll a and tropical cyclone (TC) activity in the manuscript are still valid, and may even be underestimated.

We could include detailed analysis of this validation effort in the manuscript to address concerns about the MODIS data accuracy in this region. We could also expand the validation to time periods outside of 2004-2014 in order to increase the number of cruises aggregated and systematically demonstrate validation of this MODIS dataset in the GBR region (particularly during times of TC present). This would provide a very important step in the validation of the MODIS product in these waters which is clearly lacking in the literature.

AGGREGATION

We would like to clarify that this study seeks to find a significant, generalizable, systematic relationship between tropical cyclone activity and chlorophyll a over the GBR

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in order to generate hypotheses of the mechanisms through which cyclone may affect reef water quality. We explore whether a signal can be found in the data as a precursor to more detailed studies. This study uses broad spatial and temporal scales, and finding a signal at this scale informs us of the utility of progressing to finer scale, detailed studies. Furthermore, this work stands in concert with, and does not aim to recreate the existing smaller scale, case study projects and observations.

In order to explore and identify a signal in the data, it was necessary to use a large number of cyclone cases (for a large sample size) and aggregate the data over 10 years of cyclone activity and over the whole expanse of the GBR. If necessary, we can attempt to make this motivation clearer in the manuscript.

DIRECT RESPONSES

REFEREE 1

General comment 1: we are beginning to quantitatively evaluate the MODIS chlorophyll a concentrations as discussed in the validation section above.

General comment 2: we appreciate these comments and concerns over spatial and temporal scales. As discussed in the aggregation section above, the utility and novelty of this work lies in the exploration of a signal in a large, aggregated dataset. We also agree that there would be a gradient of effect with distance from the land. However, given that we use a range of descriptive statistics including the mean, upper percentiles, and maximum values, the affected zone would be captured in these measures regardless of the location and size of the cyclones. If necessary, we could include a breakdown of the analysis to examine inshore and offshore reef environments to further constrain the mechanisms.

Specific comment 1: we agree that vertical mixing may play a role in elevating chlorophyll a concentrations. This vertical mixing could also be attributed to TC-winds and would still fit within our mechanism framework and we could include a discussion on

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this point. However, work and previous comments from Jon Brodie suggest that vertical mixing would be negligible over the GBR area given the depth of the water column in this region.

Specific comment 2: this is an interesting point regarding the co-linearity of sediment loading and chlorophyll a concentrations and we would be interested in looking into it further. However, we suggest that at the ocean surface (where the MODIS measurements are made), the phytoplankton would not be light limited by the suspended sediments further down in the water column. While the relationship may not be exactly 1:1, we maintain that sediment loading is associated with nutrient loading which can stimulate phytoplankton growth – as the reviewer also discusses.

Specific comment 3: we agree that evaluation of MODIS is necessary in this region, therefore we have begun this undertaking as discussed in the validation section above.

REFEREE 2

General comments: we thank the reviewer for their overarching comments. The validation work we are undertaking should address the concerns with MODIS accuracy over the GBR, as discussed above in validation. We would also like to reiterate that the main aim of this work is to explore systematic, generalizable relationship through aggregated data as is discussed in detail in the aggregation section. This is why we have not undertaken analyzing the TC events separately as has been done before in previous papers.

Specific comments:

We did assess the TC activity as whether the cyclone track crossed within the GBR Marine Park. As the reviewer says, during our time period of study we have not missed a relevant cyclone. This is an important point and for other time periods, additional TC systems may have to be assessed.

To the best of our understanding, the MODIS 8-day product does indeed provide the

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best available pixel from an 8-day window which is set as a fixed 8-day date by the processors of the data.

We agree that using 8-day time blocks hinders the temporal resolution and perhaps some of the confidence in the exact timings of the mechanisms. Analysis at higher temporal resolution would be hampered by the availability of daily MODIS data. However, it is important to note that TCs do not systematically occur early or late in the 8-day time period, they are randomly distributed. We sought to overcome the additional complexity of where the TC occurs in the time period by using a large number of storm systems over a 10-year period, and aggregating them to find a signal. We find significant relationships with wind speed at no time lag and then no significant relationships at any greater time lags (Section 3.2); and for rainfall and translation speeds we find the reverse, significant correlations only at time lags of 8-days and greater (Section 3.3). This systematic response with aggregated data highlights the validity of the hypothesis of the two mechanisms operating over different time scales and the relative importance of the two that can now be investigated further. Furthermore, we have assessed that the systems do often affect the GBR marine park for typically more than one day and therefore their effect stretches further into the 8-day period that they occur in.

We agree with the discussion that wind-driven resuspension is controlled by wind speed, duration of winds, and area of TC winds. We do in fact include analysis of translation speed to account for duration and radius of 64 knot winds to account for size (Section 2.2). In Section 2.4 we hypothesize that if the wind mixing mechanism and the duration the reef is exposed to TC winds were dominant, we would expect to see a negative correlation of chlorophyll a with translation speed. However, our results show no such negative correlation suggesting (Section 3.2, 3.3). We agree that TC size is affecting the wind driving experienced and we do discuss that the positive correlations between cyclone size and chlorophyll a at no time lag would be caused by a greater area of the reef being affected by TC-conditions—in this case wind mixing at

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this time lag (Section 3.2).

Examining the spatial distributions of wind and precipitation fields for each TC would be a very interesting idea. However, we would like to reiterate from the aggregation discussion above that the aim of this study is to determine whether there is a systematic response to TCs and their overall characteristics, regardless of the finer details of the wind and precipitation fields. Using only the time-lag analysis to ascertain whether the chlorophyll a response was due to the wind mixing or runoff and river discharge mechanisms is an efficient and effective method to assess a generalizable relationship between TC activity and water quality over the GBR.

We agree that adding a discussion about the observation of cyclone flood plumes through modelling techniques would be an interesting addition to the paper.

Interactive comment on Biogeosciences Discuss., doi:10.5194/bg-2017-23, 2017.

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MODIS v. In Situ Chl-a Measurement TC Present (GBR 2013-2014)

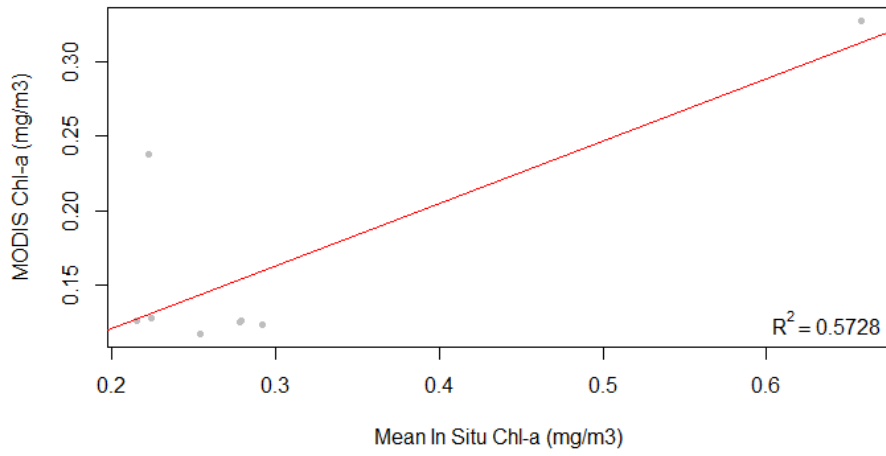


Fig. 1. The relationship between the in situ chlorophyll a concentrations measured from NOAA WOD and the MODIS chlorophyll a concentration product during times of TC presence in the area.

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MODIS v. In Situ Chl-a Measurement TC Absent (GBR 2013-2014)

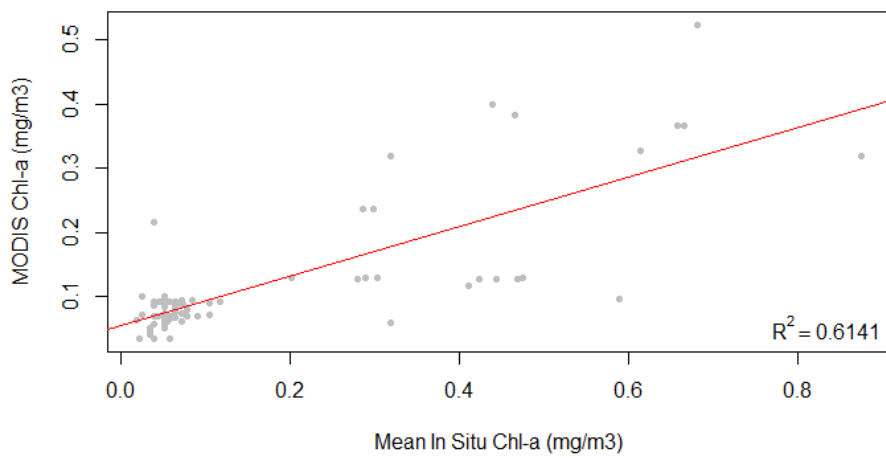


Fig. 2. The relationship between the in situ chlorophyll a concentrations measured from NOAA WOD and the MODIS chlorophyll a concentration product during times of TC absence in the area.

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