Coral Bleaching: A Grim future of corals of Andaman Islands

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By

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Certificate

This is to certify that the dissertation titled "**Coral bleaching: A Grim future of corals of Andaman Islands**" submitted by **Qumar Alam**, Roll No. **18EX40014**, to the Department of Geology and Geophysics, Indian Institute of Technology Kharagpur, in partial fulfillment of a requirements for the award of the Degree of **Master of Science, in Geophysics** is a bonafide record of the work carried out by him during the Academic Session 2019-2020 under my supervision & guidance. This work is not submitted elsewhere for any degree.

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DECLARATION

I certify that

(a) The work contained in this thesis is original and has been done by me under the guidance of my supervisor;

(b) The work has not been submitted to any other Institute for any degree or diploma;

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“**Analyses and visualizations used in this [study/paper/presentation] were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC."**

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Abstract The vulnerability of Coral reefs with increase of sea surface temperature (SST) is well known and experimented field of study. The rise of SST has already reached an alarming rate and it continues to follow the trajectory causing corals to bleach around the world, Andaman's coral reefs with an area of 948.8 sq. km, harboring more than 580 species of fringing reefs are no exception and another victim of Global warming. Tropical Andaman sea's high SST coupled with ENSO (El Nino Southern Oscillation), which elevates SST even more are considered lethal for the coral reef ecosystem as evident via the data of 2010 on widespread bleaching that caused around 70% loss of corals in South Button Island of Andaman, is one of several events recorded. Abrupt rise in SST is recorded every year which causes thermal stress to accumulate in corals and if the high SST persists for more than four weeks, it has potential to do severe damage to the ecosystem. This study has utilized the Remotely sensed SST data from 2003 to 2019, retrieved from NASA Giovanni online data system, computed for different parameters such as MMM (maximum monthly mean), MMC (monthly mean climatology), SST positive anomaly, Bleaching Threshold (BT), Degree heating week (DHW) and Hotspot. These parameters enabled analysis of thermally affected regions of Andaman islands and based on specific criterion few warm months were further analyzed. In addition, Hotspot regions then mapped for further investigation on the response of the different species of corals under high SST. Thus this study provides a localized study of the Scleractinian coral reefs of Andaman islands with the help of very high 4 km spatial resolution data so that it helps achieve regional management efficiency on conservation program in response to continuously increasing coral bleaching.

Keywords: Coral bleaching, Sea surface temperature (SST), ENSO, Bleaching threshold (BT), Degree heating weeks, Monthly mean climatology (MMC), Maximum monthly mean (MMC), Hotspot.

Introduction

Corals are one of the most diverse but at the same time most vulnerable ecosystem. They occupy of an area of 2,284,300 km^2 which is only 0.009% area of the world's oceans. They are mainly concentrated within 25∘N and 25∘S latitudes in shallow subtropical to tropical water with the bathymetry varying from 10-30 meters for the most diverse species (Majumdar et al. 2018). Coral reefs play an essential role and have manifold importance in several aspect of marine as well as human's life. It provides commercial supports such as coastal fisheries, jobs and businesses through tourism and has a great recreational value; in addition to that it provides essential ingredients for medicines and protects coasts from erosion. It gives shelter to about one third of all fish species and thousands of other aquatic dwellers (Crabbe, 2008). Corals are invertebrate animals consisting of different variety which belong to phylum Cnidaria of the class Anthozoa which comprises soft corals, hard corals, precious corals and hydrocorals. When free swimming planulae i.e. larva of corals attach to the submerged edges of islands or continents, they get settled, grow and expand, make the colony of reefs (Majumdar et al. 2018). There are three types of reefs, fringing reef, barrier reef and Atolls but mostly fringing reefs are found in Andaman Islands.

This fragile ecosystem is threatened by variety of environmental stresses causing changes in salinity, turbidity, pH, temperature etc. but elevated sea surface temperature (SST) is considered to be the primary and consistent cause for coral bleaching around the world (Li , Reidenbach , 2014). When the temperature of sea becomes unusually high, it causes stress in corals. Coral polyps get agitated and start expelling the symbiotic algae (zooxanthellae) which lives in their tissues and thus it's their pigmentation that gets disrupted over time and eventually it exposes the coral's white skeleton underneath. If the temperature does not persist for long time it may recover from mild bleaching gradually but if the bleaching is prolonged, whole colony may die of severe bleaching. Sea surface warming and extensive coral mortality as the zooxanthellae (micro algae) expulsion occurs due to significant thermal accumulation are closely correlated with the timing and geographic pattern of sea surface warming (Glynn and D'Croz 1990).

The reports prepared by Hoegh-Guldberg (1999), suggested that the change in climate has affected scleractinian corals of the world. In Andaman coral bleaching was recorded in 1997 and again in 1998 (Mondal et al. 2014). The major episode of widespread bleaching were recorded in 1997, 1998 (first recorded in eastern pacific; Galapagos) and 2002 in Belizean barrier reef, great barrier reef and other major reefs of the world including coral reefs of Andaman. The pattern of bleaching in 1997-98 is similar in many aspects with episodes of bleaching in 1982-83, 1987-88 and 1994-95 (Hoegh-Guldberg 1999). It was observed that Strong bleaching episodes were always recorded with high SST associated with El Niño periods (Hoegh-Guldberg 1999).

The chain of Andaman Islands having coastline stretch of 1962 km bounded by Andaman Sea, harbors 588 species of scleractinian fringing reefs of channel and patchy types by coral shelves 10-50 km wide, represented by species such as Heliopora coerulea, Millepora platyphylla,Tubipora musica, Among them porites And favia species are the main reef building corals (Majumdar et al. 2018). Andaman islands comprises about 80% of all the Global coral diversity, prevalent in North, Middle , South and little Andaman (Venkataraman, 2011). The symbiotic relationship of corals with zooxanthellae enhances biological activity and thus helps each other , coral provides safe environment, CO_2, nitrogen and phosphorous to algae and in return , the algae provides Oxygen and other organic material through photosynthesis (Mondal et al. 2014). When temperature increases, zooxanthellae converts excess energy of sunlight into chemicals called “reactive oxygen species” which causes breakdown in algae-coral relation, termed as Bleaching.

The spatial extent of corals of Andaman was mapped very recently in 2017 by using SENTINAL-2A series of satellite imageries. Coral distribution map was prepared using satellite, in-situ sampling data and from some previously published maps (Nair et al., 2017; Gibson et al., 2007; Spalding et al., 2001; Green et al., 2000). The declining population density of corals around the global has become a major concern and needs to be study extensively.

Literature Review

Mondal et al. (2014) have used the SST data obtained by survey conducted at fifty five sites of Andaman Islands during April 2010 to November, 2011. It provided a good estimate on scale of bleaching. Maximum Sea surface temperature of the surveyed regions varied from 28-31.7 °C during May to August, 2010. The extensive studies of more than 400 species of scleractinian corals were conducted. The maximum bleaching (90.43%) was observed at Mayabunder whereas minimum bleaching was observed at Rani Jhansi Marine National Park. Then maximum recovery was recorded at Rutland Island (85.1%) whereas minimum recovery was recorded at Mayabunder (77.4%).

Arora et al. (2019) provides a thorough study on corals of Andaman and Nicober Islands, Gulf of Mannar, Gulf of Kachchh and Lakshdweep of India. Analysis of SST data of duration 1982 to 2018 was carried out and the result supported the mass bleaching events of 1998, 2010 and 2016 over five major Indian corals reefs regions, highlighting the Andaman and Nicober to be the most vulnerable in 2010.

Glynn and D'Croz (1990) provides experimental evidence on how corals respond under elevated SST. The loss of zooxanthellae and coral tissue protien with increase of temperature was observed in Gulf of Panama and Gulf of Chiriqui. The analysis revealed the mortality of whole colonies at 32°C after only four weeks of high temperature. The study concluded with “Slightly elevated SST (30-32°C) over a few weeks (2-4weeks) led to decline in coral health and eventually death in laboratory experiments”.

Hoegh-Guldberg (1999) have focused on the rate of increase of temperature over centuries, which is ~ 1-2°C per century. Analysis on increase in sea surface temperature at this rate led to a wild prediction by the author that in future we are likely to have a sever effects on the world’s coral reefs within 20-30 years. He even pointed out based on the Present evidence, suggests that corals and their zooxanthellae are unable to acclimatize or adapt fast enough to keep pace with the present rapid rate of warming of tropical oceans.

Heron et al. (2016) have analyzed the temperature trends which indicate accelerated warming in recent decades. They analyzed SST trend and thermal stress accumulation during 1985-2012 and found 97% of reef pixels warmed through these periods. They also concluded that the corals bleaching have become and will continue to become more frequent and severe with the passage of time.

Majumdar et al. (2018) provides a thorough study on threats to Coral diversity of Andaman Islands. It sheds light on the severe suffering of corals of Andaman due to Earthquakes, land subsidence and Tsunami such as the mega earthquake hit in the year of 2004. It concludes with the warning that globally, the major threats to coral reefs come from the rising sea surface temperature often triggered by El Niño phenomenon. In Andaman, maximum bleaching was observed at 5-15 meters depth and beyond that low level of bleaching was observed.

In contrast to all the study conducted as mentioned above, this particular work is focused on analysis of SST during 2003-2019, which provides an update to the previously done study. In addition, it sheds light on regional affected regions of high thermal stress accumulation plotted as Hotspot map for corals of Andaman. Pixels representing high accumulation of stress are a clear indication of probable bleaching zone of Andaman.

Research Objective

The objective of this study is to provide full assessment on the SST trends and hotspots regions of Andaman using high spatial resolution sea surface temperature data (4Km) during 2003-2019. The region of very high thermal stress accumulation (>4 DHW) is the focus of a thorough study and eventually mapping the affected regions of Andaman Islands.

Study Area

The Andaman Islands are low chain of mountains (archipelago), a part of Union Territory of India. These Islands are located in to the north-west of the central part of Coral Triangle with a total area of 948.8 Km^2. It is surrounded by tropical Andaman Sea, which harbors more than 580 species (out of which 235 are hard corals and 111 soft corals species of corals along the coast of Islands (Majumdar et al. 2018).

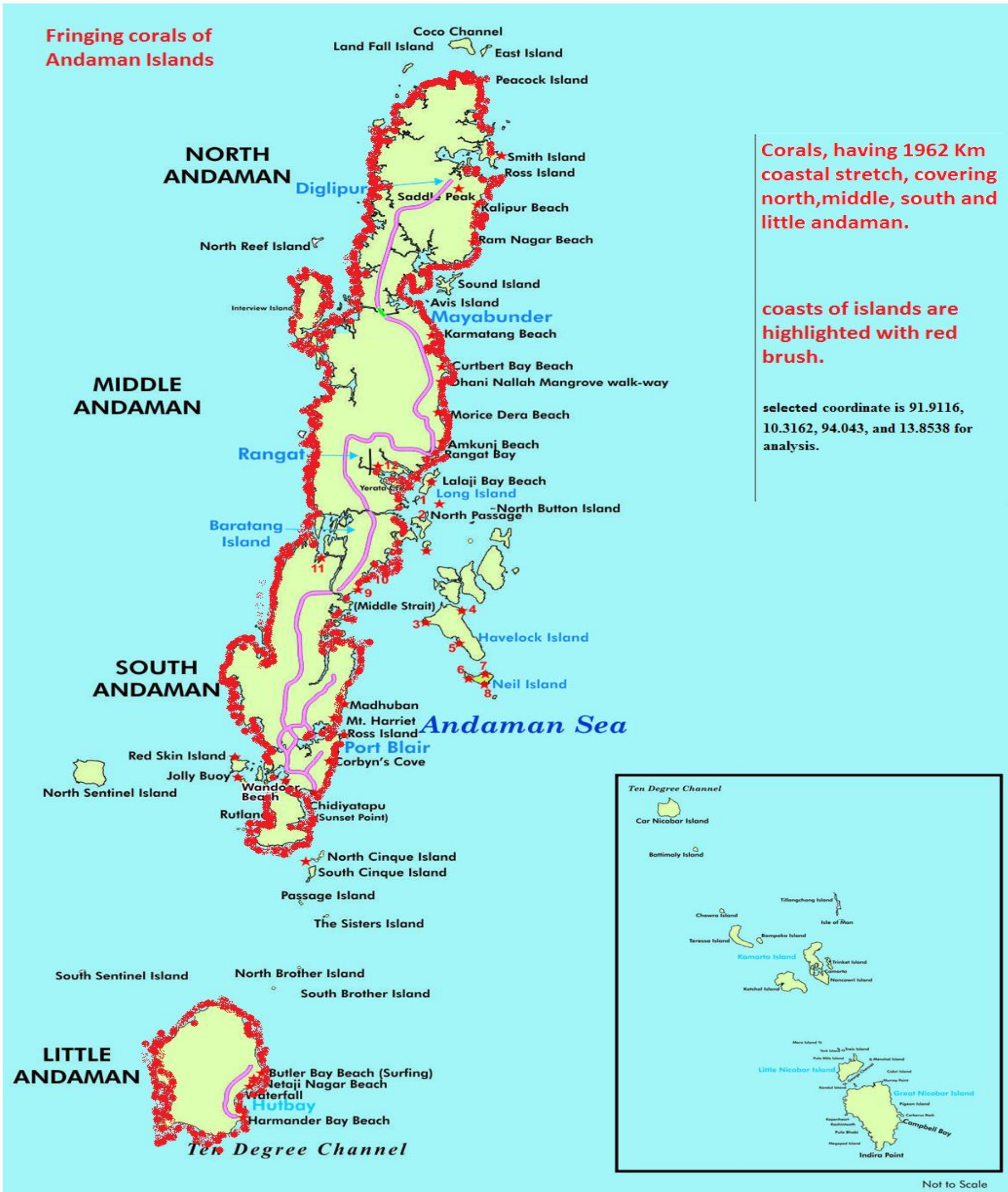

Figure 1. Coastal stretch of Andaman Islands, highlighted red line showing where fringing corals might be found.

The selected study area's coordinate is 91.9116 east, 10.3162 south, 94.043 west, and 13.8538 north. In Andaman, reefs flat extent is 500 m from the shore. Submerged reefs also meet the merged reefs in many places such as Termugli Island, Eastern part of middle Andaman, North reef Islands etc as depicted in figure 1. Deeper reef flat has been recorded in places like Boat Island, Jolly Buoy Island and North Sentinel Island whereas muddy and sandy reef flats are found in Mainland. In the west coast of Andaman, diverse species sites are found such as South Button with 89 species, Twin Island with 82 species and Flat Island with 81 species (Majumdar et al. 2018).

Several Glaciation and deglaciation in the past have resulted in alternative regression and transgression of sea water. The sea water level was 120 m lower than today about 18000 years ago. Around 14000 years ago again major sea level rise occurred due to melting of polar ice. These changes has been proved to be lethal for entire reefs colony as evident from the past such as The Northern Sunda Shelf experienced the extermination of extensive fringing coral reefs now evident as fossils along relicts of Malaysian coastline(Tija 1980). Coral biogeography of the region is closely linked to the geological and tectonic history of the regions. Surprisingly, few of the earliest records of scleractinian corals come from the Andaman Islands (Wilson and Rossen 1998) dated back to upper Triassic (~180 Mya) recorded in the Indonesia/Thailand boarder and the Indonesian Archipelago.

Geological history of the Andaman Islands as illustrated in figure 2, can be understood with the help of plate tectonics which involves Myanmar, The Andaman and Nicober, Sumatra and Malay Peninsula. The present appearance of these areas is the result of collision between Indian and Eurasian Plate in which oceanic plate subducts beneath continental Eurasian plates. Large earthquake have been recorded many times such as 1847, 1881, 1941 and most recently the devastating mega quake in 2004 nearby Sumatra. These earthquakes cause Tsunami, subsidence and upliftment of lands which severely affects coral reefs (Brown 2007).

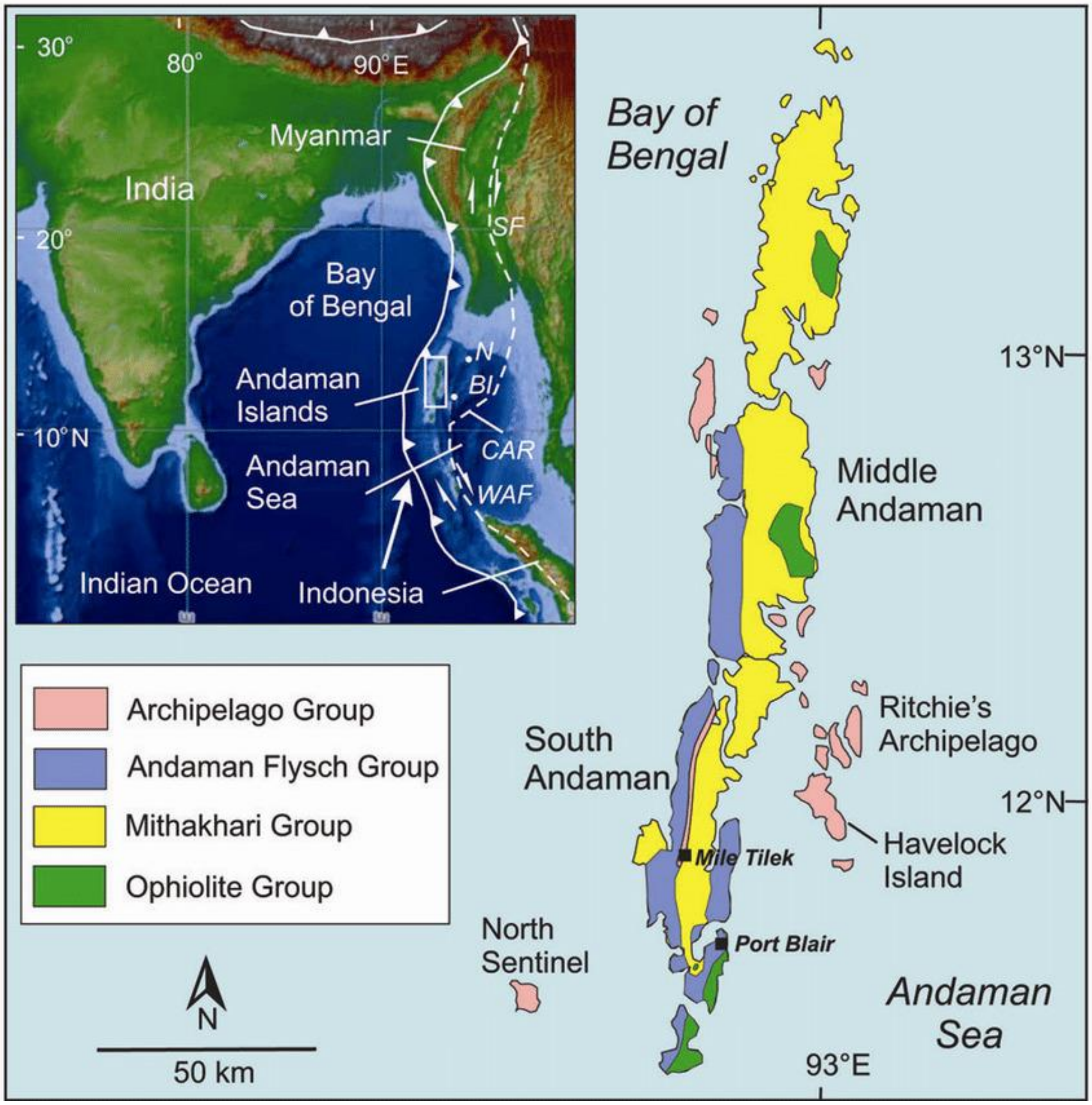

Figure 2. Geological map of the Andaman Island showing distribution of various lithological rock units and plate movements.(source: https://www.researchgate.net/figure/Geological-map-of-the-Andaman-Islands-after-Pal-et-al-9-showing-distribution-of_fig1_269954469).

Materials and Methodology

This study has utilized the sea surface temperature (SST) data provided by NASA designed MODIS (or Moderate Resolution Imaging Spectroradiometer). These datasets can be accessed at https://giovanni.gsfc.nasa.gov/ and the variable opted for the present study is Aqua MODIS Global Mapped 4μm Nighttime Sea Surface Temperature (SST4)

Data. This is a time averaged SST data of 8-day temporal resolution with a very high 4 Km spatial resolution, ranging from 2003 to2019.

Three months viz. March, April and May have been found to be warmer than the rest of the months after analyzing temperature from 2002 to 2019. However, the Andaman Island is situated in tropical region and hence the insolation is greater in those months and is more likely to have positive SST anomaly and therefore these three months have been thoroughly analyzed in this paper. Moreover, 8-day resolution data is considered as 1-week data for the sake of convenience

SST anomaly

Conventionally, anomaly is measured by taking the difference between the SST of a twice-weekly period and the long-term average for the same time period (climatology) as the NOAA CRW program follows. But in this study, mean temperature was first calculated for all three months and designated as MMC (monthly mean climatology) then the MMM (maximum monthly mean) is taken as the maximum mean of a month out of all three, in order to observe the sharp changes in day to day temperature.

Bleaching threshold (BT)

This study has followed the convention followed by NOAA, which is based on previous study in which Scientist have found that corals start to feel agitated and stressed when SST becomes 1°C warmer than the highest monthly mean temperature (Glynn and D'Croz 1990) and these thermal stress is the main cause of corals bleaching. This study has taken bleaching threshold for three months, calculated as BT = MMC + 1°C.

Degree Heat Week (DHW)

Heat stress will build up only if the temperature around the corals stays above the bleaching threshold over a longer period of time. Studies have shown that Coral bleaching events occur when surface waters become so warm and remain high for more than 28 days (Vivekanandan e.t al.2008) then there is a breakdown of the symbiosis between corals and the micro algae, zoxanthellae. The DHW shows how much heat stress has accumulated in an area over the past 12 weeks (3 months). In other words, we add up the Coral Bleaching HotSpot values whenever the temperature becomes equal or exceeds the bleaching threshold. In this study, DHW is calculated for every month separately (see Table 1) and then it is summed up for 12 weeks as shown in Table 2 below.
DHW (°C) = Σ 12 week hotspot (°C).

HotSpot

If the temperature of surface water exceeds the maximum monthly mean (MMM), those regions are called hotspot and corals in those areas experience heat stress that leads to bleaching. The Hotspot concept was developed based on earlier work by Goreau & Hayes (1994) and Montgomery & Strong (1995).

The calculation of MMM SST climatology is simply the highest of the monthly mean SST climatology showed that temperatures exceeding 1°C above the usual summertime maximum are sufficient to cause stress on the corals. HotSpot (°C) = SST – MMM (°C).

Thermal Stress Levels

The coral bleaching warning status was estimated based on the thermal stress levels using the threshold Hotspot and DHW values as done in NOAA coral reef watch (CRW) program. The warning status categories "No Stress" and "Watch" were estimated using the Hotspot values zero or less and more than zero respectively. In addition, DHW accumulation is used which is a measure of heat accumulation over a given area. The categories Warning, Alert Level1 and Alert Level2 were estimated based on both HotSpot and DHW. The warning status will be assessed as "Warning" when the conditions of HotSpot=> 1°C and 0<DHW<4°C-week were satisfied. The "Alert Level-1" was assessed when the conditions of HotSpot => 1°C and 4<=DHW<8°C-week were satisfied. Whereas "Alert Level-2" was assessed when conditions of HotSpot => 1°C and DHW >=8°C-week was satisfied. A DHW accumulation of 4°C or greater is taken as for further mapping of the regions, this area triggers a significant bleaching which is "Alert Level 1" and bleaching is expected at the site within a few weeks. An accumulation of 8°C triggers a strong bleaching with warning status "Alert Level 2" which causes widespread bleaching with likely mortality. (table 3).

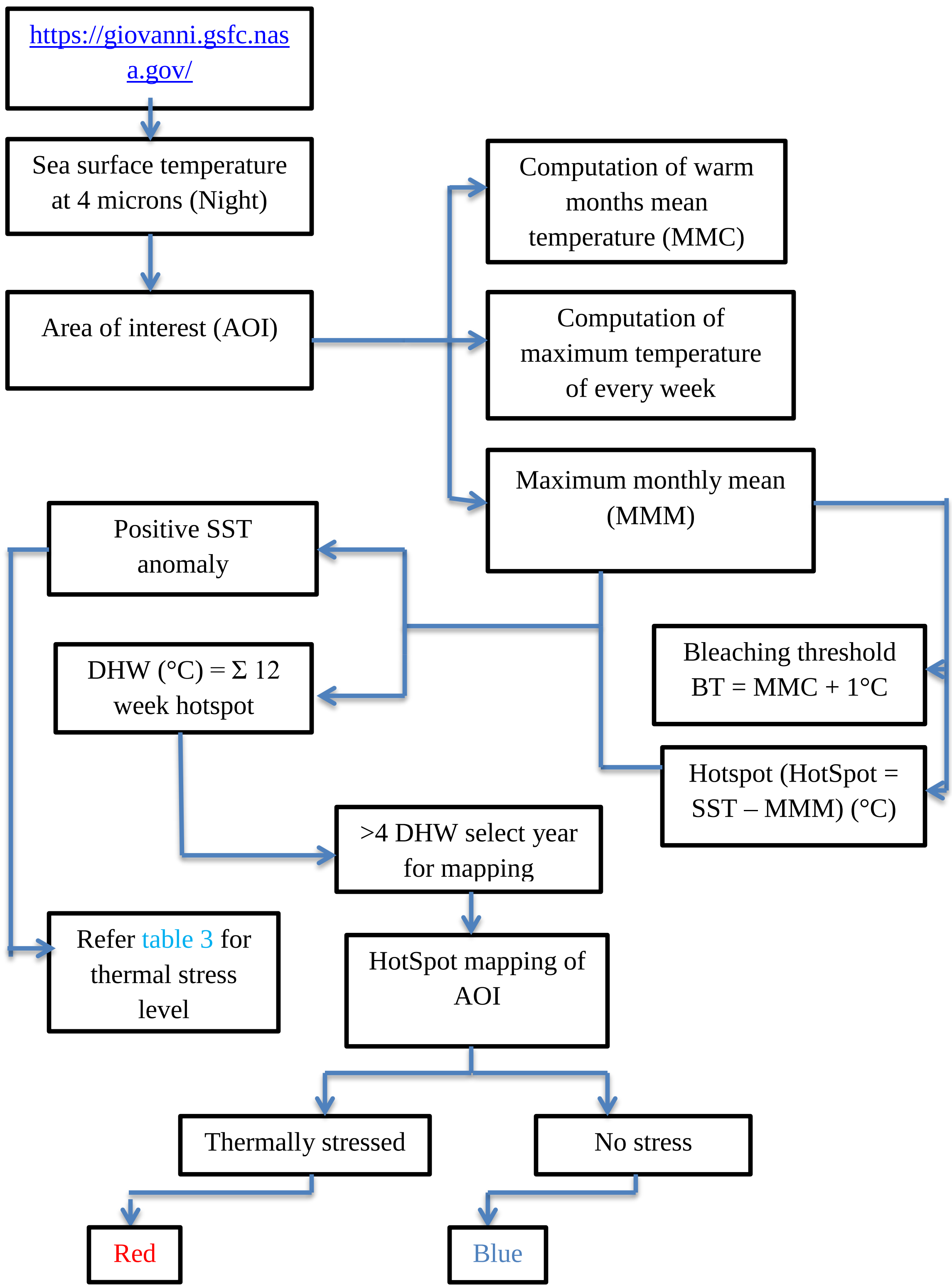

Figure 3. Flow chart for computing different parameters for coral reefs of Andaman Islands

Results and Discussion

The result shows the SST variation during the periods from 2003 to 2019 and it provides information on thermal stress experienced by the coral reefs of Andaman Islands. It was found that the 2006, 2009, 2012, 2013, 2017 and 2019 have experienced thermal stress >4 DHW and hence these months were opted for further analysis. Since the warmest month is not same for every year and therefore this study has considered warm months namely March, April and May.

In order to check the persistence of warm temperature, each week of the warm months is plotted. A prolonged 6 weeks were observed to be consistent in high temperature by either touching the bleaching threshold line or exceeding it. The same results were observed in almost all of the opted years as mentioned above. In contrast to last decade from 2003 to 2010, this decade from 2011 to 2019 have shown a significant increase and consistency in sea surface temperature rise.

Surprisingly the result for six weeks, starting from week1 of April to week2 of May (fig. 4 to fig.9) is highly incremental for all six years and they persisted as well, providing no respite to coral. The trend in SST during these six weeks of warm months have loosely followed a Gaussian curve, being April to be the warmest in most of the years but week1of May month has shown highest temperature too. These periods might have caused corals to bleach, disregarding the fact of few species being able to adapt and acclimatize since the study generically suggests that corals under high thermal stress for only 28 days are enough to trigger bleaching.

Recent year, 2019 has shown a drastic change in sea surface temperature and the highest accumulation of thermal stress, having DHW > 6.5 (table 2). As per NOAA definition, it falls in the 'bleaching alert level 1' stress level and hence likelihood of significant and severe bleaching. As depicted from fig. 4 to fig.9, the two noteworthy observations are plausible; the bleaching threshold line goes up with the increasing year which suggests the warming of sea surface temperature over time and shifting of temperature increase from left (March) to right (May), shows that March is relatively constant whereas May month is getting warmer every year.

Table 1 Monthly mean climatology (MMC), maximum monthly mean (MMM), Bleaching threshold (BT) and Degree heating week (DHW) for coral reefs of Andaman Islands.

Year	Months	max temperature of the week(°C)				MMC (°C)	MMM (°C)	BT (°C)	DHW
		1st week	2nd week	3rd week	4th week				
2003	MARCH	28.600	28.945	29.550	29.425	28.292	30.436	31.436	0.000
	APRIL	29.840	30.805	31.115	31.115	29.761			0.000
	MAY	32.365	30.360	29.010	29.495	30.436			1.929
2004	MARCH	28.400	28.825	29.360	29.880	28.552	30.307	31.307	0.000
	APRIL	31.000	30.905	31.605	31.315	30.307			2.306
	MAY	30.815	31.105	29.525	29.555	28.852			0.000
2005	MARCH	29.512	29.325	29.865	29.995	29.087	30.557	31.557	0.000
	APRIL	30.280	30.920	31.185	31.755	30.557			1.198
	MAY	31.555	30.925	30.630	30.830	29.192			1.000
2006	MARCH	29.440	29.960	30.575	29.535	28.987	29.360	30.360	1.215
	APRIL	30.105	30.070	30.615	30.330	29.360			1.255
	MAY	30.690	30.430	29.890	29.210	29.302			2.400
2007	MARCH	28.555	28.755	28.995	29.255	28.445	29.852	30.852	0.000
	APRIL	30.445	31.220	30.810	31.170	29.852			2.686
	MAY	30.095	29.760	29.325	30.060	28.922			0.000
2008	MARCH	28.645	29.380	30.095	29.815	28.407	29.230	30.230	0.000
	APRIL	29.855	30.130	30.595	29.940	29.230			1.365
	MAY	29.245	28.780	29.140	28.820	28.472			0.000

2009	MARCH	*29.110*	*30.000*	*29.535*	*30.205*	*29.182*	29.645	30.645	*0.000*
	APRIL	*30.375*	*30.355*	*29.835*	*30.820*	*29.477*			*1.175*
	MAY	*32.015*	*30.675*	*30.525*	*29.920*	*29.645*			*3.400*
2010	MARCH	*29.175*	*29.680*	*29.910*	*30.830*	*29.113*	31.363	32.363	*0.000*
	APRIL	*30.960*	*31.535*	*31.785*	*32.195*	*30.629*			*1.000*
	MAY	*32.060*	*32.435*	*31.195*	*30.230*	*31.363*			*2.072*
2011	MARCH	*29.055*	*29.125*	*29.100*	*29.155*	*27.992*	29.161	30.161	*0.000*
	APRIL	*29.095*	*29.925*	*30.405*	*30.590*	*28.999*			*2.673*
	MAY	*29.955*	*29.355*	*30.475*	*29.780*	*29.161*			*1.314*
2012	MARCH	*29.125*	*28.955*	*29.580*	*29.620*	*28.390*	29.622	30.622	*0.000*
	APRIL	*29.860*	*30.425*	*30.730*	*31.140*	*29.622*			*2.626*
	MAY	*31.255*	*30.645*	*30.190*	*29.415*	*29.503*			*2.656*
2013	MARCH	*29.465*	*30.075*	*29.815*	*30.370*	*29.083*	30.064	31.064	*0.000*
	APRIL	*30.490*	*30.420*	*31.360*	*31.055*	*29.647*			*2.296*
	MAY	*31.860*	*31.180*	*30.625*	*29.415*	*30.064*			*2.912*
2014	MARCH	*28.705*	*28.785*	*29.040*	*29.605*	*28.167*	30.410	31.410	*0.000*
	APRIL	*30.025*	*30.740*	*30.610*	*31.270*	*29.602*			*1.000*
	MAY	*31.600*	*31.885*	*30.110*	*30.555*	*30.410*			*2.665*
2015	MARCH	*28.705*	*29.115*	*29.810*	*29.195*	*28.488*	30.352	31.352	*0.000*
	APRIL	*30.460*	*30.700*	*30.855*	*31.405*	*29.683*			*1.098*
	MAY	*31.350*	*31.675*	*30.845*	*29.995*	*30.352*			*2.323*

2016	**MARCH**	***29.065***	***29.840***	***30.610***	***30.740***	***28.920***	**31.301**	**32.301**	***0.000***
	APRIL	***30.755***	***31.665***	***31.535***	***32.150***	***30.457***			***1.000***
	MAY	***32.625***	***32.625***	***31.785***	***30.190***	***31.301***			***2.648***
2017	**MARCH**	***29.915***	***30.290***	***29.580***	***29.240***	***28.609***	**29.977**	**30.977**	***0.000***
	APRIL	***31.095***	***30.400***	***30.675***	***31.185***	***29.556***			***2.326***
	MAY	***30.860***	***31.500***	***30.735***	***30.100***	***29.977***			***2.523***
2018	**MARCH**	***29.080***	***29.270***	***29.845***	***29.950***	***29.657***	**30.287**	**31.287**	***0.000***
	APRIL	***30.035***	***30.340***	***31.060***	***31.230***	***30.287***			***1.00***
	MAY	***31.065***	***31.155***	***31.215***	***30.585***	***30.407***			***1.796***
2019	**MARCH**	***29.465***	***29.620***	***30.095***	***30.220***	***28.730***	**29.833**	**30.833**	***0.000***
	APRIL	***30.545***	***31.010***	***31.430***	***31.415***	***29.833***			***4.761***
	MAY	***30.740***	***30.430***	***30.500***	***30.750***	***29.669***			***1.824***

Table 2. **Degree heating weeks for 3 months.**

Year	DHW (°C) $\sum$ 12 Weeks	Year	DHW(°C) $\sum$ 12 Weeks
2003	**1.929**	**2012**	**5.282**
2004	**2.306**	**2013**	**5.208**
2005	**2.198**	**2014**	**3.665**
2006	**4.870**	**2015**	**3.421**
2007	**2.686**	**2016**	**3.648**
2008	**1.365**	**2017**	**4.849**
2009	**4.575**	**2018**	**2.796**
2010	**3.072**	**2019**	**6.585**
2011	**3.987**	**2020**	**NA**

Table 3. **Showing different stress level.**

Stress Level	Criteria	Intensity of Bleaching
No stress	HotSpot <= 0	No Bleaching
Bleaching Watch	0 < HotSpot <1	No Bleaching
Bleaching warning	0 < DHW < 4	Possible Bleaching
Bleaching Alert level 1	4 <= DHW < 8	Likelihood of significant Bleaching
Bleaching Alert level 2	8 <= DHW	High Probability of Severe Bleaching and mortality rate

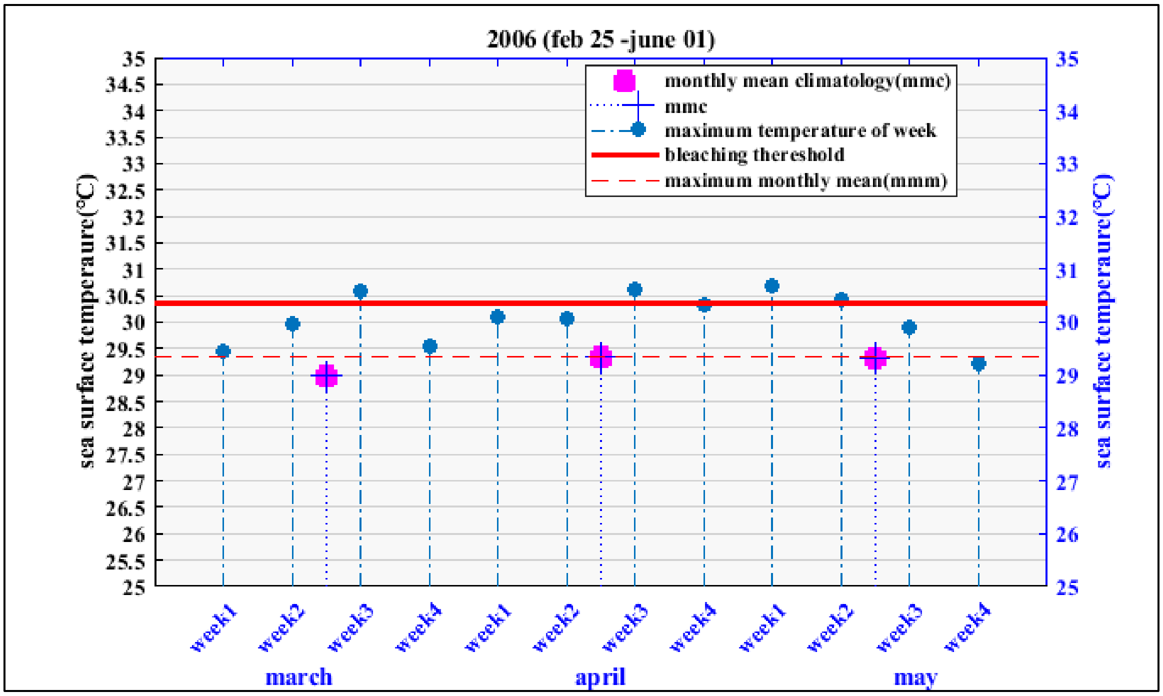

Figure 4

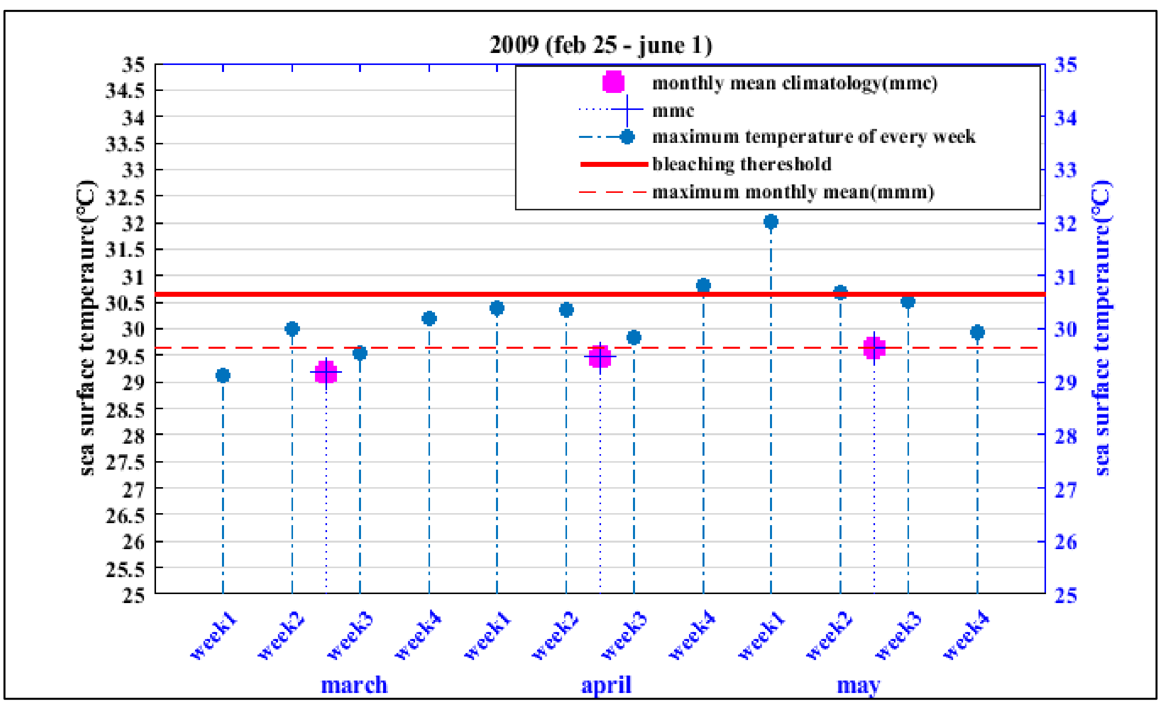

Figure 5

Fig.4 &5 represent the different SST parameters for Andaman Islands.

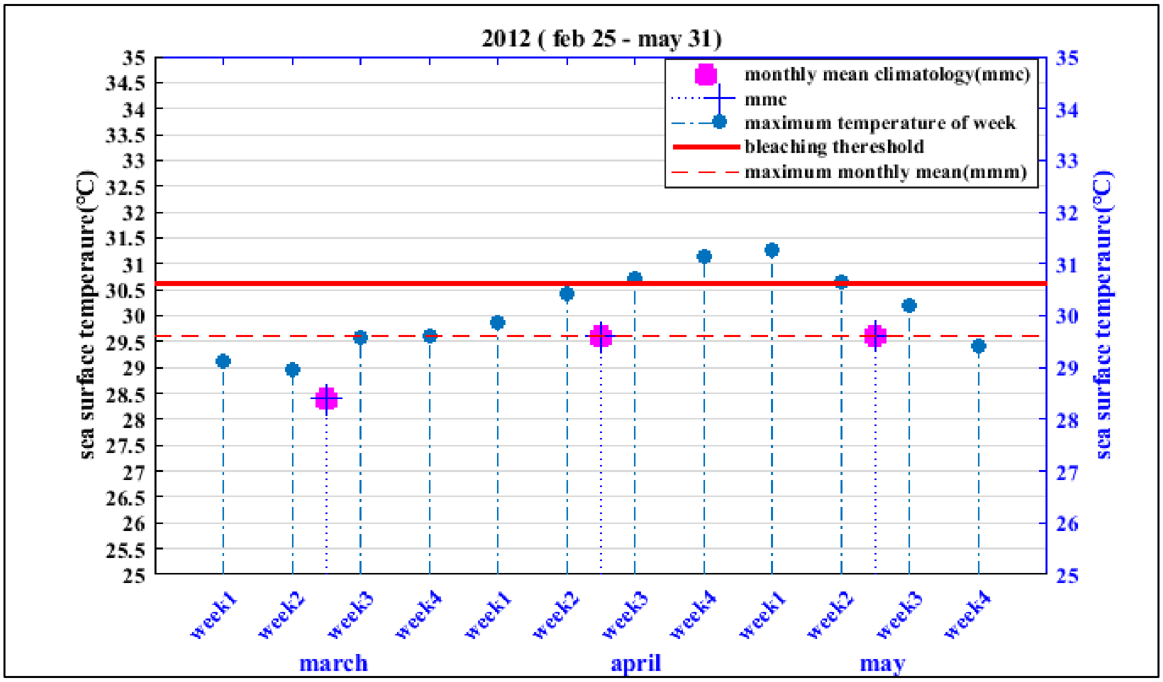

Figure 6

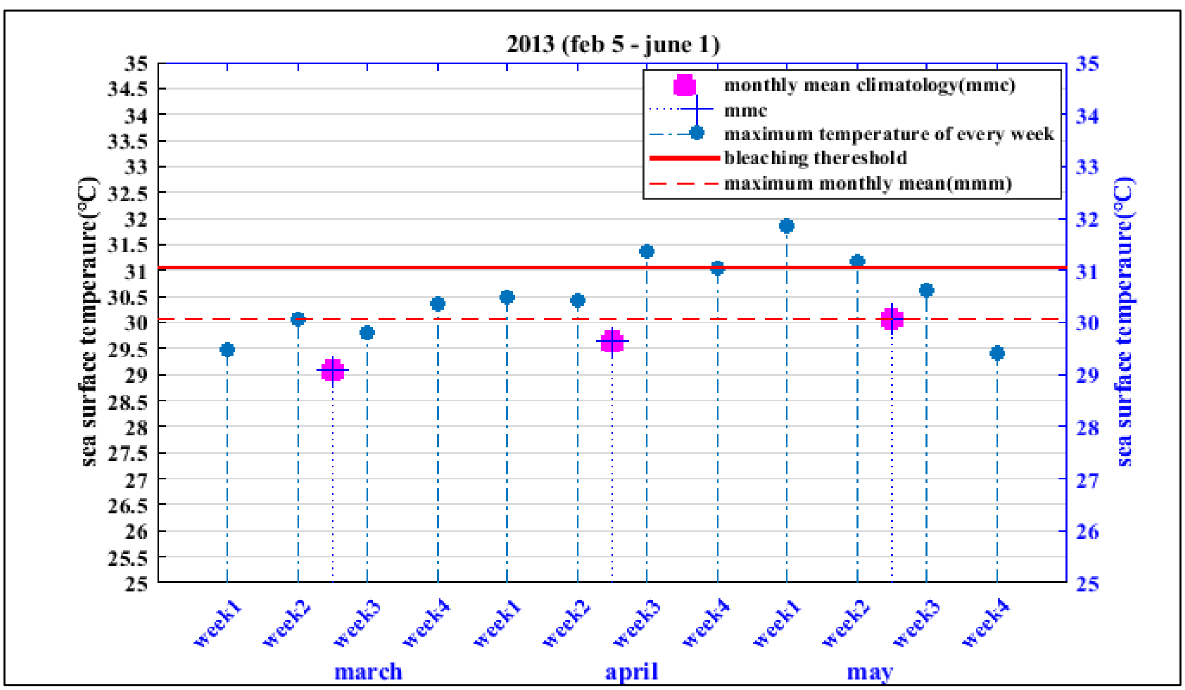

Figure 7

Fig.6 &7 represent the different SST parameters for Andaman Islands.

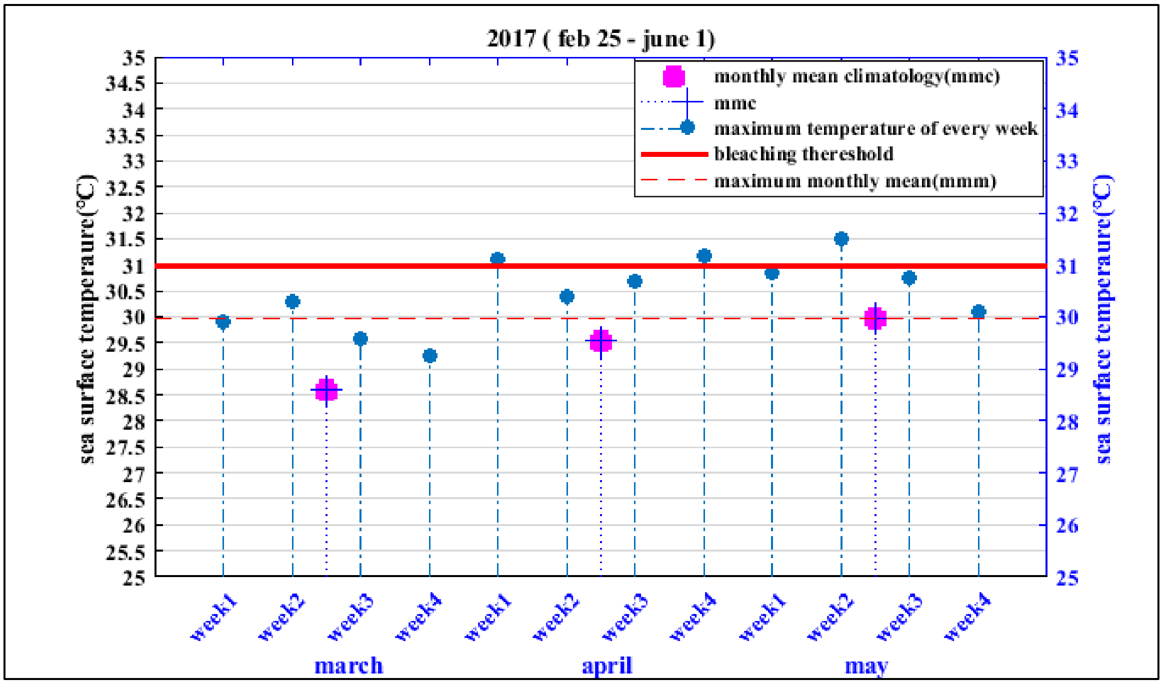

Figure 8

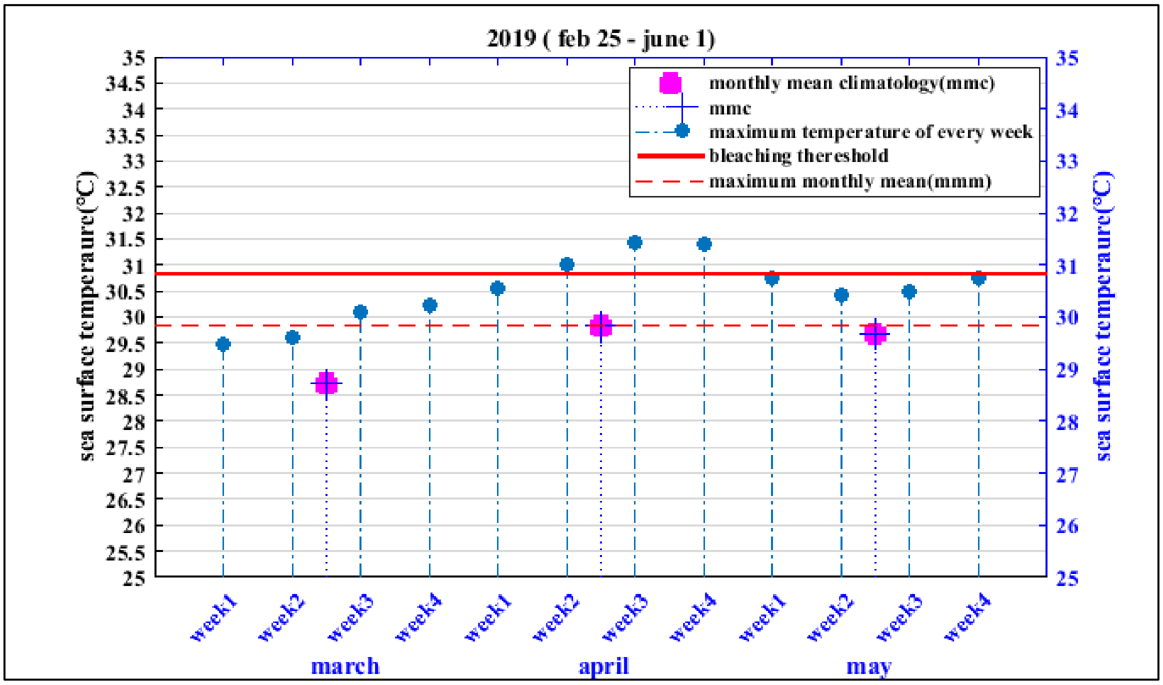

Figure 9

Fig.8 &9 represent the different SST parameters for Andaman Islands.

After analyzing fig. 3 to fig. 9, it was observed that those six weeks ranging from April week1 to May week2 showed high DHW accumulation. Moreover, thermally stressed regions of Andaman Islands for >4 DHW are plotted. Each pixel represents the sea surface temperature (SST) and the "RED" regions in the following figures below from fig.10 to fig. 15 represent thermally stressed regions and it suggests that these regions experienced dramatic warming over the described warming years.

Interestingly, when the result was compared with previous study on coral bleaching events, it revealed that the widespread coral bleaching occurred in the year of 2005 (April-may) (Krishnan et al. (2011); Sarkar and Ghosh (2013)), 2010 (April-may) (Mondal et al. (2014)), and 2016 (19th April–26th April) (Mohanty et al. (2017)) over Andaman Islands. But this study suggests although the coral bleaching occurred in 2005, 2010 and 2016, evidently the accumulation of very high thermal stress was found to be in the year of 2006, 2009, 20012, 2013 and 2017 as shown in figures above and below.

Continuous rise in SST over time coupled with El Niño years have proven to be lethal for coral reefs. Recent report on El Niño was published by Indian Meteorological Department (IMF), which confirmed that El Niño conditions from February 2019 have continued till June 2019. This study has yielded the maximum DHW (>6.5) for 2019 years and thus indicate extensive bleaching in the year of 2019.

HotSpot mapping of thermally stressed regions

Once the periods of high temperature weeks are identified and leveled as high potential bleaching intensity, the map of precise location of coral reefs which suffered high thermal stress are plotted as HotSpot maps as shown in fig.10 to fig. 15. In the fig 10, the western coast of middle Andaman shows the maximum temperature for the period of six weeks from 1st week of April to 2nd week of May, 2006. Similarly for 2009, western coast and transition of northern and middle Andaman records the high SST. However, 2012 records least SST over the proximity of coral reefs dominant regions. Year of 2013 also records low accumulation of DHW over coral reefs occurring regions.

However, the most severe depiction of extremely high thermal stress covering region has been recorded in the year of 2017 as depicted in fig. 14, in which almost whole eastern and western coast are affected. In the highest thermal accumulation year, 2019 is found to be affecting middle, lower and little Andaman. These discussed affected regions have suffered widespread coral bleaching.

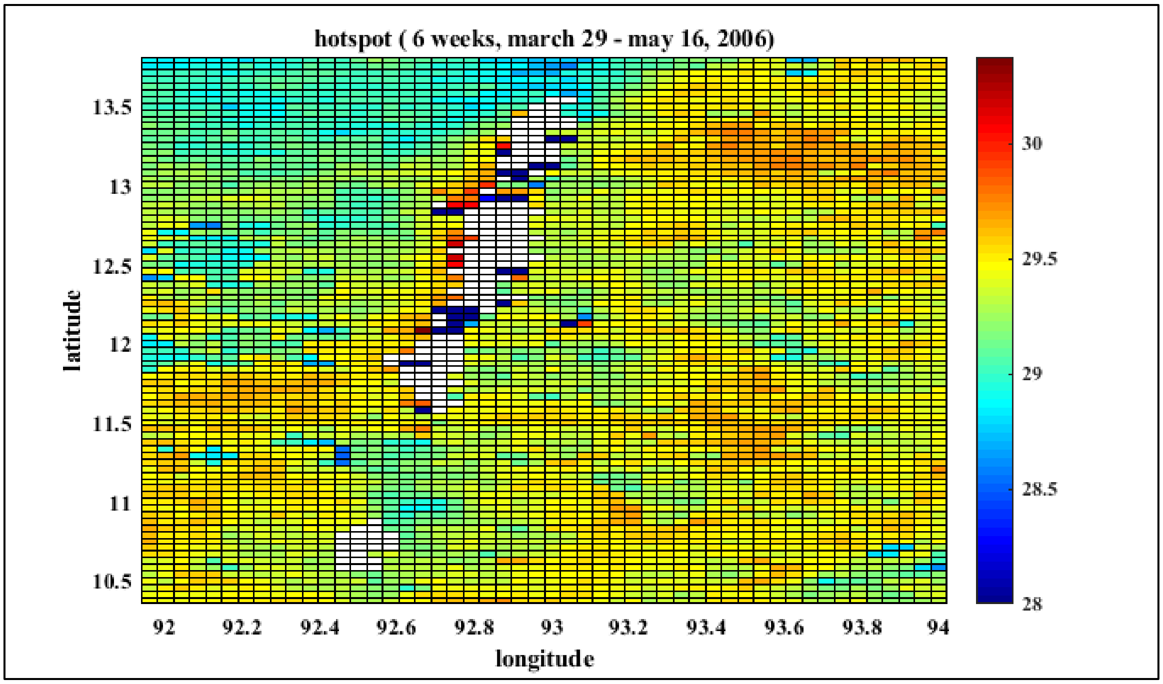

Figure 10

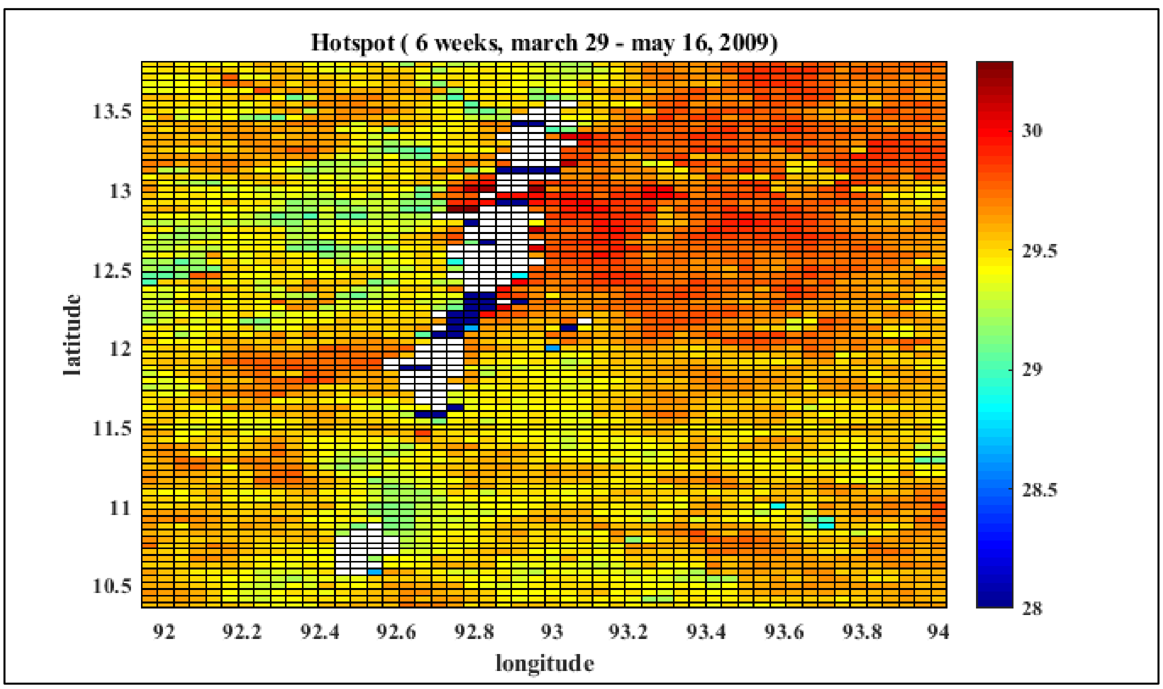

Figure 11

Fig.10 &11 represent thermally affected areas around Andaman Islands.

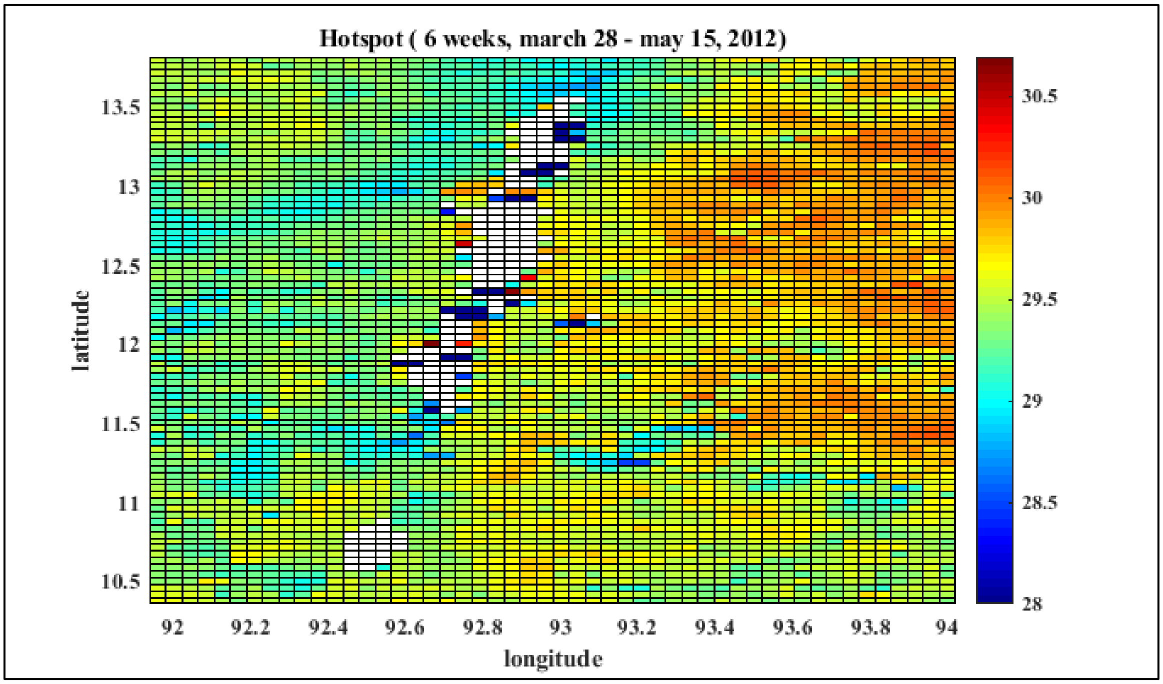

Figure 12

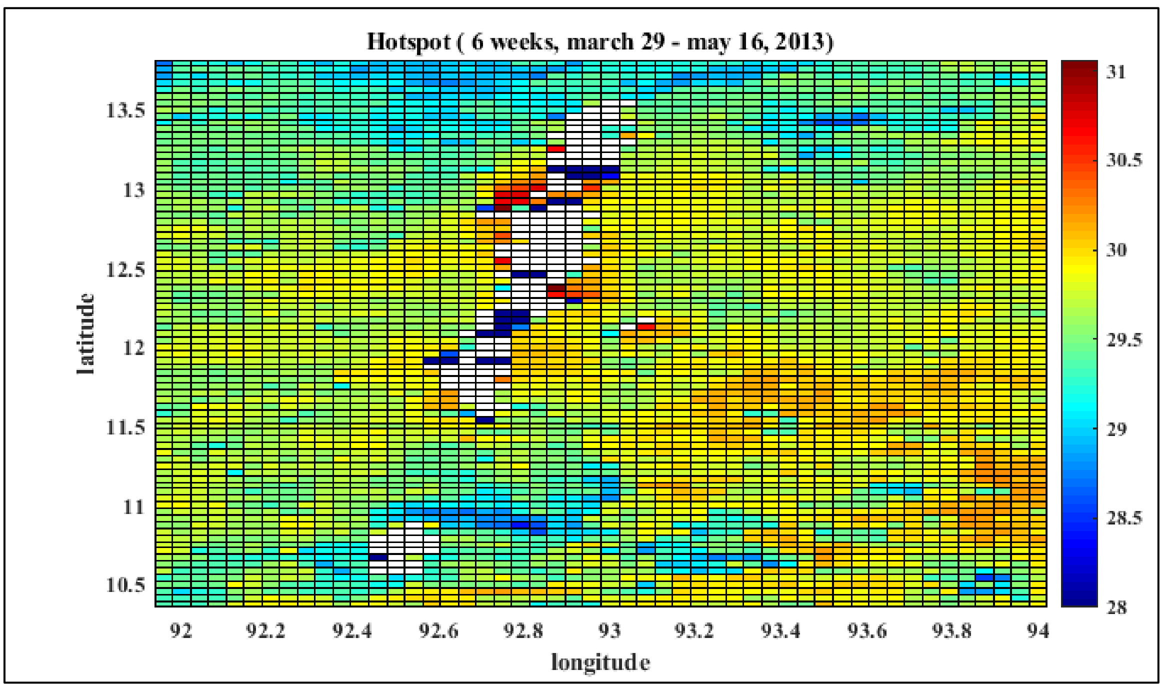

Figure 13

Fig.12 &13 represent thermally affected areas around Andaman Islands.

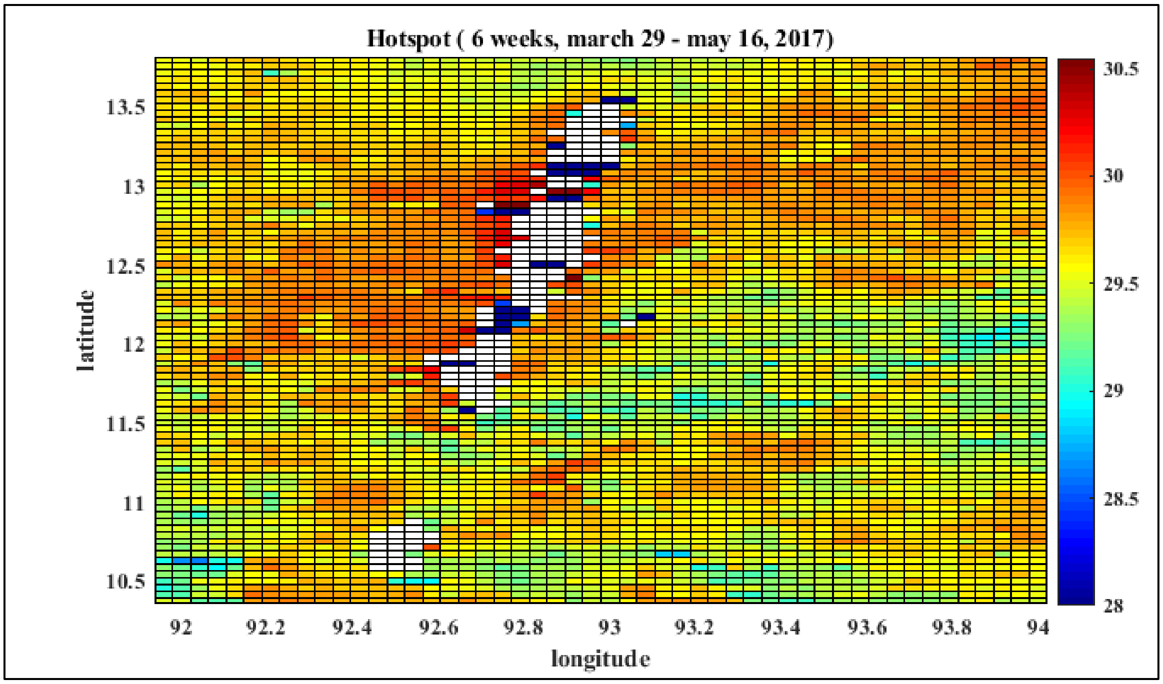

Figure 14

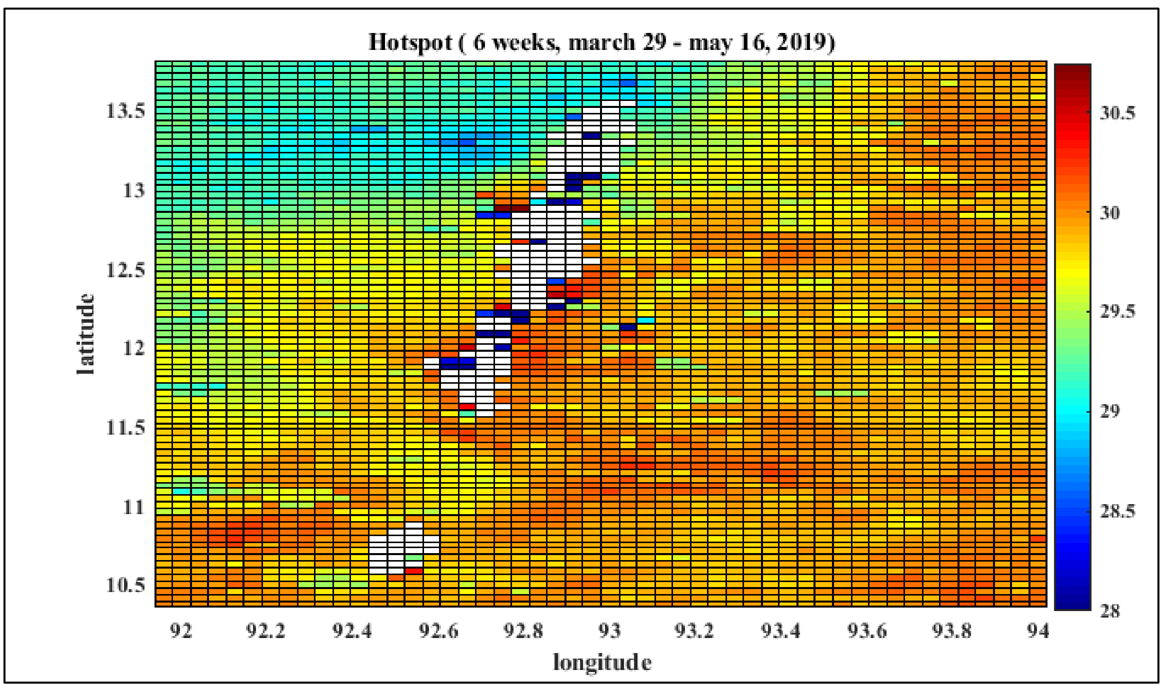

Figure 15

Fig.14 &15 represent thermally affected areas around Andaman Islands.

Summary and Conclusion

Remote sensed SST data have been widely used approach for monitoring sea surface temperature. Since the coral reefs are highly susceptible to temperature increase and primary reason for coral bleaching, ignoring the fact that few species can adapt and acclimatize, SST provides a very insightful understanding of coral behaviors under high temperature. HotSpot mapping provides regions of high thermal activity and potential bleaching areas. So this study can be used to deploy strict measurements against increasing threat to corals especially in the red zone, and government must take action to ensure sustainable environments for corals of Andaman Islands same way as the United States Coral Reef Task Force (USCRTF) were created by USA. This study showed the increasing threats to coral reef's diversity of Andaman Islands have reached an alarming level and if it persists in future, its effect will be seen in every aspect of all life form from fishery to human beings. The future is grim for not just corals but all the lives that depend on it as well.

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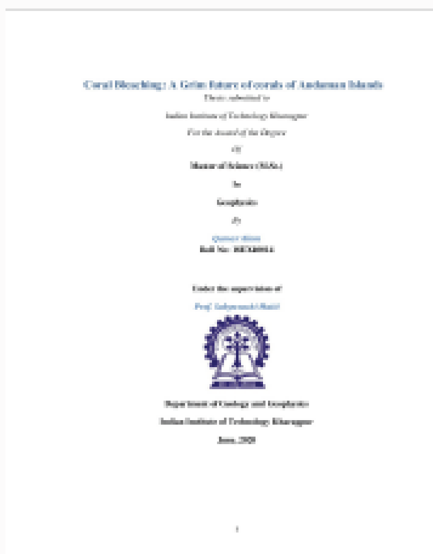

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