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Variation in subsurface seawater temperature off Discovery Bay, Jamaica and the U.S. Virgin Islands

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Abstract: Long-term, high accuracy seawater temperature data sets are essential in studies assessing environmental changes that may alter coral reef communities. Located at the approximately the same latitude, the subsurface seawater temperature (S^3T) off Discovery Bay, Jamaica (DBJ) and the U.S. Virgin Islands (USVI) had the same overall mean temperature. The USVI S^3T during the winter months is ~0.5°C warmer than DBJ, while May - July at DBJ is ~1°C warmer than USVI S^3T. With the passing of tropical storms in 1995 and 1997 in the USVI S^3T dropped as much as 1.5°C within a 20 hr period and did not revert to the previous temperature during that calendar year. Mean monthly S^3T during 2000 and 2001 in the USVI was >0.5 °C warmer than during similar periods in the early 1990s. Mean monthly S^3T during 1999-2002 at DBJ was 0.27°C cooler than during 1994-1995.

Key words: Caribbean, climate change, coral reefs, environmental monitoring.

Frequent, high accuracy subsurface seawater temperature (S^3T) observations are essential in studies involving: fish growth rates (Sadovy and Severin 1989), deleterious changes in marine population densities (Lessios *et al*. 1984), fish mortalities (Atwood 1984), and assessment of large-scale environmental changes such as coral bleaching (Winter *et al.* 1998, Quinn and Kojis 1999, Aronson *et al.* 2000; Cumming *et al*. 2002). While the upper 3 m has a long history of measurement, the available record of water temperature at depth in the Caribbean is less common. Excellent, high resolution S^3T data sets like Lee Stocking Island (Wicklund *et al.* 1991; http://www.cmrc.org/lsi_seawater_temp.htm) are uncommon. Even less common are geographical comparisons of such data sets. This study examines the S^3T time-series data sets from Discovery Bay, Jamaica (DBJ) and St. Thomas US Virgin Islands (USVI).

MATERIALS AND METHODS

Hugrun Seamon s/f brand underwater temperature recorders (UTR) with an absolute accuracy of ± 0.05°C were used to monitor hourly subsurface sea water temperatures at Lameshur Bay (18°06'N; 64°41'W) off St. John (USVI), at a depth of 7 m from June 1991 to March 1992 (N = 6 602) and near Saba Island (18°18'N; 65°00'W) off St. Thomas (USVI), at a depth of 7 m from March 1992 to November 2001 (N = 59 949). The observations were pooled to represent the USVI data set. The UTR was placed adjacent to a rich coral reef community at each site ~5 cm above

Fig. 1. Subsurface seawater temperature (°C) in the US Virgin Islands, 1992 - 2001.

the seabed to allow for a good flow around the recorder. Several times the UTR was checked and found to be reading within the stated product accuracy over the range 25-30°C. No adjustments were made to the data.

Hobo brand underwater temperature recorders with an accuracy of ± 0.34°C were deployed at 10 m off the West Fore Reef (WFR) off DBJ (18°28’00’’N, 77°24’30”W) from January 1993 to December 1996 (N = 11 000) and 14 July 1999 to 11 January 2000 (N = 4 356) as part of the CARICOMP study (Gayle and Woodley, 1998; Linton, 2000). The recorder was programmed to record every 42 minutes. A Hugrun Seamon UTR was deployed at 8 m at Dairy Bull, < 2 km from the WFR site, from 21 December 2000 to 15 May 2002 and recorded 11 707 hourly observations. The sites were similar and the data pooled. Gaps in both data sets were the result of equipment failure.

RESULTS

US Virgin Islands: The lowest recorded S^3T was 25.15°C and the highest 30.68°C, a range of 5.53°C over the total sampling period. Temperature ranges for individual years ranged from 2.78°C to 4.30°C. The precision of the instrument was 3.6% of the smallest annual range between maximum and minimum temperatures. The mean S^3T for year 1992 was 29.50°C (C.V. = 3.1%; N = 4 572) and 28.34°C (CV = 3.3%; N = 3 669) for 2000. September was the warmest month ($\bar{x}$ = 29.24°C) and February the coolest ($\bar{x}$ = 26.15°C) (Fig. 1).

The daily difference between the maximum and minimum S^3T typically varied from 0.38 - 0.62°C ($\bar{x}$ = 0.49°C; C.V. = 29%; N = 59 949) with the warmest period usually occurring in the afternoon just after a period of high insolation. The coolest temperatures of the day were commonly observed between midnight and 5:00 hr. In general, diurnal thermal variation is characterized by regular cycles with minimal secondary variations associated with tidal movements. Variations in water temperatures related to tidal movement appear to vary < 0.1°C.

On occasion, factors such as water runoff, high cloud cover and the energy demands associated with intense tropical storms would alter the typical pattern and cool the water by as much as 1.5°C during a 20 hr period. As

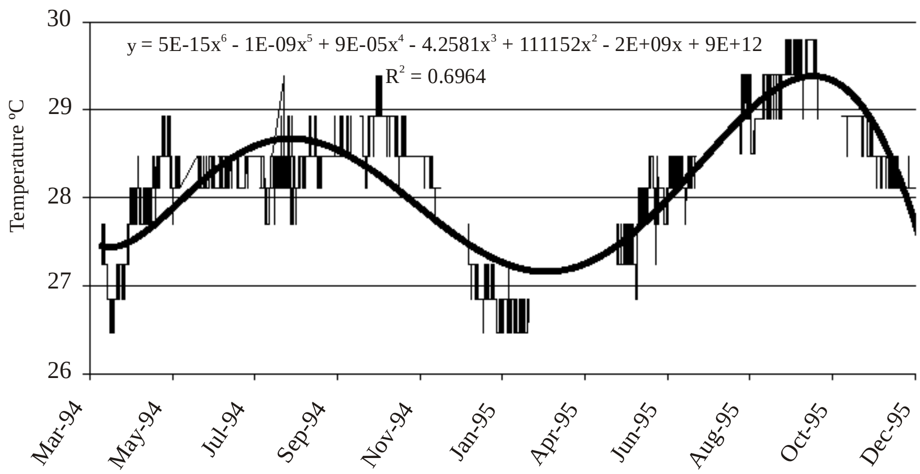

Fig. 2. Subsurface seawater temperature (°C) from the West Fore Reef at Discovery Bay, Jamaica, 1994-1995. Block effect is the result of limited resolution of the Hobo temperature sensor. CARICOMP data.

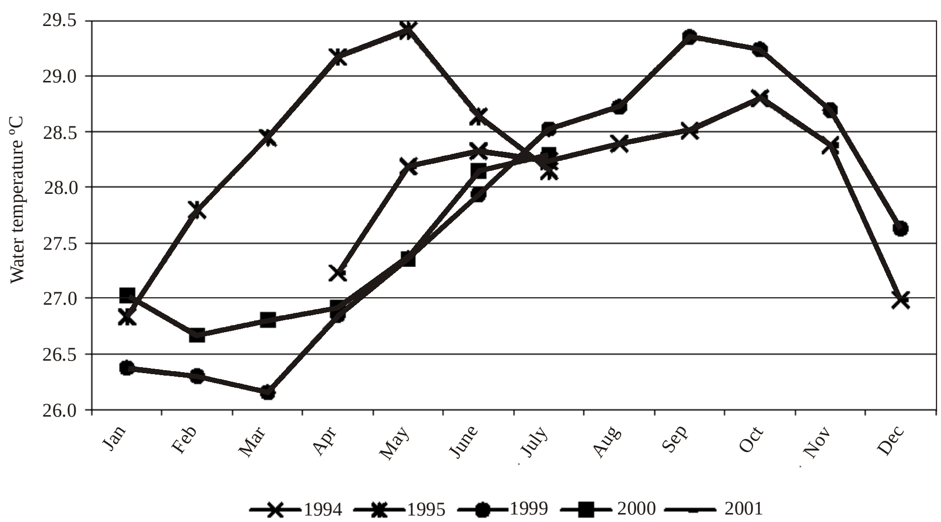

Fig. 3. Mean monthly subsurface seawater temperatures (°C) during 1993-1996, 1999-2002 Discovery Bay, Jamaica.

Hurricane Marilyn passed the islands in September 1995, S^3T dropped as much as 1.5°C. When Hurricane Georges passed the islands on 13 October 1997, S^3T dropped 0.475°C.

Discovery Bay, Jamaica: Distinct daily periodic cycles in subsurface sea temperatures were present in addition to seasonal heating and cooling trends. During 1994-1995, the mean difference between daily maximum and minimum S^3T was 0.26°C (C.V. = 84%). On many occasions there was no recorded temperature change for up to 32 hrs. A total of 49 days out of 458 days (10.8%) had no recorded difference between the daily maximum and minimum (Fig. 2). A daily difference of 0.05°C to 0.97°C ($\bar{x}$ = 0.27°C, C.V. = 83.0%, N = 511) was recorded from December 2000 - May 2002.

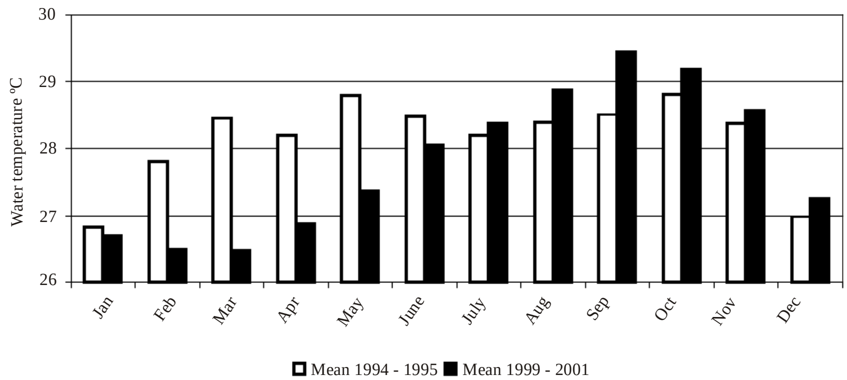

Fig. 4. Comparison between 1994-1995 and 1999-2000 mean monthly subsurface seawater temperatures (°C) at Discovery Bay, Jamaica.

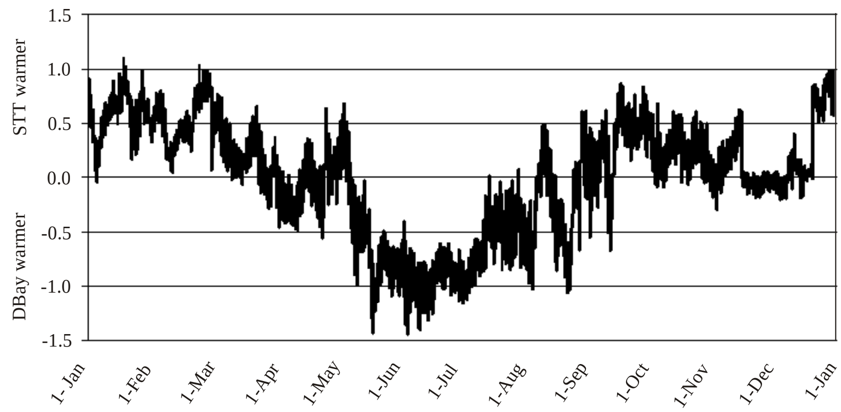

Fig. 5. Seasonal differences between Jamaican and US Virgin Islands subsurface seawater temperature (°C). DBML - Discovery Bay, Jamaica; STT - St. Thomas, US Virgin Islands.

During 1994-1995, October was the warmest month ($\bar{x}$ = 28.80°C; C.V. = 0.9%) and January the coolest ($\bar{x}$ = 26.83°C; C.V. = 1.2%), while during 1999-2002, September was the warmest ($\bar{x}$ = 29.35°C; C.V. = 0.98%), and March was the coolest month ($\bar{x}$ = 26.48°C; C.V. = 0.63%). The highest S^3T recorded was 30.26°C and the lowest 25.20°C, a range of 5.06°C (Fig. 3). The smallest annual range in maximum temperatures was 2.95°C. The sum of the difference in mean monthly temperatures between April 1994 - July 1995 and July 1999 - May 2002 is -0.27°C suggesting that there was cooling during the five years. This is mainly because the months February to May during 1999-2002 were 1.25°C to 1.73°C cooler (Fig. 4).

Geographical Comparison: Located at the same approximate latitude, the S^3T off DBJ and USVI, had the same overall mean temperature within, the accuracy of the instrumentation. However, there were seasonal differences between the sites. The USVI S^3T during the winter months is ~0.5°C warmer than DBJ, while May - July at DBJ is ~1°C warmer than USVI waters (Fig. 5).

DISCUSSION

It is universally believed that the efforts to relate the severity and extent of large-scale coral reef bleaching events to particular causes have been hampered by a lack of continuous, long-term data relating to environmental conditions over the periods of interest (Glynn 1993). As Goreau *et al*. (1993) state, "...many non-coral specialists have been skeptical of such an explanation because of the lack of adequately documented sea temperatures from coral reef sites."

Experimental data suggest that tropical organisms exist closer to their upper temperature tolerance limits and are more vulnerable to relatively small thermal variations than organisms living in cooler biomes (Emiliani *et al*. 1981). As such, coral reefs are likely to be among the first communities damaged as a consequence of climate change (Goreau 1990, Smith and Buddemeier 1992, Goreau and Hayes 1994). Regional specific variations like the upwelling (~6.5°C variation within 2 hr) in the coastal waters in the Gulf of Oman off Muscat in the Sultanate of Oman (Quinn and Johnson 1996) are likely to have a major impact on coral reef communities and are unlikely to be detected by satellite because they do not reach the surface.

While sea surface temperatures derived from orbiting satellites have been useful in predicting areas likely to experience coral bleaching (Goreau and Hayes 1994, Cumming *et al.* 2002), the data is usually only taken at night when there are fewer clouds. The number of monthly observations from satellites commonly ranges from 3 to 15 measurements compared with ~720 hourly *in situ* measurements (Quinn and Kojis 1994).

To satisfy the requirements of long-term environmental monitoring and weather and climate forecasting, SST and S^3T products must be available over long time periods with known or accurately estimated error characteristics. This requires that the data, methods and algorithms be applied and archived consistently over long time periods. Recording of the lineage of data is important in all cases, it is particularly important when "blended" data sets are constructed and used in analysis.

The Hobo thermometer is accurate to ± 0.34°C, which is about 12% of the smallest annual S^3T range or more than 100% of the typical diurnal variation. The imprecision of the equipment probably precludes the use of the observations in accurately measuring small, short-term annual temperature changes characteristic around Discovery Bay. Cost is commonly an important consideration when setting up programs and more accurate, more expensive, UTRs are either beyond the scope of many programs or are not considered a necessary expense.

The greater diurnal variability at DBJ is probably associated with meteorological conditions associated with a larger land mass and the passing North American weather fronts. Smaller islands further from the North American continent are less able to generate their own weather and are less affected by fronts.

Sea surface temperatures (SST) and subsurface seawater temperatures represent one of the most important data sets for monitoring the global environment and need to be measured with a high resolution, accurate device. During a coral bleaching event in 1993 mean monthly S^3T was only 0.5°C warmer than during the previous year (Quinn and Kojis 1999). The use of Hobo brand temperature recorders is less likely to detect subtle temperature increases, such as those associated with minor bleaching events, than other more precise instruments currently in production.

While research studies are needed to develop the techniques and products, larger-scope institutional efforts and commitments are required to control the quality and maintain the lineage record of the products. The Caribbean Coastal Data Centre (CCDC) is located at the University of the West Indies and archives and manages data from the regional monitoring programs, CARICOMP and CPACC – Caribbean Planning for Adaptation to Global Climate Change project. The Centre functions to: provide data archival support to various regional and international marine monitoring programs, including error-checking and data entry, design and develop appropriate databases to facilitate easy retrieval of data and the exploration of relationships in the datasets and disseminate data to facilitate the production of reports. The CCDC has developed a relational database in Microsoft Access to store the dataset from CARICOMP including Weekly Sea Water Temperature, Daily Maximum and Minimum Temperature and other parameters.

We further urge the development of mathematical models to predict subsurface water temperatures for coastal waters around the islands based on meteorological and satellite observations. Meteorological factors including air temperature, wind speed, humidity, and insolation could possibly be used in the absence of *in situ* S^3T observations to estimate coastal subsurface seawater temperature.

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RESUMEN

Se examinaron registros de alta precisión de temperatura sub-superficial (TSS) (1994-2002), de Discovery Bay, Jamaica (DBJ) y St. Thomas, Islas Vírgenes (IV); encontrándose promedios totales similares para ambos lugares. La TSS en IV fue ~0.5°C mayor que en DBJ durante los meses invernales, mientras que entre mayo y julio fue ~1°C más cálida en DBJ que en IV. Con el paso de sendas tormentas tropicales en 1995 y 1997, la TSS en IV descendió hasta en 1.5°C en un lapso de 20 hr, sin retornar a las temperaturas normales durante lo restante de dichos periodos anuales. Promedios mensuales de TSS en IV durante 2000 y 2001 fueron superiores en más de 0.5°C que en los meses respectivos de los años registrados durante los primeros años de la década de los 90s. El promedio mensual de TSS en DBJ entre 1999 y 2002 estuvo 0.27°C por abajo del registrado entre 1994 y 1995.

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