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Red tide evolution in the Mazatlán Bay area from remotely sensed sea surface temperatures

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RESUMEN

En este artículo se presenta la evolución de un evento de marea roja ocurrido en la bahía de Mazatlán, localizada al noroeste de México, durante febrero de 1996. Las imágenes de temperatura superficial del mar (TSM), obtenidas mediante el radiómetro avanzado de muy alta resolución (AVHRR), mostraron una temperatura superficial inicial relativamente alta de 24°C en la zona costera, seguido de un decremento abrupto de 2.5°C debido a un enfriamiento eólico. Inmediatamente se restablecen las condiciones cálidas en la región. Las imágenes de satélite muestran buen potencial en el análisis de los procesos oceánicos de corto plazo responsables del desarrollo y comportamiento de las mareas rojas. La resolución espacial de 1.1 km del sensor AVHRR fue satisfactoria en latitudes cercanas a los 23° N.

PALABRAS CLAVE: Mareas rojas, temperatura superficial del mar, imágenes AVHRR.

ABSTRACT

The evolution of a red tide episode in Mazatlán Bay, Mexico, during February 1996 is described from images of sea surface temperatures (SST), obtained from the advanced very high resolution radiometer (AVHRR). An initial nearshore high surface temperature of 24°C was followed by a sharp decrease of 2.5°C due to wind cooling. Finally, a warmer condition was re-established at the nearshore region. The sequence of satellite images showed potential for identifying short-term oceanic processes responsible for the development and behaviour of red tides. The 1.1-km spatial resolution of the AVHRR was adequate for latitudes around 23° N.

KEY WORDS: Red tides, sea surface temperature, AVHRR imagery.

INTRODUCTION

When water temperature, salinity, and nutrients reach certain levels, a massive increase in the number of dinoflagellate or ciliate algal groups occurs. The resulting reddish - brown discoloration of seawater is known as a r*ed tide*. Many kinds of marine life can be affected, for the dinoflagellates produce a neurotoxin that affects muscle function in susceptible organisms. Humans may also be affected by ciguatera, from eating contaminated fish, and by paralytic shellfish poisoning, or PSP, from clams, mussels, and oysters (Kao, 1966). Hence the importance of timely identification of the location and extension of red tides.

Remote sensing of sea surface temperatures is a useful tool in studies of bloom dynamics of the red tides. SST images have been used to locate and track fronts, water masses, and other physical features where phytoplankton accumulates (Peláez, 1987). It is a powerful technique for studying the distribution of red tide organisms over larger areas and shorter time scales than is possible with ship-based sampling (*e.g.* Muñoz *et al.*, 1991; Keafer and Anderson, 1993).

In Mazatlán Bay no red tide events have previously been studied with remote sensors. Red tides are frequent, although ephemeral, during the winter - spring period. They are produced mainly by the protozoon *Mesodinium rubrum* and the toxic dinoflagellate *Gymnodinium catenatum* (Cortés and Nuñez, 1992).

We follow the evolution of the thermal conditions of the sea for a red tide event in Mazatlán Bay through NOAA satellite imagery, using a model of the physical mechanism involved.

RED TIDES IN MAZATLAN BAY

Mazatlán Bay is on the Pacific coast of Sinaloa, northwestern Mexico (Figure 1). Circulation is governed by oceanographic processes occurring at the entrance of the Gulf of California, a triangular area between Cape San Lucas, Mazatlán and Cape Corrientes. It is a highly dynamic zone, due to the confluence of the Pacific and Gulf of California waters (Griffiths, 1968). The region has an approximate depth of 3000 metres and a complex thermohaline structure of

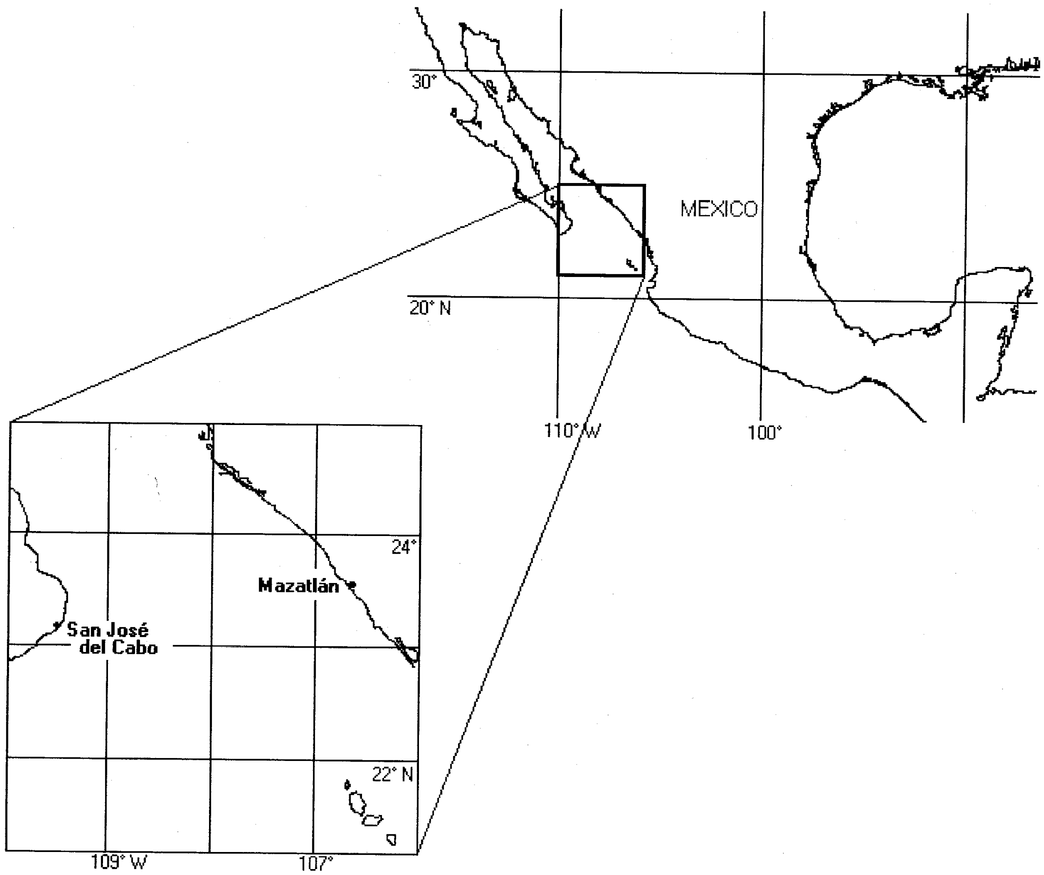

Fig. 1. Location of Mazatlán Bay in north-western Mexico.

eddies, fronts and intrusions originated by the confluence of three currents (Alvarez and Lara, 1991):

a) The California current characterised by cold water of low salinity (34.5 ppt), which flows southwards along the west coast of Baja California peninsula.

b) The Pacific current characterised by temperate waters of intermediate salinity (34.6 - 34.85 ppt), which flows northwards from the south-east.

c) The Gulf of California current which provides warm and highly saline (> 34.9 ppt) waters, flowing southwards through the gulf.

The regional climate is monsoon-like. Cold and dry continental winds from the north-west dominate the winter - spring period (November to May). The rest of the year humid oceanic winds from the south-east produce more stable weather conditions. The mean sea surface temperature in February is μ = 21.48°C with a standard deviation $\sigma = \pm$ 1.86°C (Secretaría de Marina, 1984). Mazatlán Bay is subjected to a semidiurnal tide with a maximum height of 1.3 metres.

In wintertime the general circulation at the entrance of the gulf is towards the SE describing a superficial anti-cyclonic gyre, due to geostrophic flow (Rosas-Cota, 1977). In summer and autumn the circulation is towards the NW and the gyre inverts (Alvarez-Sánchez, 1978).

Dinoflagellate blooms in Mazatlán bay are common from November until May but are generally absent during the summer months (Cortés and Núñez, 1992). The continental shelf waters are fertilised by nutrients as a result of recycling, horizontal advection, relatively small-scale anthropogenic inputs and upwelling events which are particularly frequent from March until June (Mee *et al.*, 1985).

OBSERVATIONS

Twenty-four satellite overpasses were selected and analysed for monitoring SST variations related to the initiation, maintenance, and dissipation of a red tide event. These overpasses include SST measurements performed during the night, morning and afternoon. Thus, some measurements may correspond to a same day. Satellite data were obtained during February 1996 by the AVHRR onboard the NOAA-12 and 14 satellites, which have a temperature resolution of 0.1° C and can yield reliable temperature variations over this area. AVHRR data were processed using the Terascan system (SeaSpace Corporation, California, USA), by applying a multichannel algorithm (Split - Window) proposed by McClain *et al.* (1985), as follows:

$$T_s = 1.017342T_{11} + 2.139588(T_{11}\text{-}T_{12}) + 0.779706$$

where T_s stands for the SST value, and T_{11} and T_{12} represent the brightness temperatures in the AVHRR infrared channels 4 and 5, respectively. Nine images corresponding to afternoon daytime overpasses were processed. Since NOAA-14 is the satellite collecting data at this time of day, coefficients appearing in the equation correspond to this satellite in the split-window algorithm.

Red tide information was obtained from the Mazatlán station of the Instituto de Ciencias del Mar y Limnología (ICMyL) of the Universidad Nacional Autónoma de México (UNAM). Sampling was carried out south of Mazatlán as described by Cortés *et al.* (1995). They collected water samples for identifying and quantifying dinoflagellates and protozoa species responsible for red tides, following a methodology described by Cortés and Nuñez (1992). Tidal information was obtained from the Servicio Mareográfico of UNAM.

RESULTS AND DISCUSSION

Data at Mazatlán indicated the occurrence of a red tide event from February 19 to 22, 1996. SST data show relatively high temperatures at the beginning of the month (24.5°C on average), followed by a sharp decrease by 2.5°C in mid February and a rapid increase to 24° C at the end of the month. This coincided with the red tide event. The average mean temperature measured between 1920 and 1980 during February in Mazatlán Bay is $\mu = 23.9$°C ($\sigma = \pm 0.67$) (Secretaría de Marina, 1984). SST data obtained from AVHRR images for some days in February are shown in Figure 2.

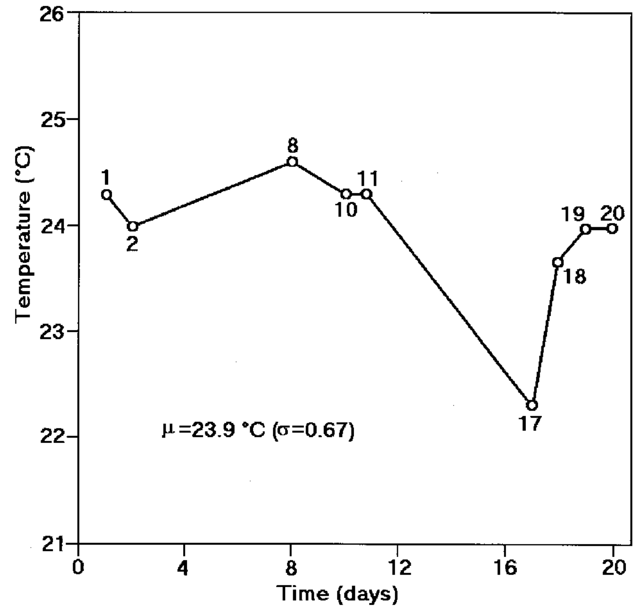

Fig. 2. Diagram showing the SST variations during February 1996, with a mean value (μ) of 23.9° C and a standard deviation (σ) of 0.67. Numbers indicate the day of the month.

The oceanographic processes related to red tides are not well understood. However, there is an association between upwelling incidents and red tides along the Pacific coasts of California, Baja California and Peru (Dugdale, 1979). There is some question as to whether or not, by diurnal migratory behaviour, dinoflagellates can take up nutrients from below the euphotic zone in places where it is relatively shallow (Mee *et al.*, 1986). The red tide event described here is in the concentration stage, accordingly to the dynamics proposed by Steidinger (1983), and supported by Seliger (1993).

Let us describe the set of SST maps showing thermal conditions in the area. The temperature ranges from 21°C, representing relatively cold waters, to 27°C characterising warmer waters. Land and clouds are masked in black. Thermal conditions have been coupled to Seliger's physical model by associating temperature variations to the observed physical and biological effects.

Figure 3 (February 8) shows a warm water mass along the Mazatlán coast (yellow tones). This thermal nearshore system, produced by solar warming, is characterised by a warm surface layer, few nutrients and a deep nutricline, and can be associated to stratified waters. It can be associated with the Pacific current flowing northwards. The confluence of the California and Gulf of California currents is also seen near San José del Cabo.

Under conditions of increased and sustained alongshore winds, an upwelling event may develop. This effect brings to the surface, in the nearshore region, saltier, colder, and nutrient - rich bottom waters. The cooling episode is seen in Figure 4 (February 17). It shows relatively cold waters near Mazatlán Bay with temperatures around 22°C (violet-blue tones). The cooling process is apparent mainly near the coast, both off the continent and east of Baja California peninsula. It is due to an external agent such as wind, rather than to oceanographic conditions. If the wind is persistent, the higher density, upwelled waters, will be subject to wind - driven surface Ekman transport (Seliger, 1993). Mazatlán Station (Servicio Meteorológico Nacional, 1996) reported that typical winter winds from the northeast (227.5° on average) prevailed in the region (Figure 5). An instability develops be-

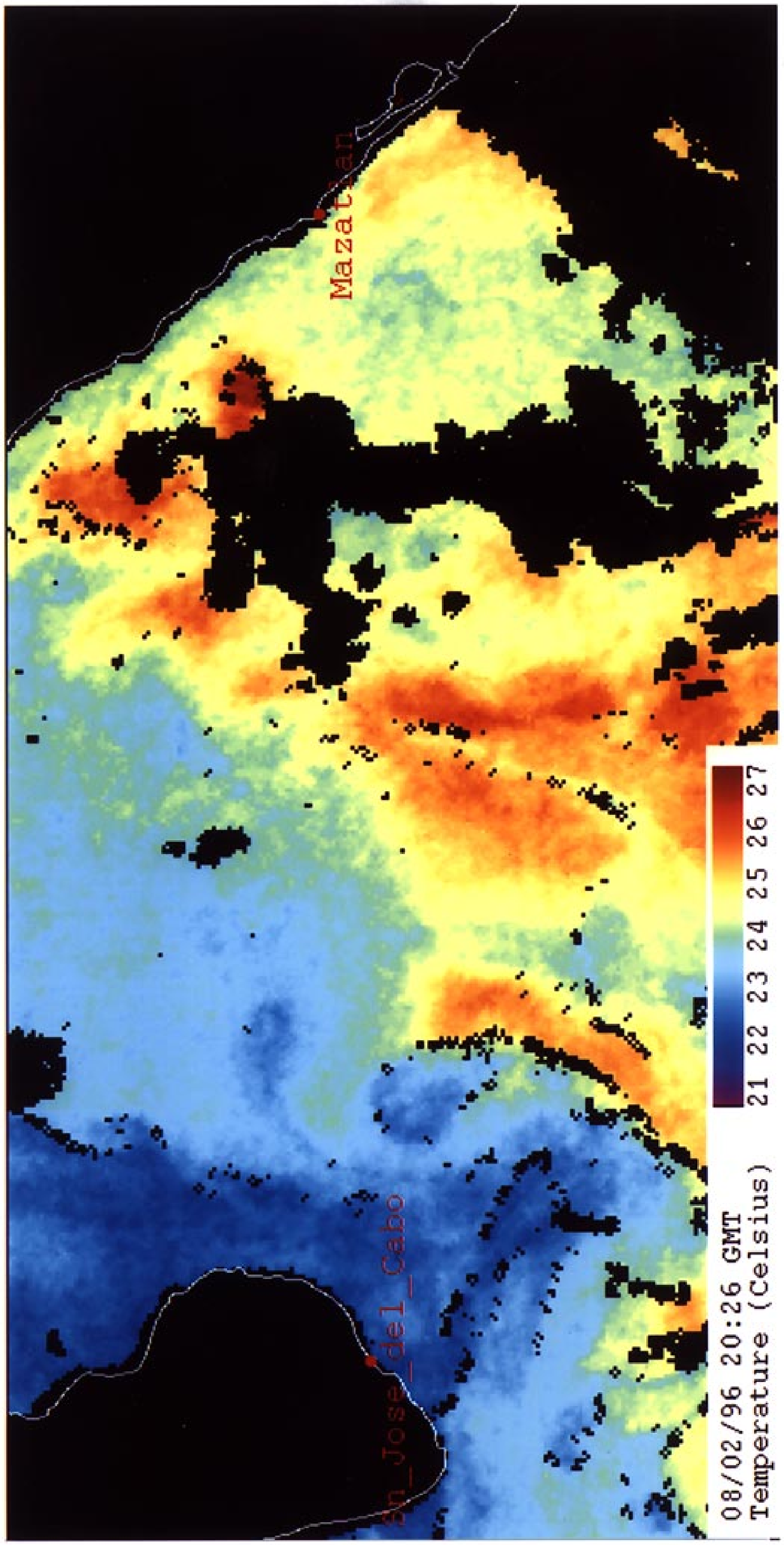

Fig. 3. NOAA SST image from February 8, 1996 at 14:26 hrs. (local time). Warm water (red tones) implies a thermally stratified nearshore system around Mazatlán Bay.

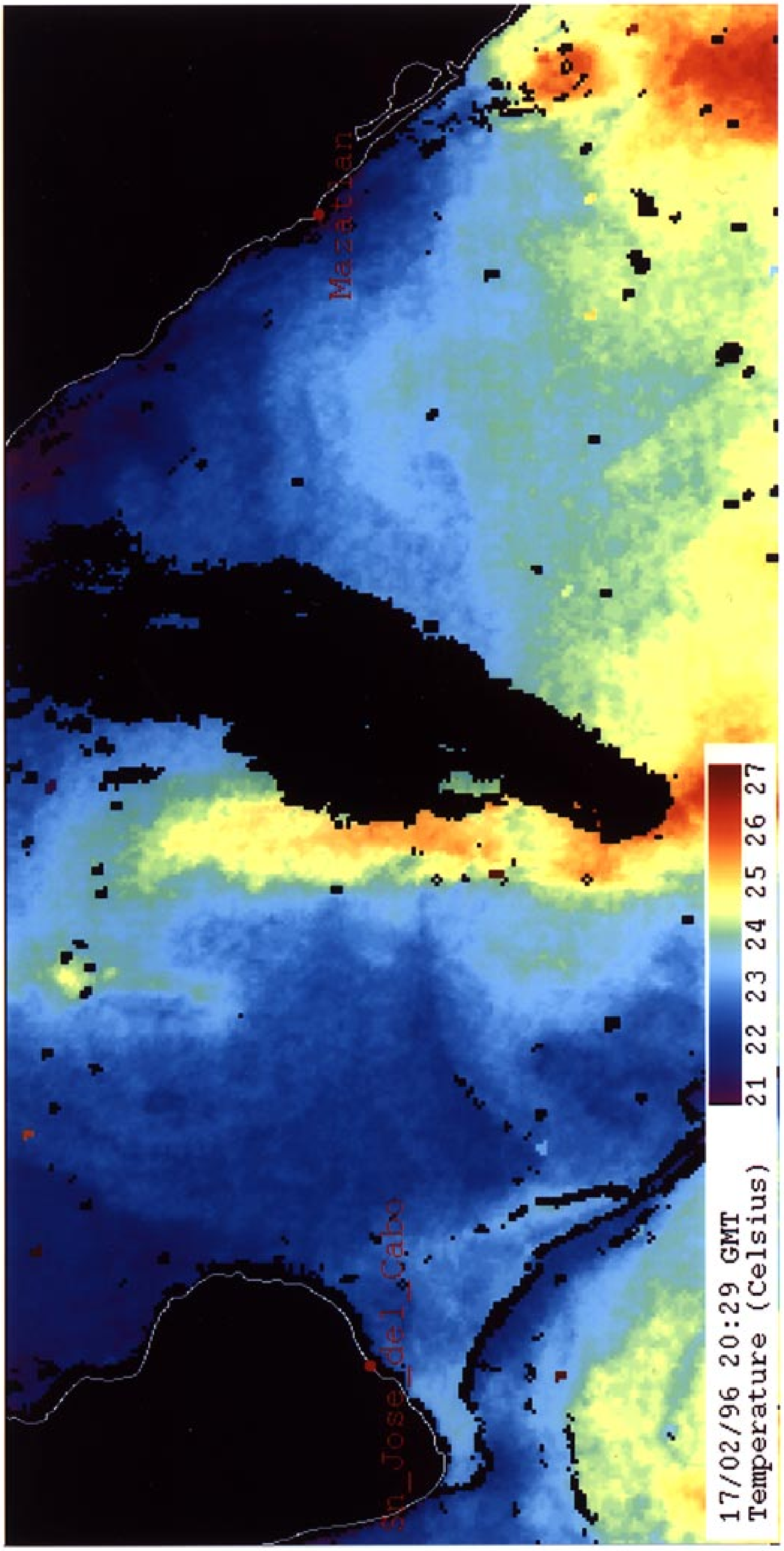

Fig. 4. NOAA SST image from February 17, 1996 at 14:29 hrs. (local time) during a cooling episode. Colder waters (blue tones) along Mazatlán Bay suggest a nearshore upwelling.

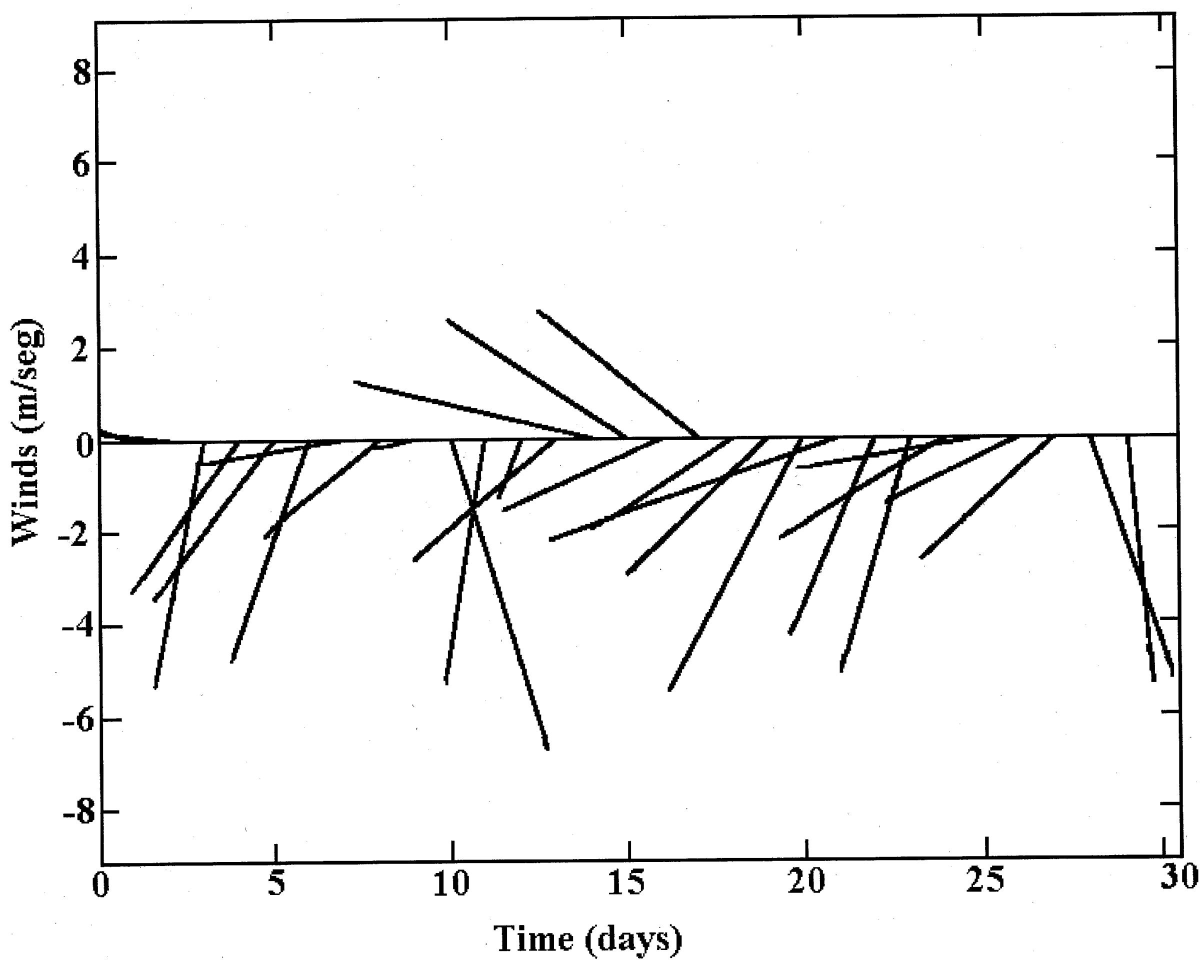

Fig. 5. Coastal winds measured at Mazatlán station. The diagram shows the prevalence of continental north-eastern winds which are typical in wintertime.

cause the Ekman layer is now the upwelling water, which is denser than the warmer and less saline waters seaward of the upwelling region. As the denser Ekman layer sinks below the lighter waters, an intermediate-density layer forms, resulting in a shallow density gradient between adjacent upwelling waters, on one side, and the surface waters at the frontal interface. Thus, there is nutrient mixing into the frontal interface. With continued wind, upwelled, nutrient-rich waters are mixed into the nearshore upwelling region (diatom dominance) and move seaward by Ekman transport, thus forming a shallow, density-stratified layer seaward of the upwelling region. This condition is suitable for dinoflagellate and protozoa dominance.

When the wind subsides, insolation re-establishes stratification in the nearshore region. The resulting increment in temperature can be seen in Figure 6 (February 19). Temperatures at Mazatlán are colder than the surroundings, but a warm intrusion (yellow-orange tones) from the Pacific current may be observed to develop. The new warmer conditions coincide with the red tide occurrence.

Sudden changes of temperature may destroy some algal species while not affecting others (Lee, 1992). We assume that in early February a number of different algal species were present off the coast of Mazatlán. After the sharp cooling episode some algal groups disappeared, allowing temperature-resistant species such as *Gymnodinium catenatum* to flourish virtually without competition. However, in order to validate this hypothesis more experimental work is needed.

The sequence of events just described suggests a major role of the cooling process in triggering red tide events, in agreement with Seliger's model.

Supplementary data suggest that the red tide event occurred just after spring tide. There are some studies relating spring - neap tidal mixing to red tides (e.g. Balch, 1986).

The extent of the anomalous temperature region may yield a preliminary estimate of the extent of the red tide area.

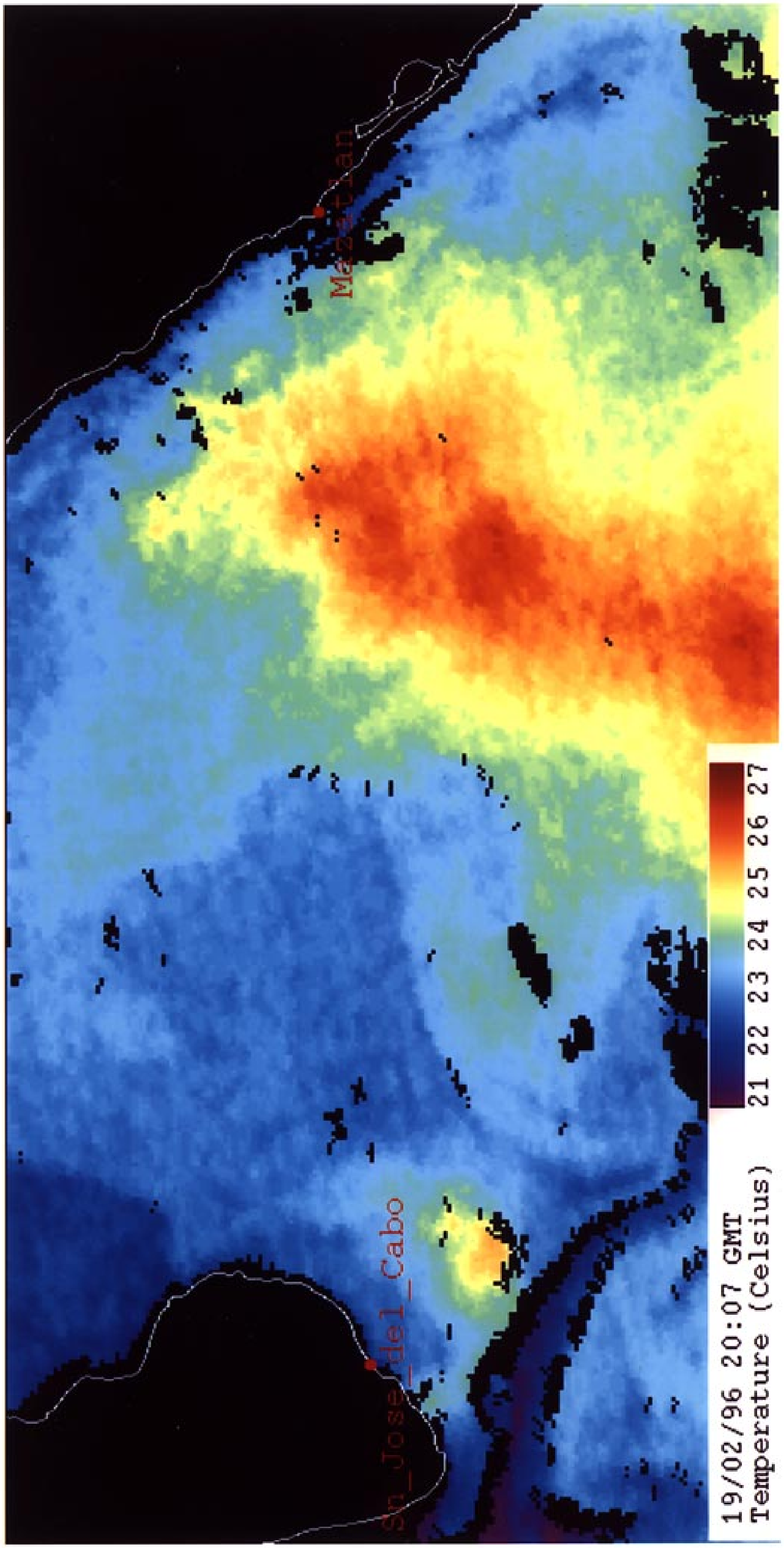

Fig. 6. NOAA SST image from February 19, 1997 at 1407 hrs. (local time). This image shows an increment in temperature (red tones) which is correlated with the red tide episode.

CONCLUSIONS

Our results show that remotely sensed sea surface temperatures have potential for monitoring red tide bloom development. The SST maps show variations which can be associated to meteorological and oceanic processes, such as upwellings, which may be responsible for the development and behaviour of red tides. The 1.1-km spatial resolution of the NOAA-AVHRR was satisfactory for this type of work at latitudes around 23° N. The most obvious limitation to the use of SST imagery is the number of good images, restricted because of cloud coverage. It is important to use supplementary data (meteorological and hydrographic) plus *in situ* sampling for validating and supporting satellite data interpretations.

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