

Comparison of *in situ* temperature data from the southern Seychelles with SST data: can satellite data alone be used to predict coral bleaching events?

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Abstract. In 2003 the Aldabra Marine Programme initiated a temperature monitoring network in the southern Seychelles. It currently involves 40 temperature data loggers located at Aldabra, Assomption, Astove and St. Pierre. The annual temperature cycle in the region is marked by a shorter period of winter lows (min 23°C) between June and October, and extended high summer temperatures (max 30°C) between December and April. We compare satellite sea surface temperature data from four locations with *in situ* temperature measurements at 6m, 10m and 20m depth. Typically *in situ* temperature measurements do not differ from satellite measurements by more than 1°C, though on occasions the difference can be as much as 4°C. SST data is most similar to *in situ* data during the winter, and least similar during the summer. This is most likely due to water column stratification during the summer which is typified by calm weather with weak winds, while during the winter strong south easterly winds reduce stratification. In this case a combination of greater stratification during the summer period, along with periods of cool water upwelling, may in some cases reduce the reliability of SST data for predicting bleaching events.

Key words: sea surface temperature, coral bleaching, southern Seychelles, *in situ* temperature.

Introduction

Satellite sea surface temperature (hereafter referred to as SST) readings are now commonly used to predict where bleaching is likely to occur (Liu et al. 2006, Strong et al. 2002). Temperatures obtained using the Advanced Very High Resolution Radiometer (AVHRR) are supplied online by NOAA's Coral Reef Watch (CRW) in the form of several near-real-time global coral bleaching monitoring tools (Liu et al. 2006). Satellite temperatures used to provide these tools have been exhaustively calibrated with *in situ* sea surface temperature readings from buoys and boats (Reynolds and Smith 1994). The correlation of sea surface temperature readings used in these monitoring tools with real coral bleaching events has also been established (e.g. Cumming et al. 2003, Liu et al. 2003, Wellington et al. 2001a), demonstrating that they are reliable for predicting when and where bleaching is likely to occur.

The link between satellite SST's and coral bleaching, however, relies on the assumption that surface temperatures will be reflected in some way at the depths where corals live. In most cases this will be a valid assumption, although local oceanographic conditions will determine the depth to which SST readings are likely to be representative. For example, satellite SST readings taken during conditions of low

wind speed tend to be less consistent with bulk temperatures due to poor mixing of the surface layer (McAtee et al. 2007). This is due to the fact that satellite SST's record the temperature from the top 10µm to 1mm of the ocean, whereas they are trained to buoy and ship readings that record bulk temperatures within the first metre or so of the ocean surface (McAtee et al. 2007). It is therefore not difficult to imagine a scenario where features such as thermoclines or upwellings could spare corals from bleaching at times when surface conditions suggest it should be taking place.

In 2003 the Aldabra Marine Programme established an array of temperature data loggers at Aldabra atoll, Assomption, Astove and St. Pierre in the southern Seychelles (Downing et al. 2003). These loggers were deployed as part of a monitoring effort following the 1998 El Niño bleaching event. In particular, it was decided that such data should be collected to better evaluate the causes of future bleaching in an area of the world where there is very little monitoring of seawater temperature. The southern Seychelles is also an area where very little temperature data is available for the calibration of satellite SST readings (Reynolds et al. 2005).

Here we compare our *in situ* temperature (hereafter referred to as IST) readings with SSTs from the same

area. These temperatures are not directly comparable as SSTs are obtained from a large area as opposed to our single point temperatures, and our temperature data are obtained from different depths. However, our objective is to compare temperatures obtained by the two methods in order to determine how different they really are, and to establish whether there is a consistent difference between SSTs and IST depth readings. This will allow us to better estimate IST bleaching temperatures from SST data alone. With this in mind we also examine temperatures from both sources during a real bleaching event in the study area that occurred in March 2005.

Methods

In situ data

In May 2003 the Aldabra Marine Programme (AMP) initiated temperature monitoring in the southern Seychelles at 9 sites at Aldabra atoll and at single sites at Assumption, Astove and St. Pierre (Fig. 1). For this study we present results for the period between May 2003 and March 2006. We shall only show results for the outer reef Site 3 at Aldabra, as results are similar for all 9 sites at Aldabra. We also present results for the single sites at the other locations.

Seawater temperatures were recorded using Onset Hobo Pro[®] and Tidbit[®] temperature data loggers (accuracy $\pm 0.2^{\circ}\text{C}$) located at 10m and 20m at all locations, and additionally from 6m at Aldabra Site 3 and Astove. At each depth two loggers (generally one Hobo Pro[®] and one Tidbit[®]) were attached to metal stakes at approximately 50cm from the seabed. Having a second logger was found to be a useful way of verifying their stability over time, as data from the two could be compared to look for evidence of drifting. Loggers were set to record every hour (though for the first two years recording was every half hour) and downloaded at approximately 18 month intervals using Onset BoxCar Pro v4.3 software. IST data was then converted to Excel format and daily averages computed for comparison with satellite data. Daily averages were used as night-day temperature differences were very small (normally much less than 0.1°C).

Satellite data

SST data were provided by NOAA Coral Reef Watch. The satellite data used for the comparison were average values derived from a 3 to 4 day composite of night-time sea surface temperatures (SSTs) observed by the AVHRR over a 0.5 by 0.5 degree pixel. For more information on how this is computed refer to <http://coralreefwatch.noaa.gov/satellite/methodology/methodology.html#hotspot>.

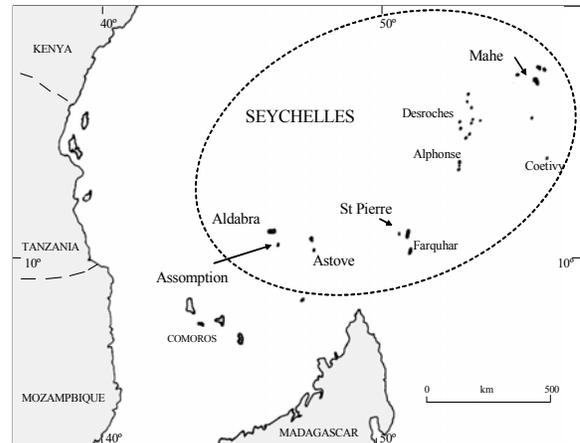


Figure 1: Location of AMP sites in the Seychelles, western Indian Ocean.

Data comparison

In order to compare satellite data with our *in situ* data we matched up our *in situ* average daily temperatures with the last day of the satellite temperature composite. From any composite data the last day is the only date provided. We used data from the satellite pixel closest to each of our sites. Where more than one pixel was available close to one of our sites we obtained an average. Midpoints of pixels used were Aldabra ($09^{\circ}\text{S } 46.5^{\circ}\text{E}$), Assumption ($10^{\circ}\text{S } 46.5^{\circ}\text{E}$), Astove ($10^{\circ}\text{S } 47^{\circ}\text{E}$; $10^{\circ}\text{S } 47.5^{\circ}\text{E}$; $10^{\circ}\text{S } 48^{\circ}\text{E}$; $10.5^{\circ}\text{S } 48^{\circ}\text{E}$) and St Pierre ($9^{\circ}\text{S } 50.5^{\circ}\text{E}$; $9.5^{\circ}\text{S } 50.5^{\circ}\text{E}$). For comparison of the two temperature sources we subtracted IST from SST readings, giving a bias reading where positive represents cooler IST than SST and vice versa.

Results

Yearly temperature cycle

Temperature at all sites ranged from summer daily averages of approximately 28°C to winter lows of $24\text{--}25^{\circ}\text{C}$ (Table 1). There was little difference in temperatures at 6m and 10m, while there was evidence of thermoclines becoming established in the summer between 10m and 20m. Mean differences between the two depths in the summer were greatest for St. Pierre (mean = 0.6°C , SD = 0.4°C , Max = 2.4°C) and less at the other locations (Aldabra mean = 0.4°C , SD = 0.3°C , Max = 1.4°C ; Astove mean = 0.3°C , SD = 0.3°C , Max = 1.5°C and Assumption mean = 0.2°C , SD = 0.2°C , Max = 1.0°C). At all locations during the winter period there was little difference in temperatures with depth. The general trend at all sites is one of very stable winter temperatures that do not vary much from day to day and summer temperatures that fluctuate more (see Fig. 2 for a typical example of the temperature cycle, here seen at Aldabra Site 3).

Table 1. Mean summer and winter temperatures ($^{\circ}\text{C}$) \pm Standard Error of Mean (SEM) for AMP sites in the southern Seychelles for the period May 2003 to present (December 2006 to March 2008 depending on site). n = number of summers or winters, Max = summer maximum and Min = winter minimum temperature \pm SD.

Location	Depth m	Summer average	n	SEM	Winter average	n	SEM	Mean Max	SD	Mean Min	SD
Aldabra	6	28.3	4	0.3	25.4	4	0.2	29.5	0.4	23.8	0.3
	10	28.2	5	0.2	25.4	5	0.2	29.5	0.3	23.8	0.3
	20	27.8	5	0.2	25.3	5	0.2	29.2	0.3	23.7	0.3
Assomption	10	27.9	4	0.3	25.2	4	0.2	29.5	0.4	23.5	0.3
	20	27.7	3	0.4	25.1	3	0.2	29.1	0.5	23.3	0.3
Astove	6	27.8	3	0.4	25.1	2	0.2	29.4	0.1	23.8	1.8
	10	27.8	5	0.3	24.9	4	0.2	29.1	0.6	23.2	1.5
	20	27.6	5	0.3	24.9	4	0.2	28.9	0.5	22.9	1.5
St. Pierre	10	27.9	6	0.2	26.0	5	0.2	29.3	0.4	24.1	0.7
	20	27.4	6	0.3	25.8	5	0.3	29.0	0.4	23.6	0.9

SST – IST comparison

The greatest differences between SST and IST temperatures occurred during the summer months for all sites (Fig. 3), with the transition between stratified and unstratified occurring later at Assomption and Astove.

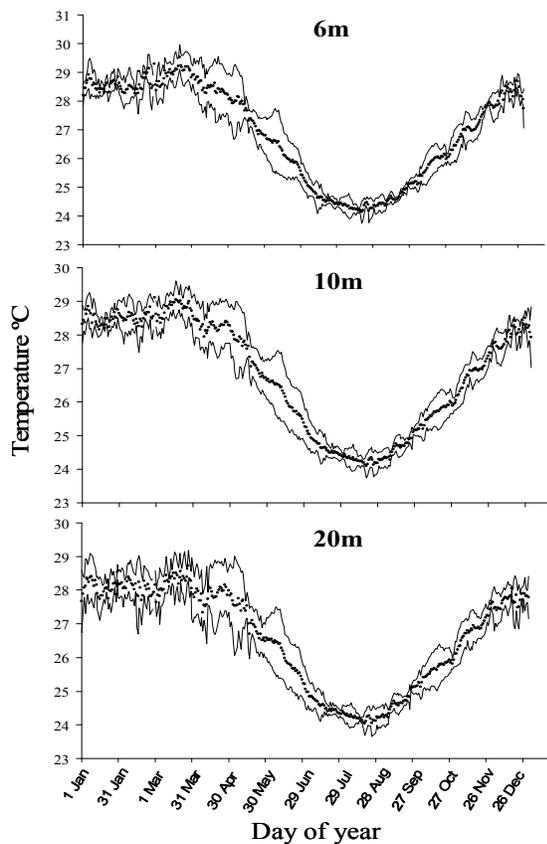


Figure 2. Example of yearly temperature cycle for the southern Seychelles based on mean daily temperature calculated from the period Feb. 2002 to Dec. 2006 for three depths at Aldabra Atoll. Dots represent mean temperatures while solid lines represent \pm SD.

We examined the summer period temperatures (January to May) independently as these contrast most from those obtained by satellite. During this period the difference between SST and IST increases with depth at all sites (Fig. 4). The mean difference between SST and IST during the summer period, and at 20m depth, was highest at St Pierre (1.4°C), intermediate at Aldabra and Astove (0.8°C), and lowest at Assomption (0.5°C) (Fig. 4). Points of maximum difference were reached at St Pierre (4.2°C) and Astove (3.6°C).

The 2005 coral bleaching event

The AMP conducted coral monitoring surveys at all sites in April 2005. During surveys we noticed diseased corals at Aldabra and Assomption, and coral bleaching at Astove. This extended from the intertidal down to over 30m depth. It included many species including members of the families Acroporidae, Poritidae, Faviidae and Agariciidae amongst others. The bleaching was, however, not intense and in many cases only parts of colonies were affected.

During this period the NOAA satellite products indicated up to 3 degree heating weeks (DHW) and 1.25°C HotSpots for the area from Aldabra to Astove which suggests likelihood of bleaching in the period leading up to our detection of bleaching. The period of stress did, however, move in from the southeast, indicating that Astove would have been subject to a longer overall period of high temperatures.

Mean summer temperature for the region is approximately 28°C (Table 2). We have therefore set the bleaching threshold at temperatures greater than 29°C in line with current thinking that bleaching is likely at temperatures greater than 1°C above the mean summer temperature (Hoegh-Guldberg 1999). IST data confirms that, while temperatures in 2005 were not excessive for the time of year, there was a

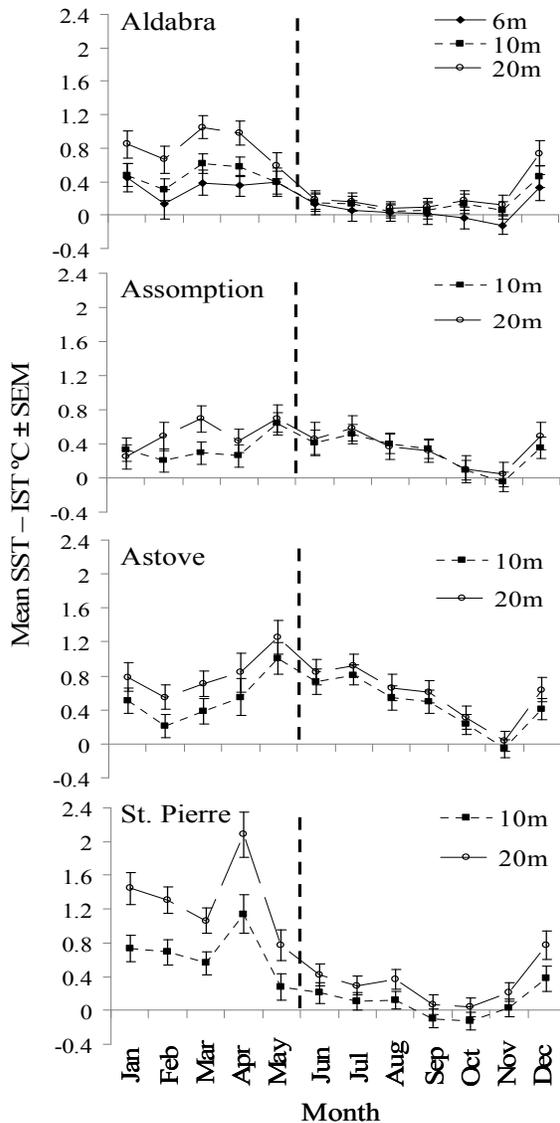


Figure 3. Mean monthly difference \pm SEM between SST and IST (10m and 20m depth) temperatures obtained between May 2003 and March 2006. Dotted line represents the start of strong southeasterly winds typical of the winter period.

more prolonged period of high temperatures than for the previous years recorded. In particular, temperatures at Astove were above the 29°C threshold on a higher percentage of days than at any of the other sites (Fig. 5). When SST data is examined it also shows the prolonged period of stress at Aldabra, Assomption and Astove. However, there is no

Table 2. Mean summer temperatures (°C) *in situ* for all AMP sites and for SST data. n = number of summers used for estimates, SEM = standard error of the mean.

	SST	6m	10m	20m
Mean	28.5	28.0	28.0	27.7
n	16	7	17	16
SEM	0.2	0.3	0.2	0.2

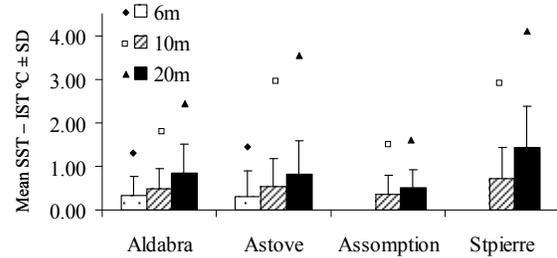


Figure 4. Mean summer differences (°C) \pm SD between SST and IST (6m, 10m and 20m depth) temperatures at AMP sites. Single symbols represent the maximum differences achieved per site and depth.

indication that Astove should be more prone to bleaching than these other locations as the percentage of days above 29°C is similar at all of the locations (Fig. 5).

In this case SST data did not highlight Astove as a

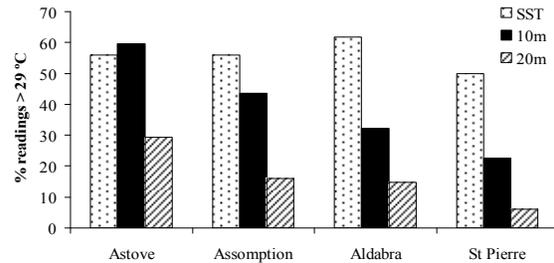


Figure 5. Percentage of days at the sea surface (SST), 10m and 20m depth with mean temperatures in excess of 29°C at all AMP sites in the summer period leading to the detection of bleaching at Astove (01/01 to 26/04 2005).

potential risk due to several periods, particularly in February, when SSTs were lower than IST temperatures at 10m, and also, though to a lesser extent, at 20m.

Discussion

The IST temperature data we obtained from the southern Seychelles is mostly similar to SST readings provided by NOAA in spite of the differences in depths they represent. The differences between IST and SST data are negligible in the winter. The mean summer differences we obtained at 10m, with a maximum of 0.6°C for St Pierre, are no greater than differences recorded elsewhere for *in situ* sea surface readings (e.g. Kawai and Kawamura 1997, Wellington et al. 2001b, Sreejith and Shenoi 2002).

In the winter, between June and November, strong south-easterly winds generate rough weather that leads to good mixing, thus explaining the little difference between SST and IST temperatures. Astove and Assomption are exceptions, with the winter IST and SST temperatures only equalising towards the end of winter. This is possibly due to the fact that the AMP sites at these two locations are

particularly well sheltered from south-easterly winds. The summer is typically a period of calm weather with occasional storms. Calm periods last long enough to allow the generation of thermoclines in the water column, as seen by the differences between IST and SST readings, though the temperature differences are generally not very large and the thermoclines appear to be broken down periodically by storms.

The close matching of data is also likely due to the fact that all of our locations are oceanic, with coastlines dropping off to depths in excess of 2000m very close to the shore. In essence this means that our temperature data loggers are behaving not much differently to what you would expect if they were deployed on a line in open ocean. Other SST-IST comparisons have had the confounding effect of shallower coastal waters that can warm above those suggested by SST readings (e.g. Wellington et al. 2001 b, McClanahan et al. 2007).

In spite of the good matching of SST and IST data from the southern Seychelles we must highlight the differences in the data. Generally corals below 10m will be subject to temperatures lower than those at the surface, and at levels that could mean the difference between bleaching or not. This idea is supported by our coral cover data which shows that corals below 20m were much less affected by the 1998 coral bleaching event (Teleki et al. 1999). Conversely, in 2005 we have an example at Astove of warmer water at depth than suggested by SST data. This demonstrates that local conditions can be very different to the general pattern shown by SST readings. We shall address the correspondence of SST and IST anomalies during periods of bleaching in a future publication.

The likelihood of coral bleaching is a function of the length of time that coral is exposed to temperatures above a certain threshold. Our data has shown that at these southern Seychelles sites there is a difference between SSTs and ISTs during the summer months, when the corals are most susceptible to heat-related bleaching. We conclude that while SSTs may give reasonably accurate predictions of bleaching events over a broad spatial scale, they do not always record the water temperatures to which the corals are actually being subjected. Therefore, and in agreement with the view put forward by McClanahan et al. (2007), we believe that in areas of special interest, IST data should always be gathered to more fully understand the patterns of water temperature fluctuations at the depths that really matter: not the surface, but the depths at which the corals live.

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