Coral Bleaching Alert System

Technical Document

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1. Introduction

The coral reefs are massive biological set up in the coastal seas and have taken several millenniums to attain their current form. However, during the last decade, worldwide coral reef ecosystems have been degrading largely, alarming the threat to vital coral ecosystems. Coral bleaching has been one of the significant contributors to the increased deterioration of reef health.

Coral bleaching is a phenomenon that takes place when the symbiotic relationship between algae (*zooxanthellae*) and their host corals breaks down under specific environmental stresses. This results in the host expelling their *zooxanthellae.* In the absence of symbiotic algae, the corals expose their white underlying calcium carbonate coral skeleton and the affected coral colony becomes pale in color. Coral bleaching can be activated and persist during varied environmental stresses. It was observed that massive coral bleaching worldwide due to increased anomalous warm waters during recent years. Coral bleaching can occur even 1-2°C increase in ambient water temperature during summer months (Berkelmans and Willis, 1999; Reaser et al., 2000). Prolonged partial/total bleaching events on coral environs can cause coral deaths. Stern bleaching events have striking long-term ecological and social impacts, including the extinction of reef-building corals, changes in benthic habitat, and, in some cases, even changes in fish populations. It can take several years for severely bleached reefs to recover, even if favorable conditions prevail after the event.

There is a strong need for improved understanding, monitoring, and predicting coral bleaching. The application of satellite remote sensing is an essential tool to provide synoptic views of the global oceans in near-real-time and the ability to monitor global reef areas. Therefore, to provide early warnings on coral bleaching, the nocturnal Sea Surface Temperature (SST) is an important parameter to assess the thermal conditions and intensity of the bleaching. There are several remote sensing satellites revolving around the globe that can provide SST information during the day and night routinely. This facilitates the development of the coral reef bleaching warning system to generate early warning advisories/bulletins in near real-time. Earlier studies (Strong et al. 2004; Liu et al. 2005; Goreau and Hayes 1994 and Montgomery and Strong 1995) reflected the impact of thermal stress on coral reefs, their monitoring and assessment over the global synoptic view.

2. Objective

The objective of the current study is to provide coral bleaching warning based on thermal stress. The parameters SST climatology, bleaching HotSpot (HS) and Degree of Heating Weeks (DHWs) were used for the study. These parameters were generated using SST data with 5X5 km grid resolution retrieved from an Advanced Very High-Resolution Radiometer (AVHRR) sensor on board National Oceanic and Atmospheric Administration (NOAA) satellites.

3. Study Area

The bleaching alerts/warnings were generated for the Indian coral environs (Figure 1). The individual geographic areas were selected based on the coral environs. These designated areas are coral environs from Andaman, Nicobar, Lakshadweep, Gulf of Kachchh (GOK), Gulf of Mannar (GOM) and Malvan.

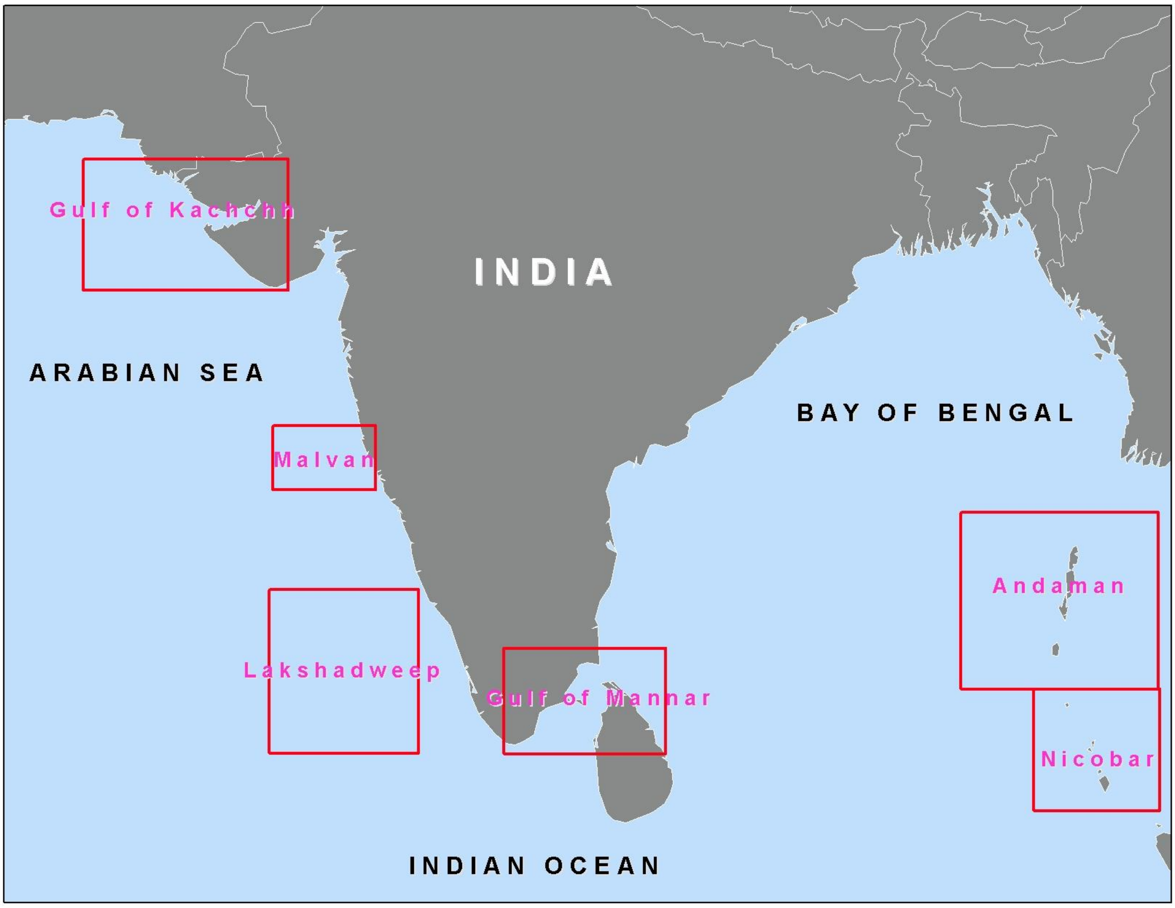

Fig. 1 Map showing the areas of the coral environs of India

4. Data Used

Sea Surface Temperature (SST) data from NOAA, AVHRR or data from the GHRSST was used in the current study.

5. Methods

The thermal stress calculation is similar to NOAA coral reef watch (URL: coralreefwatch.nooa.gov). According to Coral Reef Watch (CRW), the coral reef bleaching warning levels scheme is presented in the flowchart (Fig. 2).

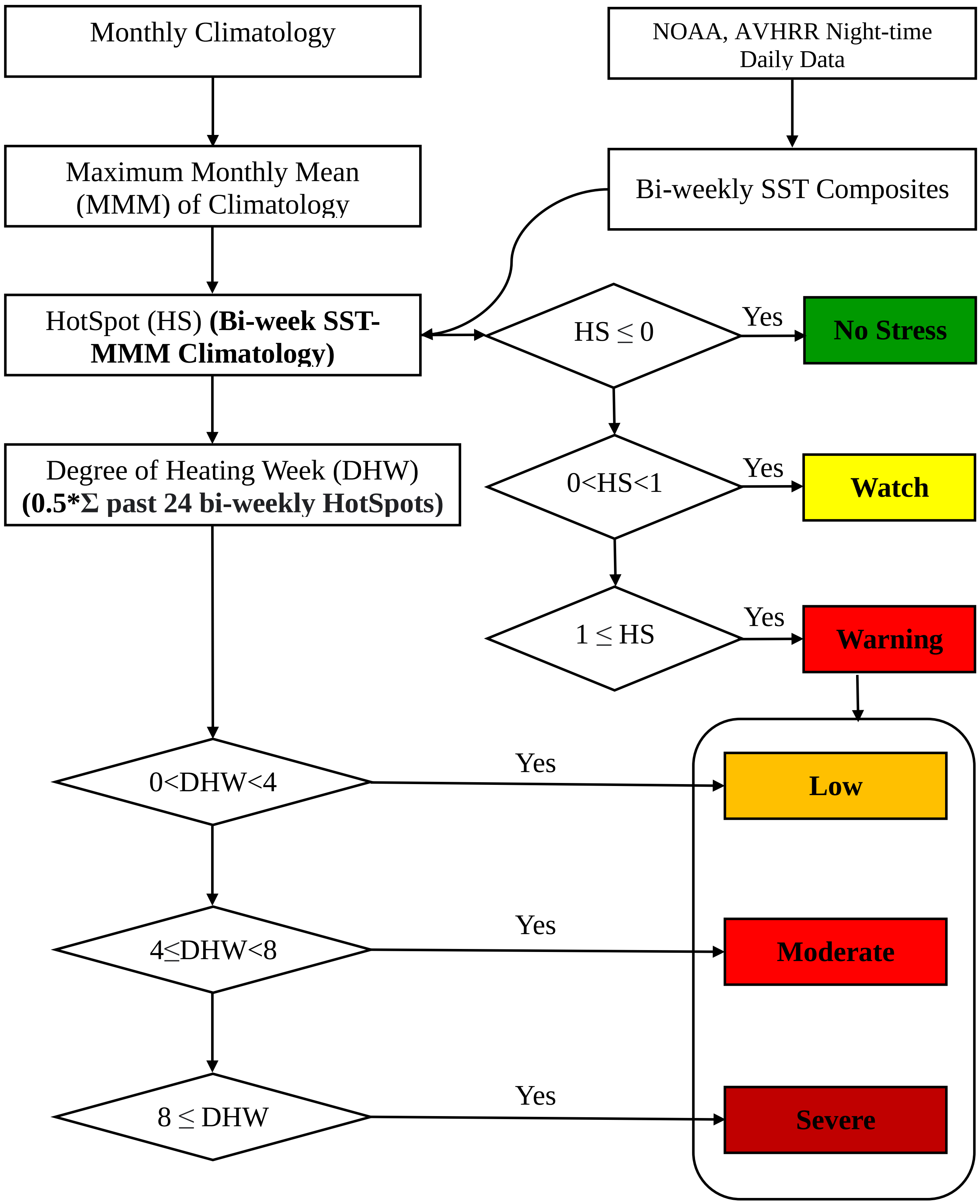

Fig. 2 Flow Chart depicting the methodology and the decision criteria for the coral bleaching status

5.1 Estimation of Monthly Maximum Mean of SST Climatology

The estimation of MMM of SST climatology using nighttime SST data retrieved using NOAA, AVHRR. The nighttime images are used to eliminate the effect of solar glare and reduce the variation in SST caused by the heating during the daytime. The daily nighttime SST data were used to generate monthly mean composites. Monthly SST climatology was calculated, and the Maximum Monthly Mean is defined as the warmest monthly mean value for each pixel around the area.

5.2 Coral Bleaching HotSpot (HS) Analysis

Corals are vulnerable to bleaching when the SST exceeds the temperatures they usually experience in the hottest month. This reveals in the coral bleaching HS product, which highlights regions where the SST is currently warmer than the highest MMM of SST. The HS value lesser than or equal to zero were categorized as a "No Stress" condition, the HS value within the range of 0 to 1°C is categorized as "watch," and values above 1.0°C were a threshold for thermal stress leading to coral bleaching updated twice-weekly (Fig. 2).

Coral bleaching HS is a measure of the occurrence of thermal stress approaching conducive to coral bleaching for a location. The HS anomaly is based on the climatological mean SST of the hottest month (Liu et al., 2003; Liu et al., 2005; Skirving, 2006). The calculation of MMM SST climatology is simply the highest of the monthly mean SST climatology, showing that temperatures exceeding 1°C above the usual summertime maximum are sufficient to cause stress on corals. Based on this study, MMM SST climatology was derived as a threshold for monitoring coral bleaching. The value of HS gives the difference between the measured near-real time SST and the MMM SST climatology as given in equation1.

$$\text{HotSpot } (°\text{C}) = \text{SST} - (\text{MMM SST Climatology}) \qquad \ldots\ldots (1)$$

Only positive values are derived as the HS is designed to depict the incidence and distribution of thermal stress conducive to coral bleaching.

5.3 Calculation of Degree of Heating Weeks (DHWs)

It was observed to cause coral bleaching if the thermal stress persists for a prolonged duration. The DHWs product that sums up HotSpots greater than 1° C recorded over the past 12 weeks shows that stressful conditions prevailed in corals environs for the previous three months. It is a cumulative measurement of the intensity and duration of thermal stress expressed in the unit °C-weeks. The areas recorded DHWs up to 4°C-weeks depict "Low" status, which will cause stress on corals. DHWs 4-8°C-weeks depicts the "Moderate," and these have been shown to cause significant coral bleaching. The DHWs above 8°C-weeks depict the "Severe," and this can cause widespread bleaching (Fig. 2). While the Coral Bleaching HotSpot provides an instantaneous measure of the thermal stress conducive to coral bleaching, there is evidence that corals are sensitive to an accumulation of thermal stress over time. To monitor this cumulative effect, a thermal stress index termed Coral Bleaching DHWs was developed by Liu et al., 2003; Liu et al., 2005. Glynn and D'Croz (1990) reported that temperatures exceeding 1°C above the usual summertime maximum are sufficient to cause stress on corals. This is commonly known as the temperature threshold for coral bleaching.

A half-week approach is used because near-real-time coral bleaching monitoring products are updated twice weekly. With this approach, the DHWs are accumulated based on twice-weekly HotSpots using equation 2.

$$\text{DHWs (°C-week)} = 0.5 * \sum \text{preceding 24 bi-weekly HotSpots} \qquad \text{...... (2)}$$

HS values more than or equal to 1.0°C-week required to be accumulated for calculating the DHWs.

5.4 Assessment of Thermal Stress Levels

The coral bleaching warning status was estimated based on the thermal stress levels using the threshold HotSpot and DHWs values (Fig. 2). The HotSpot status categories “No Stress,” “Watch,” and “Warning” were estimated using HotSpot values less than 0°C, 0-1°C and greater than 1°C respectively. The DHWs categories Low, Moderate, and Severe were estimated based on DHWs values. The DHW will be assessed as “Low” when the conditions of HotSpot => 1°C and 0<DHWs<4°C-week are satisfied. The “Moderate” was assessed when the conditions of HotSpot => 1°C and 4<=DHWs<8°C-week were satisfied. Whereas “Severe” was considered when conditions of HotSpot => 1°C and DHWs >=8°C-week were satisfied. A DHWs accumulation of more than 4°C-weeks is triggered significant bleaching, which is Moderate, and bleaching is expected at the site within a few weeks. An accumulation of 8°C-weeks triggers strong bleaching with a warning status. Severe causes widespread bleaching with likely coral mortality.

5.5 Warning status

The warning status has been assessed based on the criteria mentioned in the following table 1

Table 1. Criteria of the coral bleaching warning/alert symbology color used

HotSpot (º C)	Degree of Heating Weeks (º C-week)
HS<=0	--
0<HS<1	--
1<=HS	0<=DHWs<4
	4<=DHWs<8
	8<=DHWs

No stress: No thermal stress on the corals.
Watch: Low thermal stress on the corals.
Low: Corals are under stressful conditions.
Moderate: Strong thermal stress on the corals may result in significant bleaching.
Severe: Severe thermal stress on corals, which may result in widespread bleaching with likely coral mortality.

5.6 Time series graphs

The time series graphs of the HS and Climatology from a virtual station from each coral environment as given in the Figure1

6. Deliverables

- ✓ Warning status
- ✓ HS composites
- ✓ DHWs composites
- ✓ Time series graphs

References

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Version Control

The DHW categories changed as mentioned in the following table with effect from 31st December 2022. However, the symbology remains the same

Earlier Categories names	**Renamed categories**	**DHW**
Warning	Low	$0<DHW<4$
Alert Level1	Moderate	$4 \leq DHW<8$
Alert Level2	Severe	$8 \leq DHW$