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APPLYING MCSST TO CORAL REEF BLEACHING

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ABSTRACT

In the 1980s and early 1990s, coral reef bleaching events of unprecedented frequency and global extent were observed. Elevated water temperature is suspected as the primary causal stress of mass bleaching events from this period. The relationship between sea surface temperatures (SSTs) and coral bleaching events was investigated using National Oceanic and Atmospheric Administration (NOAA) Multi-Channel Sea Surface Temperature (MCSST) satellite imagery from 1982-1992. Nighttime MCSST weekly averages were compared with moored-buoy temperatures for sea-truthing the satellite. Average errors from 11 individual buoy comparisons throughout the tropics were found to be approximately 0.5°C. Confirmed satellite SST data were applied to bleaching events at Bermuda (1988, 1991), Tahiti (1984, 1987, 1991), and Jamaica (1987, 1989, 1990), with a non-bleached site off Belize selected as control. MCSST data showed elevated SSTs coincided with bleaching events both in onset and duration. Bleaching thresholds were developed. An MCSST *Degree Heating Weeks* (DHW) bleaching index was developed for the Belizean and Jamaican reef sites. A cumulative heating stress of 26 DHW is proposed as the threshold for mass reef bleaching at Belize and Jamaica.

INTRODUCTION

The coral reef is a unique and very rich ecosystem which supports a vast array of animal and plant species. The fisheries dependent on coral reefs have supported many cultures for ages. Corals form the structural and ecological foundation of the reef system. Coral reefs flourish mainly in the tropical latitudes, extending at most to 30° north or south of the Equator in only a few cases. Every coral species, as well as numerous other reef inhabitants, maintains a special symbiotic relationship with a microscopic organism (algae) called zooxanthallae. These organisms provide their hosts with oxygen and a portion of the organic compounds they produce through photosynthesis. When stressed, many reef inhabitants have been observed to expel their zooxanthallae *en masse*. The polyps of the coral are left bereft of pigmentation and appear nearly transparent on the animal's white skeleton. This phenomenon is normally referred to as coral bleaching.

More severe bleaching events have dramatic long-term effects on the coral. The ability of the coral to feed itself in the absence of zooxanthallae may be very important to its survivability during and after a bleaching event. Recovery rates, however, appear to differ greatly from species to species, and time to full recovery of symbiotic algae may take as little as 2 months or as much as a year /1/. When the level of environmental stress is high and sustained however, death of the coral may result /2/.

The bleaching events reported prior to the 1980s were generally attributed to localized phenomena such as major storm events, severe tidal exposures, sedimentation, rapid salinity changes, pollution, or thermal shock /3/. The events since 1980 have not been so easily explained. Numerous laboratory studies have shown a direct relationship between bleaching and water temperature stress /4/. Elevated water temperatures are suspected in a number of the major events of the 1980s and 1990s.

OBJECTIVES AND METHODS

This research explores the relationship between elevated sea surface temperatures (SSTs) and coral bleaching events. No reliable *in-situ* SST time series exist for many coral reef locations. Therefore, the primary data source for this study was National Oceanic and Atmospheric Administration (NOAA) Multi-Channel Sea Surface Temperature (MCSST) data collected from 1982 through 1992. Global SST weekly average images of nighttime MCSST data were manipulated on the VAX workstations in the Cooperative Project in Oceanic Remote Sensing (CPORS) laboratory at the United States Naval Academy. Satellite-derived time series were produced at 11 NOAA buoy sites and then compared with the buoy records. Locations of buoys used and coral reefs examined are shown in Table 1.

The second objective of this project was to apply the confirmed satellite record to coral bleaching events at selected reef sites. Once the satellite performance had been validated for the appropriate periods, the MCSST record was used to investigate the relationship between elevated sea surface temperatures and coral bleaching events at Bermuda, Tahiti, and Jamaica. Belize was selected as a control site based upon its latitudinal proximity to Jamaica and zero incidence of reported bleaching from Glover Reef, Belize /3/.

ELEVATED WATER TEMPERATURES AND BLEACHING

High temperature water has been suggested as the causative element in a number of studies focused on locally unexplainable mass bleaching events /2,4,5/. Researchers argue that corals live close to their maximum temperature threshold during the warmest summer months, and a slight increase over that threshold may stress the corals, leading to bleaching. The severe bleaching that recently hit the eastern tropical Pacific and Caribbean have been found to correlate very closely with the *El Niño* and/or other related anomalous SST warming in the region /5/. The unprecedented nature of bleaching events in the 1980s have led some to claim global warming as the culprit /6/. This has yet to be proven.

REMOTE SENSING OF SEA SURFACE TEMPERATURE

Nighttime weekly average MCSST values at 0.2° lat/lon resolution were used to construct SST time series at buoy locations and reef sites. Nighttime data have been determined to be more accurate when compared to *in-situ* measurements /7/. Satellite grid-point time series were constructed for the four reef sites. The resolution limitations of the satellite (approximately 18km) would not allow direct sampling over coral sites. The forced extraction of the satellite temperatures from offshore locations avoided land contamination of the MCSST data. Those years [1982-1983 and 1991-1992] with volcanic contamination (El Chichón and Mt. Pinatubo /8/) were discarded based on excessive offsets in the statistical analysis.

RESULTS

Comparison of MCSST to Moored-Buoy SSTs

Eleven individual NOAA buoy comparisons were conducted. The daily values were averaged to obtain weekly values to compare with the MCSST record. Table 1 shows the statistical results of the comparisons. For this study's observation period, the average bias was less than 0.1°C and standard error of estimate 0.5°C.

Reef Site Coral Bleaching Records and MCSST Analyses

Bermuda

Coral reef bleaching related to remotely sensed SSTs at Bermuda, previously investigated in a "pilot study" /7/. Earlier results demonstrated a significantly lower bias in nighttime MCSST data and led to the exclusive use of nighttime imagery in this study. Figure 1 presents the time series at Bermuda.

Tahiti

The bleaching reports from Tahiti are less complete than from the other sites at Bermuda and Jamaica. Mass bleachings, however, have taken place on the reefs off Moorea Island in 1984, 1987, and 1991 /9/. MCSST indicates those three years were the warmest in terms of peak temperatures. A satellite-derived threshold temperature of 29.8°C was generated from a comparison of bleaching and non-bleaching years at Tahiti.

Figure 2 is the MCSST time series analysis for this site.

Jamaica

The reefs of Jamaica are some of the most thoroughly studied in the world. Mass coral reef bleaching events that affected many of the Jamaican reefs were observed in 1987, 1989, and 1990 /5/. The MCSST retrieval site was chosen off the north coast of the island in some of Jamaica's most pristine waters. Inspection of the MCSST time series in Figure 3 reveals mass bleaching years were significantly warmer than non-bleaching years with a satellite temperature threshold for Jamaica at 29.6°C (30°C has previously been suggested /5/).

Belize

According to Glynn /3/ only two studied reef systems have not reported mass bleaching events: (1) the barrier reef system in Belize, and (2) Gulf of Eliat reefs in the Red Sea. Belize, with its similar latitude, was selected as a control site for Jamaica. The MCSST mean temperature at Belize was 27.7°C; Jamaica's mean was 27.8°C. MCSST record for Belize does not show any appreciably higher peaks in SST for the years studied.

Degree Heating Weeks (DHW) Bleaching Index for Belize and Jamaica

In an effort to represent the relative heating stress a coral reef experiences in the course of one year, a *Degree Heating Weeks* (DHW) index was proposed and developed. The index is based on the mean MCSST value at each reef site. The mean MCSST was subtracted from each weekly MCSST value for the entire record from 1984-1990. Difference were accumulated from the last 30 weeks of each year (corresponding to the warmest time of the year and hence positive difference values) to obtain the index value. DHW is representative of the cumulative heating stress on the coral reef for a given year. Plots of the DHW values for Jamaica, in Figure 5, and Belize, in Figure 6, reveal higher heating stress values in 1987, 1989, and 1990 for both sites. We propose that a heating stress of 26 DHW may indeed be the threshold tolerance of reefs at these two locations.

CONCLUSIONS AND DISCUSSION

This study notes that major coral reef bleaching events since 1979 were unexplainable in terms of previously recognized local bleaching stressors. Elevated water temperatures are implicated in all bleaching cases studied. Results indicate that not only the intensity, but also the duration of elevated water temperature on a reef, can be an excellent predictor of the strength of a bleaching event. A *Degree Heating Weeks* (DHW) index was developed in order to represent accumulations of heating stress near the reef. 26 DHW is proposed as the threshold for accumulated heat tolerance at the Jamaican and Belizean sites.

New reports of mass bleaching underway off Tahiti and in the islands of French Polynesia, as this paper is written (April 1994), indicate the problem has not eased /9/.

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TABLE 1. MCSST
a) extraction points: buoys and reef sites
b) statistical results from comparisons
(Weeks = # weeks available during period)

Buoy/Reef Location:		Weeks	Std Err	Bias (°C)
25.9N	89.7W	279	0.56	-0.04
26N	93.5W	269	0.58	-0.09
23.4N	162.3W	305	0.59	-0.09
2S	110W	196	0.46	-0.09
2N	110W	207	0.69	-0.44
8S	110W	64	0.20	0.02
0S	124W	143	0.44	-0.02
2N	140W	184	0.47	-0.21
0S	169W	110	0.37	0.10
2S	165E	183	0.50	-0.00
2N	165E	113	0.43	-0.01
32.43N	64.78W	Bermuda		
17.37S	149.27W	Tahiti		
18.72N	77.08W	Jamaica		
16.8N	87.7W	Belize		

Figures 1 - 6 are not recoverable from old files.