TEMPERATURE AND WATER EXCHANGE IN A SEMI-ENCLOSED LAGOON, BAMBURI, KENYA.

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INTRODUCTION

In the context of high sea-surface temperature anomalies causing widespread coral mortality, this study investigates the heat balance of a semi-enclosed coral reef lagoon system and any additional contribution of UV radiation as a trigger for bleaching. The study lagoon is situated north of Mombasa Island, along the Nyali- Bamburi-Shanzu coastline, at 4°0'01" S, 39°0'44" E (Figure 1) and has a surface area of 3.75 km^2 and 12.5 km^2 during spring low and high tides respectively. It consists of three topographic features: the shallow back-reef lagoon, the 300 m wide, 7.5 km long reef crest that is exposed during low tide and shelters the lagoon from oceanic swells and the relatively deep central longitudinal channel that collects all lagoon water at spring low tide. The mean depth of the lagoon does not exceed 0.7 m and the width varies between 1.5 km and 2.0 km at MSL. The main channel system connects the lagoon southwards to Nyali lagoon through a 250 m wide, 5.8 m deep point. Towards the northern end of the lagoon is a shallower (2.5 m) channel system connecting the lagoon to the mouth of Mtwapa creek (Kirugara *et al.,* 1998).

The lagoon water circulation has been described previously and modeled by Kirugara *et al.* (1998). Lagoon water exchange is driven by the wave-induced flow that is dependent on the degree of the reef submergence by tide and wave conditions, the characteristics of the incoming swell and the difference between the oceanic and lagoonal tidal levels. During spring tides, more than 80% of lagoon water is exchanged at each tidal cycle. In neap tides, unlike many other coastal marine areas, the continuous pumping of water over the reef (wave-induced flow) into the lagoon maintains a higher lagoon sea level compared with the typical oceanic level. This forces a simultaneous exit of lagoon water through the channels modulated by the tidal regime ensuring that more than 60% of lagoon water is exchanged during every tidal cycle. These mechanisms ensure the efficient flushing of lagoon waters during 1 - 2 tidal cycles.

The study monitors the following biophysical factors, integrating them over space and time: salinity and temperature inside the shallow lagoon and adjacent oceanic waters at 10 m to 30 m depth, solar radiative heat flux at the sea surface, and attenuation of this radiation into the lagoon and ocean, possibly differentiating UV and PAR. With this information an attempt will be made to estimate the heat balance for the lagoon on a long-term basis, taking into consideration the different monsoon periods.

METHODS

Three lagoon sites and two 'oceanic' sites at 10 m and 20 m outside the reef were used. Temperature and conductivity (salinity) measurements were recorded at 10 minute intervals for

90 consecutive days (18th September- 14th December 1999) using four bottom-mounted conductivity- temperatures meters (Type Hugrun) (Figure 1). One bottom mounted pressure gauge was deployed at 10 m at the oceanic site to record pressure and temperature, logging data every 10 minutes. An Aanderaa Automatic Weather Station 2700 was securely erected at KMFRI, 2 km from the study site, equipped with the following sensors: short wave radiation (0.3m - 2.5m), reflected long wave back radiation (0.3m - 60m), sunshine duration, wind speed and direction, air pressure, temperature, relative humidity and rainfall. This equipment simultaneously logged data from all the sensors at 10 minutes interval also. The entire raw data set was processed into half-hourly means and later smoothed with a moving average filter to obtain average measurements over a 24 hourly window. Further data analysis will be carried out in future.

RESULTS

Figure 2a shows a short-term temperature series in two shallow lagoon sampling sites, showing strong diurnal and semi-diurnal signatures in temperature variability. The diurnal trends are in response to the daytime heating and night time cooling while the semi-diurnal trends respond to the tidal phase. The tidal effect including the spring-neap variability is masked in this figure but is important because flooding brings cooler waters into the lagoon while ebbing water removes the excess lagoon heat and maintains a thermal balance (Pugh & Rayner 1988; Mwangi *et al.*, 1998). Generally, comparison of the two lagoon stations reveals that the waters are well mixed and homogenous with no pronounced salinity-temperature fields within the lagoon stations.

Figure 2b shows a different record of the half-hourly oceanic temperatures at 10 m and 20 m for two days. This figure highlights the possible existence of a shallow dynamic thermocline between 10 m and 20 m. The thermocline seems to be unsteady and the water becomes unstratified within short duration. It will be interesting to monitor this feature to establish whether the thermocline is maintained for long periods and its possible ecological consequence particularly as related to temperature induced bleaching.

Figure 3 shows a 20 day comparison of oceanic temperatures at 20 m depth with lagoon temperatures using a 30 minute average. The oceanic station showed a relatively stable cooler temperature profile, and no influence of tides. However, the lagoon temperatures increased from 28^{o} C to 30^{o} C during the same period. This difference between oceanic and lagoon temperatures, of the order of 2^{o} C is consistent with that suggested by Pugh & Rayner (1981) for tropical lagoons in cloudless, windless weather.

Figure 4 shows three month records of water and air temperature and solar radiation beginning on the 18th September 1999, the period of transition into the North East monsoon season. These data show a daily insolation of about 300 W/m^2 (clear skies) on most days and slowly increasing air and water temperatures throughout the study period. During the same period a steady decline in wind speed from daily means of 4 $m \cdot s^{-1}$ to 2 $m \cdot s^{-1}$ was recorded.

DISCUSSION

Substantial amounts of data are now available to begin heat flux calculations based on the work of Mahongo (1997) at Chwaka Bay, Zanzibar. These calculations will show long term trends of incoming radiation intensity (flux). An additional feature that could potentially be measured would be to distinguish between PAR and UV wavelengths, as these have different roles in coral biology and bleaching dynamics. Parameters to be dete mined will include whether UV(A, B or C) flux is a function of the total radiation or is constant, and their penetration characteristics at different depths. The extinction co-efficients for UV radiation are known for clear waters, but not for lagoon waters.

An important factor for the heat balance in this lagoon, was that spring low tides always coincide with maximum insolation between 09:00 hours and 12:00 hours (Kirugara, in press), resulting in maximal heating of exposed reef surfaces and interstitial waters. Influx of the flooding tide transfers much of this heat into the lagoon, such that lagoon temperature records show a peak during and immediately after spring low tides.

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