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2003 SUMMER UPWELLING EVENTS OFF FLORIDA'S CENTRAL ATLANTIC COAST

DANIEL A. MCCARTHY

Smithsonian Marine Station at Fort Pierce, 701 Seaway Drive, Fort Pierce, FL 34949-3140

ABSTRACT: *During the summer of 2003, an uncharacteristically high number of intense upwelling events occurred along the east central coast of Florida. A bottom-mounted temperature logger collected hourly seawater temperatures on hard-bottom habitat 0.4 km offshore of North Hutchinson Island from 29 May to 21 August 2003. During this time, six upwelling events occurred in which low temperatures ranged between 16–21°C. Early and late summer upwelling events averaged 12.3 and 5.3 days, respectively. A series of Pearson correlations between time series data from the logger and those of surface estimates from SeaWiFS suggest that the longer upwelling events in early summer eventually resulted in similar surface and bottom temperatures. In turn, the shorter upwelling events during late summer appear to have resulted in stronger thermoclines because of less time for mixing between surface and bottom waters. Analysis of local meteorological data suggests that wind stress was not upwelling favorable during most of the summer yet may have played a supplementary role in producing some of the upwelling events.*

Key Words: upwelling, seawater temperature, satellite imagery, SeaWiFS, Florida nearshore reefs

SEASONAL upwelling has often been reported over the past 50 years in Atlantic shelf waters off the east central Atlantic Coast of Florida (Green, 1944; Taylor and Stewart 1958; Blanton, 1971; Atkinson, 1977; Lee et al., 1981; Smith, 1981; 1982; 1983; Reed and Mikkelsen, 1987; Pitts, 1993; Pitts and Smith, 1997). These intrusions of cold, deep, nutrient-rich water onto the continental shelf can decrease seawater temperatures 6°–10°C for 1–3 wks during mid- to late-summer although additional short-term cooling events sometimes occur throughout the summer (Smith, 1981; 1982; Pitts and Smith, 1997). Upwelling events most likely occur when the Florida Current meanders to the west and contacts the continental shelf, which facilitates a shoreward–directed pressure gradient in the benthic boundary layer and onshore advection of cooler water onto the shelf (Smith, 1981; 1982; 1983; Pitts, 1993; Pitts and Smith, 1997). Also, wind forcing encourages upwelling when wind directions are persistently out of the SE quadrant (Smith, 1981; 1982; 1983; Pitts, 1993; Pitts and Smith, 1997).

During the summer of 2003, there were an unusual number and intensity of upwelling events off the Atlantic coast of central Florida with reports of negative effects on local marine fauna. During upwelling events, there were lower numbers of loggerhead turtles nesting, and hatchlings were often observed to be cold-stunned shortly after entering the water (Martin, 2003). In addition, there were observations

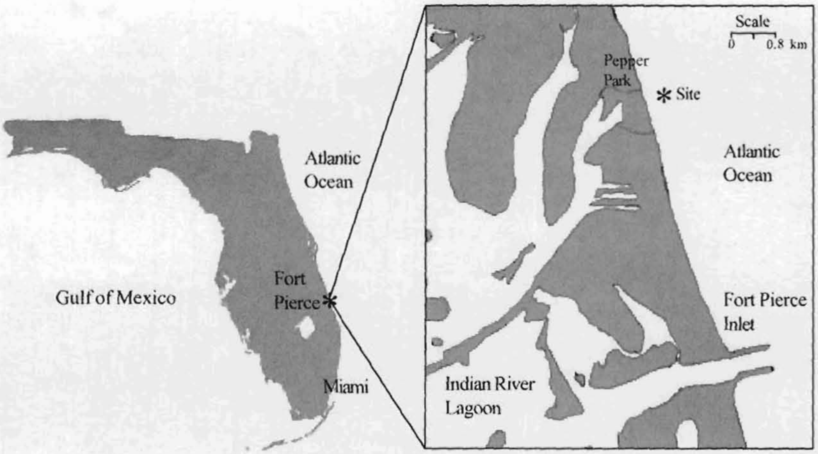

FIG. 1. Map of Florida showing Fort Pierce. Inset shows close up of Pepper Park with location of data logger. The ONSET temperature logger was cable-tied to a PVC-framed, vexar cage, which was nailed to the hard bottom with masonry nails.

of bottom-dwelling reef fish either being found dead, or swimming sluggishly near the water's surface or in the surf zone (Reed, 2003). Although it appears likely that these upwelling events were responsible for observed biological effects, attempts to relate water temperature and biological effects are usually done with time-series data obtained from satellite imagery. Sea surface satellite imagery is useful for showing spatial patterns, but has the following limitations of: 1) not always being available due to cloud cover or satellite problems, 2) only providing surface water temperatures, and/or 3) sometimes not being accurate because of atmospheric effects such as humidity. Time-series data from nearshore *in situ* devices are generally rare yet important, because they provide a more continuous data set as well as subsurface temperatures. Further, they can be used with satellite techniques to obtain a more accurate picture of seasonal changes of seawater temperature throughout the water column.

The main objectives of this paper are to report 2003 summer, subsurface seawater temperatures for the Pepper Park location, and compare such data with satellite estimates (SeaWiFS) of surface temperatures for the same area. An additional objective is to explore the role of wind stress in producing the observed upwelling events.

METHODS—During the summer of 2003, weekly field experiments were conducted on hard-bottom habitats off Pepper Park (Fort Pierce), Florida (27°29.872′ N; 080°17.775′ W) (Fig. 1). A temperature logger (ONSET HOBO Water Temp Pro; Accuracy = ~0.2–0.33°C) was deployed 0.4 km offshore in 3 m depth on hard-bottom habitat from 29 May 2003 to 21 August 2003. Seawater temperatures were recorded every hour during this period. Satellite estimates of seawater temperatures for this same location and period were derived several times per day from infrared observations collected by the Advanced Very High Resolution Radiometer (AVHRR) sensors flown on the National Oceanic and Atmospheric Administrations Polar Orbiting Environmental Satellite (SeaWiFS; Accuracy = ~0.5°C; Spatial Resolution = 1.5 × 1.3 km). Daily seawater temperature means were separately computed for satellite

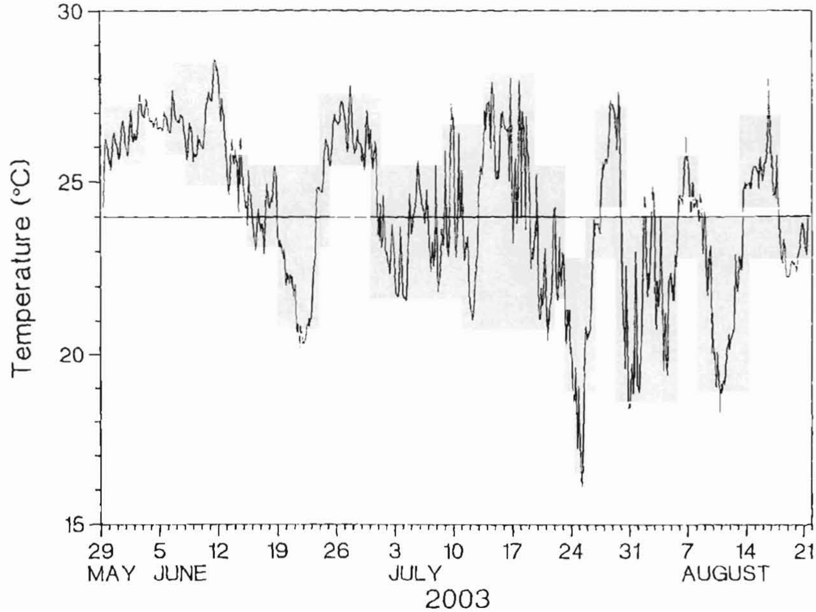

FIG. 2. Hourly seawater temperatures recorded at the study site at Pepper Park during May 29–Aug. 21, 2003. The line in the plot represents the threshold temperature for an upwelling event..

estimates and the temperature loggers by averaging respective data available for each day. Correlation analysis was used to examine how closely both techniques documented the seawater temperatures and upwelling events that occurred during the summer. An upwelling event was defined as occurring during any time period where the daily mean seawater temperature went below 24°C. This value was chosen as the threshold because normal "warm" water periods of the summer generally vary between 25 and 29°C (Smith, 1981; 1982; 1983; Pitts, 1993; Pitts and Smith, 1997). Because there were time periods of rapid temperature changes that were likely related to cold water moving in and out of the immediate area of the logger, an upwelling event was considered clearly over if the daily mean temperature exceeded 24°C for more than two consecutive days.

The role of wind stress in producing these observed upwelling events was explored by obtaining hourly wind speeds and directions from the Vero Beach Municipal Airport (17 km NW of the study site) for the same time period as the logger data. Since the airport is ~6 km inland, wind speeds were increased to better approximate over-water conditions (Hsu, 1981). Wind data were then converted to wind stress vectors using a drag coefficient developed by (Wu (1969) for moderate wind speeds. The wind stress vector was decomposed into longshore and cross-shelf components that were smoothed using an exponential filter (emphasizes the most recent wind stress but incorporates to a lesser extent winds recorded earlier). The longshore components were then compared with the seawater temperature series using regression analyses.

RESULTS AND DISCUSSION—Six upwelling events were recorded at the study site from 29 May to 21 August 2003 (Figs. 2 and 3). Subsurface temperatures ranged between 24.5 and 28.7°C from May 29 to June 10. The first upwelling event occurred from 15 to 23 June (9 d) with a low temperature of 20.5°C. After this upwelling event, the temperature increased back to 24.5–28.7°C. A second upwelling event occurred from 1–12 July (12 d) with a low of 21°C. After a brief

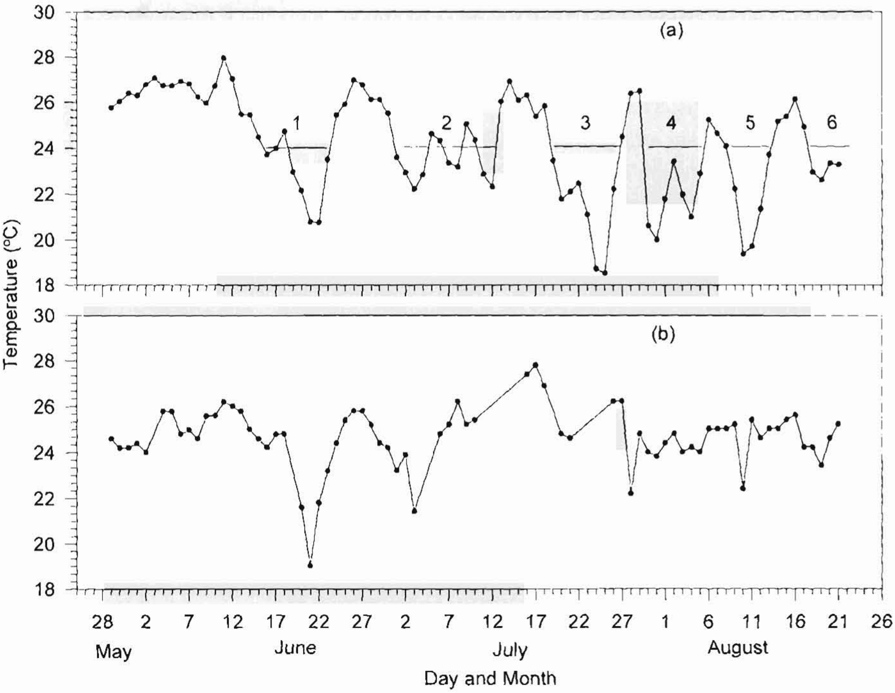

FIG. 3. A comparison between Pepper Park daily means of seawater temperatures obtained by ONSET logger (3 m depth) (a) and SeaWiFS (surface waters) (b). Note that high cloud cover during 10–26 July limited the availability of SeaWiFS data. The numbered lines represent periods of upwelling.

return to warmer temperatures, the upwelling with the lowest temperature (16.0°C) of the summer was recorded during 19–26 July (8 d). The following temperature increase reached 24.5–28.0°C and remained at those temperatures between the upwelling events that occurred on 30 July–5 August (6 days), 9–13 August (5 d) and 17–21 August (5 d). In the final 3 events, minimum seawater temperatures ranged between 18.0 and 23.0°C. In addition, the final upwelling event may have lasted longer but I recovered the data logger before its completion.

Comparison of satellite and logger temperatures were generally similar throughout the summer, yet were more strongly correlated during early summer (Fig. 3). A Pearson Correlation (SYSTAT for Windows: Statistics, 1992) revealed that daily mean seawater temperatures of the satellite estimates and logger were moderately correlated ($r = 0.480$; $p < 0.001$; $n = 71$) during the entire summer. However, from May until the time period where there were numerous gaps in the satellite data (July 10–26), the logger data were 1.0–2.0°C warmer than that provided by the satellite, and showed a much stronger similarity in pattern ($r = 0.860$; $p < 0.001$; $n = 43$). A comparison of the data sets after July 26 show that the logger data are generally 2.0–5.0°C cooler than that of the satellite data, yet have no similarity in pattern ($r = 0.236$; Not significant; $n = 26$).

Observed differences between the daily averaged seawater temperature data of the satellite estimates and those of the logger may be related to inaccuracies between these methods, or the existence of a thermocline as influenced by upwelling duration. From May 29 to July 10 (when there was complete overlap between satellite and logger data), the significant correlation between the data sets may have been due to the relatively long duration of upwelling events (mean = 12.3 d; s.d. = 3.5; n = 3) that allowed for more uniform cooling throughout the water column. The generally warmer logger temperatures during this time may be a result of either instrument accuracy differences or an air-cooling effect on surface waters. From July 10–26, the low number of satellite data points (due to cloud cover) clearly prevents a good assessment of temperature changes using SeaWiFS, although the few satellite data points generally correspond to those of the logger. However, after July 26 when the satellite data had no gaps, the difference between surface and subsurface temperatures is greater and reversed. Errors in satellite estimates may have occurred because of increased atmospheric affects related to humidity that may occur during the late summer. However, surface and subsurface temperatures during this time may not have been the same. Further, during this time the correlation between the logger and satellite temperatures becomes non-significant which may be because upwelling events were shorter (mean=5.33 days; s.d.=0.58; n=3). This short duration may not have allowed enough time for cool subsurface waters to mix with the surface before being withdrawn back into deeper waters. Indeed, I encountered the highest number of thermoclines or patches of cold water when scuba diving at Pepper Park during August.

Regression analysis revealed that the wind stress vector having the strongest relationship ($r^2 = 0.09459$, $p < 0.01$) with seawater temperature was the longshore component 127°–307°. Figure 4 shows time-plots of the exponentially-filtered, longshore component of wind stress and Pepper Park bottom seawater temperatures. Negative values in the upper plot indicate longshore stress to the Northwest, which is upwelling favorable. Results show that during most of the summer, wind stress is upwelling unfavorable. However, four times during the summer (June 2, 9–10, and 19–24; August 6–8) winds were upwelling favorable although generally weak in strength. Only one of the upwelling events recorded corresponded in time to a period of upwelling-favorable wind stress (June 19–24).

In summary, six upwelling events occurred with minimum temperatures values within 16–22.5°C. While there were numerous reports of similar events occurring along the east Florida coast (Martin, 2003; Reed, 2003), these results may not necessarily reflect the exact same patterns as observed at other locations, because upwelling events can be very localized (Smith, 1983; Pitts, 1993). The most intense of the observed upwelling events occurred from 19–26 July. Early summer upwelling events generally were longer than those during late summer. Seawater temperatures from the *in situ* logger and satellite estimates were most similar during early versus late summer. This may be because the longer upwelling events in early summer allowed for more time for surface and bottom waters to mix and become less stratified. Finally, winds were generally not upwelling favorable during the summer yet may have played a supplementary role in producing some of the upwelling events particularly during mid-June.

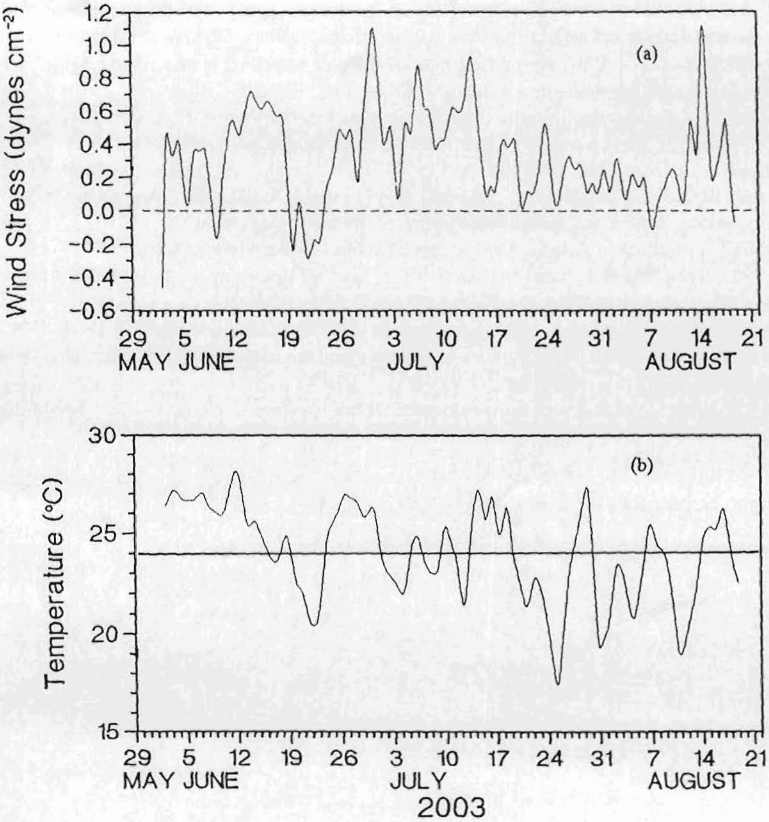

FIG. 4. Time-plots of exponentially-filtered, longshore component of wind stress (dynes/cm^2) (a) and Pepper Park seawater temperatures (b) from May 29 to August 21, 2003. Negative values in the top plot indicate upwelling-favorable winds. The line in the bottom plot represents the threshold temperature for an upwelling event.

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