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Wind driven upwelling in the Gulf of Nicoya, Costa Rica

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Abstract. Using satellite sensor data and information from local meteorological stations, a transient upwelling event in the Gulf of Nicoya, Costa Rica, has been observed during the period 6–8 March 1997 in coincidence with strong upwelling in the Gulf of Papagayo. Strong north-easterlies funnelled through two mountain passes are responsible for this feature, observed intermittently between November and March.

1. Introduction

Wind-driven upwelling along the Central American Pacific coast has been studied since the pioneering studies of Hurd (1929) and Roden (1961). From November to March, winds associated with the high pressure systems in the Gulf of Mexico and the Caribbean Sea are blocked by a mountain chain (2000–3000 m) extending from the south of Mexico to Panama except for four passages: Isthmus of Tehuantepec in México, the Gulf of Fonseca in Honduras, Lake Nicaragua, and the Panama Canal. Strong wind jets through these passages blow offshore on the Pacific inducing a fast oceanic response lowering sea surface temperature (SST) up to 10° C within a day (Barton *et al.* 1993, Trasviña *et al.* 1995).

During November–March, small cooling events are observed intermittently in the Gulf of Nicoya (GN), Costa Rica, lasting for two to three days. The GN (10° N 85° W) is a small body of water of 1550 km^2 which plays an important role in the local economy, including tourism and fishing activities. Cold waters and a saline front in the GN have been reported in past field studies without a clear explanation of their origin. Discharge from the Tárcoles River and the presence of Negritos Island, which produces a wall effect over the waters that flow through the eastern part of the GN coming from the open sea, have been held responsible for the distribution of temperature and salinity in this area of the GN (Klemas *et al.* 1983, Voorhis *et al.* 1983).

Using Advanced Very High Resolution Radiometer (AVHRR) data several cooling events were identified in the GN during the first three months of 1997. The SST

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field for the event of 7 March is analysed together with meteorological conditions and topographic characteristics of the zone to show that the prevailing winds during the dry season (November–April), funnelled through gaps in the mountain system, produce upwelling in the GN.

2. Data and methods

We used 1° spatial resolution wind data derived from the NASA Scatterometer (NSCAT) flying on the Japanese ADEOS Mission (which ended June 1997). See the appendix of Chelton *et al.* (2000a) for details of the techniques applied to obtain the NSCAT winds.

AVHRR data acquired at the Universidad Nacional ground station (9° 58′ N, 84° 29′ W), Costa Rica, were used to obtain 1 km spatial resolution SST fields using the MCSST algorithm (McClain *et al.* 1985). Five local meteorological stations provided wind, pressure and temperature data.

3. Results and discussion

Several cooling events were observed during the first three months of 1997 in the GN, which were also noted during the same season in 1996. Figures 1 and 2 show, respectively, the AVHRR SST and NSCAT winds for the event of 7 March. SST

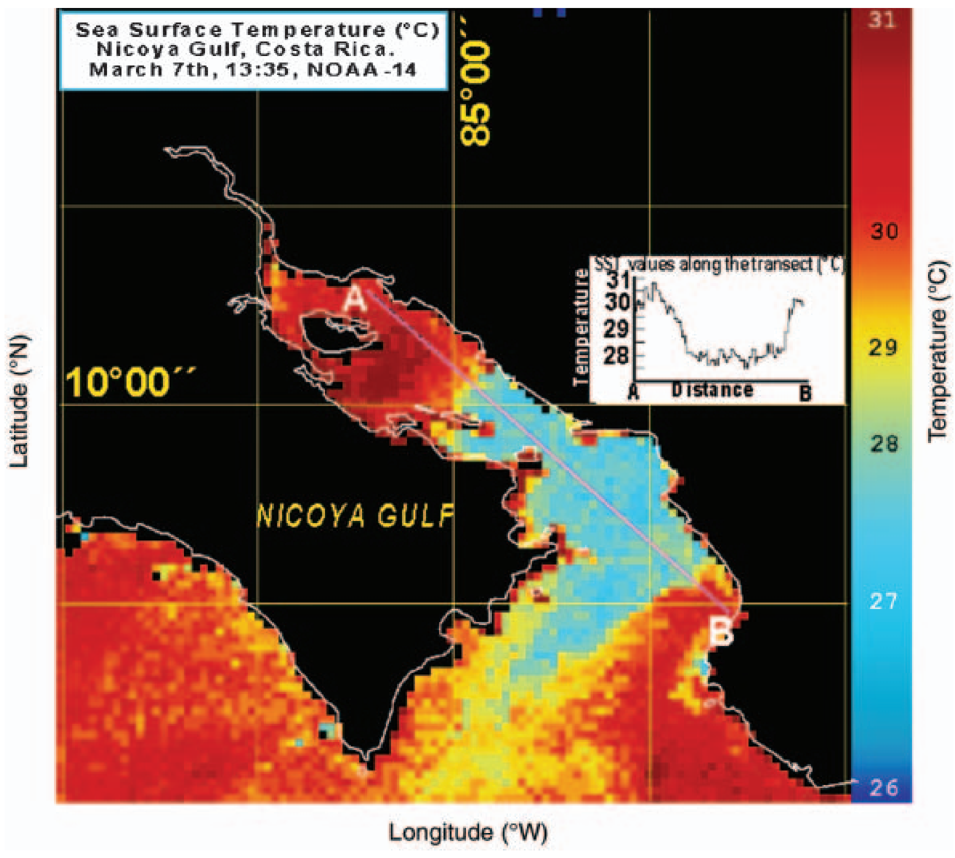

Figure 1. SST on the Gulf of Nicoya (7 March 1997).

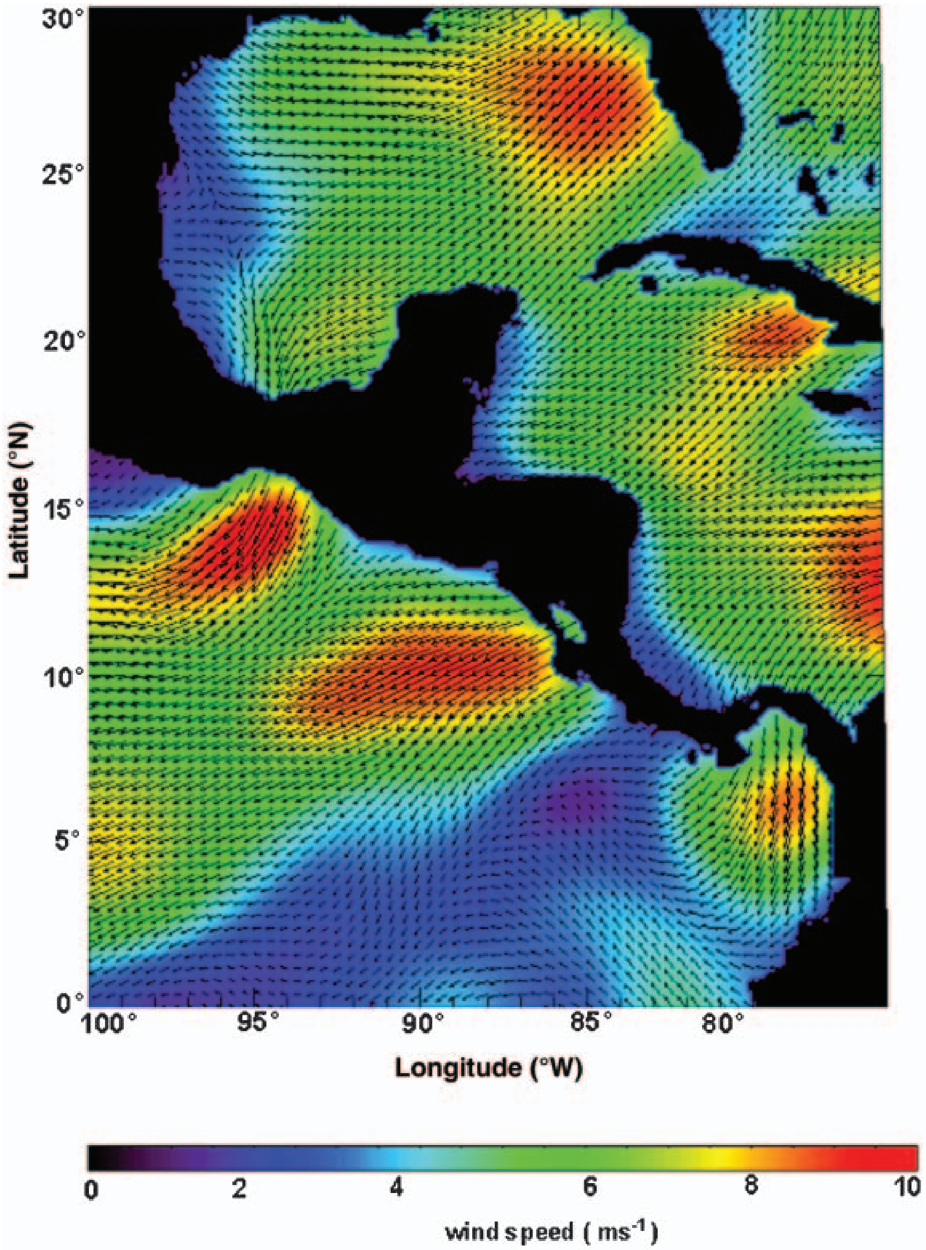

Figure 2. NSCAT winds (7 March 1997).

decreased by up to 3° C over an area of about 500 km^2 within a plume that extended from the eastern boundary of the GN in a northeast–southwest direction toward the mid-gulf (figure 1). At the beginning of March 1997, moderate offshore winds were well established over the Gulfs of Papagayo and Panama. The trade winds over the Caribbean remained strong throughout this period and the Papagayo and Panama jets continued to blow offshore with the Papagayo winds extending deep into the Pacific (Chelton *et al.* 2000a, 2000b) as shown in figure 2. On 7 March the north-easterly winds intensified at Orotina, near the Gulf of Nicoya, compared to the Central Valley (San Jose and Pavas) and Puntarenas winds (figure 3).

The conditions outlined above result from the interaction between the synoptic flow and the pronounced orography of Costa Rica. During the Northern Hemisphere winter the displacement of polar air towards the Gulf of Mexico and the Caribbean increases the meridional pressure gradient and the trade winds in the lower troposphere of Central America generating a number of features in the mesoscale flow. On the Pacific coast, leeward of the easterly Caribbean flow, there are calm regions

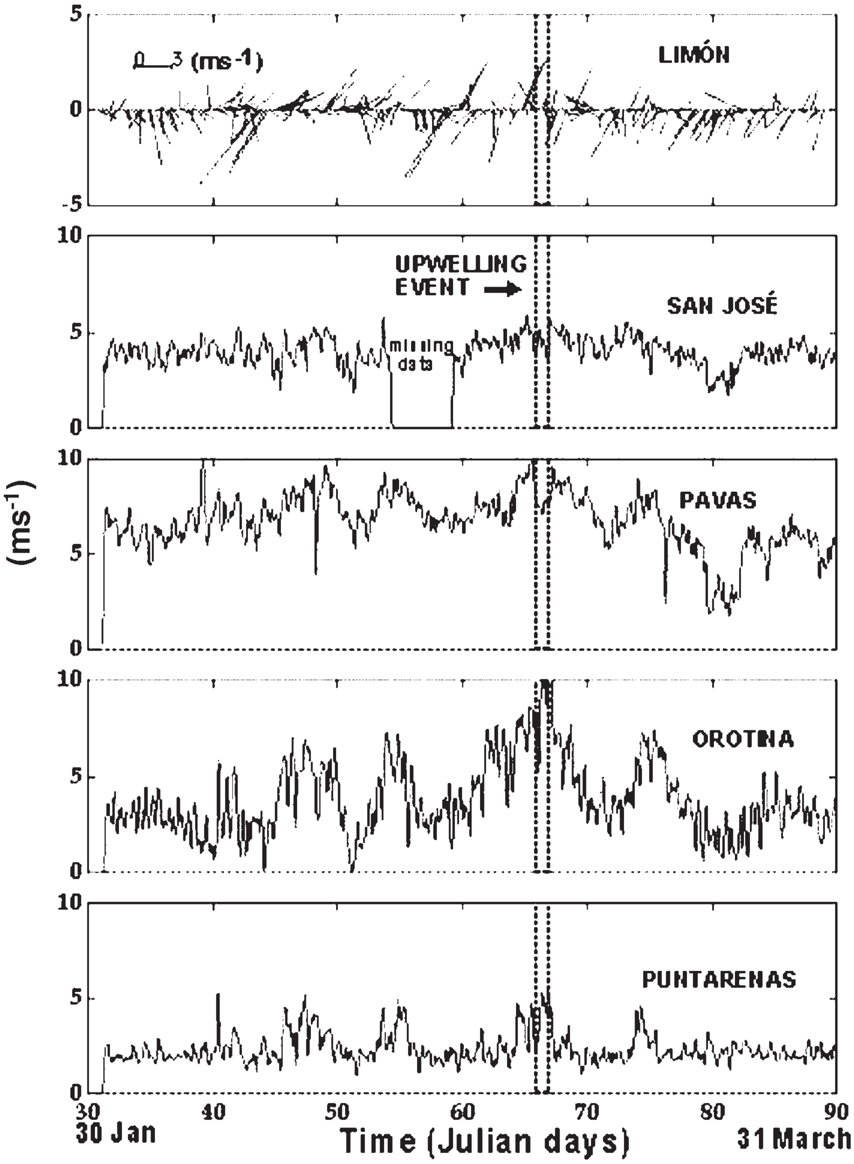

Figure 3. Wind velocity at Limón and north-easterly wind speed at four additional stations during February and March. Units are ms^{-1}. Velocity at Limón is toward the east and north in the positive X and Y directions, respectively.

where the mountain chain is higher, deflecting the synoptic north-easterly flow around the mountain peaks and through the passes (Grandoso *et al.* 1982).

The Talamanca range, in the southern part of Costa Rica, is an obstacle with several peaks of height above 3000 m for which the minimum altitude is over 2000 m. The Cordillera Central has maximum heights below 3000 m, with a gap of less than 1400 m called Paso de la Palma. The ranges in the northern part of the country are lower, with some peaks ranging up to 2000 m and with several passages between 500 and 1000 m. As shown in figure 4, the orographic system has several discontinuities making the surface wind field variable along the Costa Rican Pacific coast.

Such winds are driven by tradewind variations extending from the Caribbean Sea into the eastern tropical Pacific. These wind pulses are in quasigeostrophic balance and are strongly correlated with the meridional pressure gradient upstream of the Papagayo gap (Chelton *et al.* 2000b). The winds are very strong in the northern part of Costa Rica, with speeds between 10 and 30 km h^{-1} and gusts reaching 90 km h^{-1}. When crossing the mountain ranges the flow produces a foehn effect over Guanacaste and the Central Valley with descending winds (Coen 1964, 1983, Grandoso *et al.* 1982). There is also historic evidence of volcanic ash from eruptions of the Irazu volcano (9° 58′ N, 83° 50′ W) in November 1918 and March 1963 being transported easterly through the Tárcoles River basin and reaching the Nicoya peninsula. In the southern part of Costa Rica, the high Talamanca Range produces

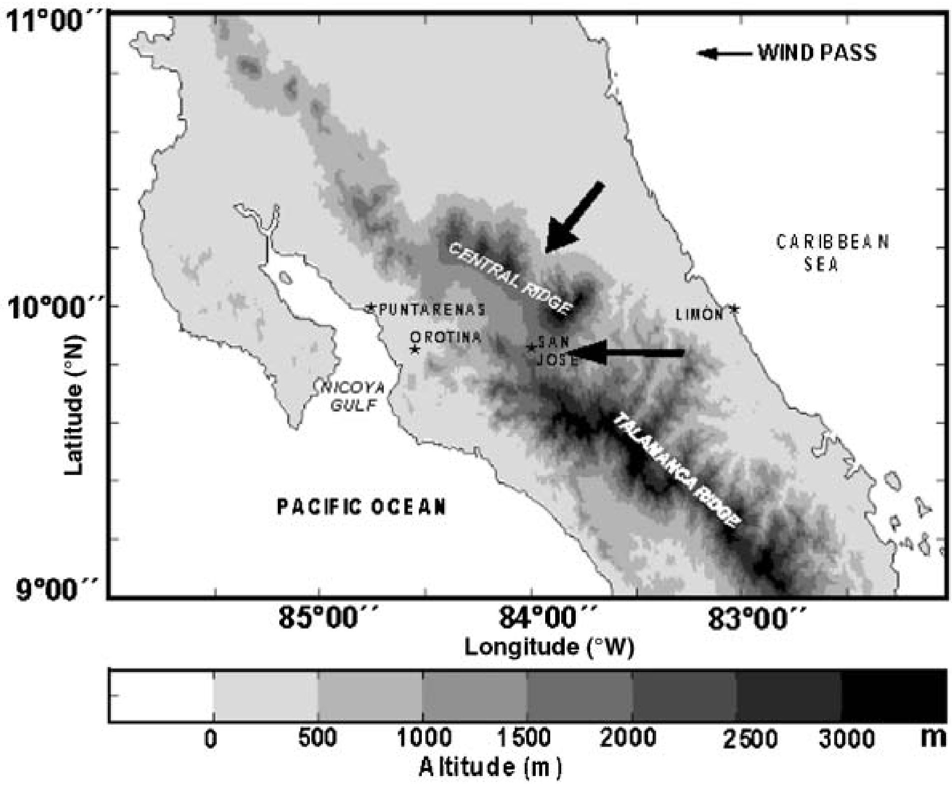

Figure 4. Costa Rica topographic map showing mountain passages.

a rotor (vortex) on both slopes, and consequently the wind field over the Pacific coast in this region is very weak (Coen 1983).

The 7 March NSCAT winds (figure 2) are consistent with the conditions outlined above and we interpret the cooling observed in the GN as the result of upwelling induced by easterly winds funnelled by the mountain passes of 800–1000 m elevation along the basin of the Virilla-Tarcoles River, which empties onto the opening of the Gulf of Nicoya. We simulated the event of 7 March by forcing the Princeton Oceanic Model with wind data from the Orotina weather station to test our interpretation (Kress *et al.* 1997). In spite of a slight southern displacement of the upwelling centre (figure 5), our simulation replicates well ($\pm 1^{\circ}$C) the observed SST field and is consistent with wind forcing as the driving mechanism for the cooling events in the GN.

4. Biological importance

Besides the fertilization of the GN by the discharge of several rivers, the upwelling events described in this study may account for the extraordinary productivity of the GN. Furthermore, the introduction of subsurface, nutrient-rich waters into the upper layer might be important to sustain a healthy food-web in this ecosystem.

The GN receives pollutants and nutrients from sewage, industrial and agricultural activity through river discharges, and the composition of the nutrients introduced by the rivers is affected by human activity, favouring the occurrence of red tides in the GN. Conversely, naturally occurring ratios of nutrients in upwelled waters may

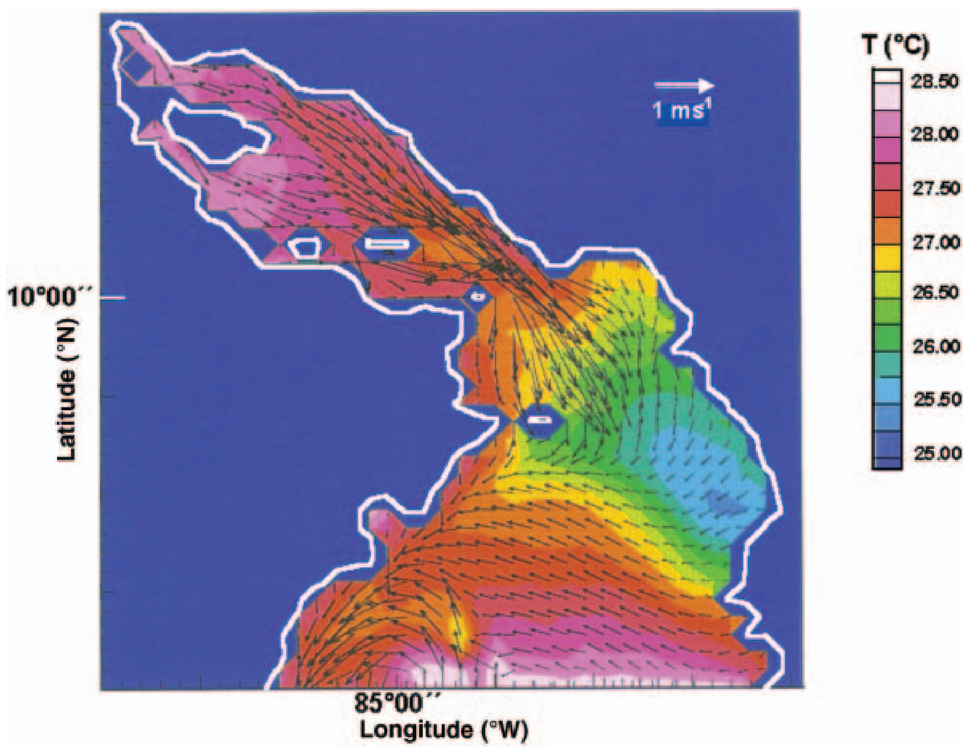

Figure 5. Water velocity and temperature in topmost model layer (7 March 1997) (Kress *et al.* 1997).

sustain non-harmful algal production which can be exported to higher trophic levels more efficiently.

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