Satellite Detection of Upwelling in the Gulf of Tehuantepec, Mexico

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ABSTRACT

The daily acquisition of thermal infrared imagery from the NOAA-2 satellite permitted the delineation and monitoring of a series of upwellings in the Gulf of Tehuantepec during December 1973. Following the upwelling, a large anticyclonic gyre was detected in the imagery as the coastal currents returned to their historical positions.

1. Introduction

The Gulf of Tehuantepec, Mexico, is a heavily-fished area noted for strong winter upwellings that lead to sea-surface temperatures several degrees lower than elsewhere along the coast of southern Mexico and Central America. December 1973 was a month marked by a series of such upwellings, and the imaging radiometers aboard the NOAA-2 environmental satellite (now superseded by NOAA-3) provided a number of unique infrared images of the sea-surface temperature patterns before, during and after their occurrence.

The NOAA-2 and NOAA-3 satellites are in near-polar, sun-synchronous orbits at an altitude of 1460 km. Approximate local observation times are 0900 (daylight) and 2100 (night). These satellites carry two types of imaging radiometers, a Very High Resolution Radiometer (VHRR) and a Scanning Radiometer (SR). The VHRR has visible (0.6–0.7 μm) and thermal infrared (10.5–12.5 μm) channels collecting data with a resolution of 1 km at nadir. The SR is similarly equipped (0.5–0.7 and 10.5–12.5 μm, with resolutions of 4 and 8 km, respectively). Both radiometers have provision for onboard calibration of the measurements. The VHRR is primarily a direct-broadcast sensor system with very limited onboard data storage capacity. The SR, however, has sufficient magnetic tape data storage capacity to provide global coverage twice daily. The VHRR and SR images are composed of successive and contiguous scan lines generated by the movement of the satellite over the earth’s surface combined with the scanning motion of the instruments in a direction perpendicular to the track from horizon to horizon. The IR radiation information can be displayed pictorially as gray-tone imagery such that cooler features are shown as light areas (less radiant energy reaching the radiometer) and warmer areas are represented by darker tones.

The Gulf of Tehuantepec lies immediately south of the Isthmus of Tehuantepec, a major break in the Sierra Madre range of southern Mexico (Fig. 1). At the narrowest point of the Isthmus, where it is barely 220 km wide, there is a gap of nearly 40 km in the mountain range. In this area the maximum elevation is approximately 250 m above sea level.

During the dry and windy season, from November through April, cold winds originating in the Gulf of Mexico anticyclone are channeled by this topographic feature through the Isthmus over the eastern tropical Pacific Ocean (Roden, 1961). During these periods of high atmospheric pressure over the western Gulf of Mexico, the pressure “head” finds a “release” through this break in the Sierra Madre (Strong et al., 1972). These strong regional northerlies, locally referred to as “Tehuantepecers,” are felt several hundred kilometers to seaward (Hurd, 1929; Roden, 1961; Strong et al., 1972). These winds effect a movement of the surface water to the south, causing entrainment of water from the sides and upwelling of water from below; a significant amount of vertical mixing occurs along the core of maximum winds as well. These effects lead to a marked decrease in the surface temperatures in the Gulf of Tehuantepec as compared to the surrounding
waters. When the strong north wind moderates or ceases entirely, normal circulation features are re-established and southward transport ceases. The historical December current system consists of easterly and westerly coastal currents that converge in the western part of the Gulf, then turn seaward to become part of an accelerating westward current 200 km offshore (Fig. 1).

2. Case study

a. Upwelling

There were five separate Tehuantepecers (and associated upwellings) during December 1973. The first one began on 29 November and lasted through 3 December. Fig. 2 consists of nighttime and daytime NOAA-2 VHRR thermal IR images of this single continuous upwelling. According to the Inter-American Tropical Tuna Commission, which is charged with studying and managing the yellowfin and skipjack tuna resources in the eastern tropical Pacific Ocean, this was the longest Tehuantepecer noted in recent years (Miller, 1973, personal communication) as the high pressure system remained in the western Gulf of Mexico for several days longer than usual. This Tehuantepecer was followed quickly by four others of shorter duration (7–9 December, 10–11 December, 16–18 December, 20–22 December); the series finally ended on 22 December. Each of the Tehuantepecers was characterized by northerly winds averaging 10 m s\(^{-1}\); maximum wind velocities often exceeded 20 m s\(^{-1}\). (During another norther in late February 1974, one ship 3 km offshore in the Gulf recorded a sustained wind of 50 m s\(^{-1}\) with gusts to 60 m s\(^{-1}\) and suffered extensive sandblasting.) Surface temperatures from ships in the area of upwelling (light area in Fig. 2) ranged from 17–22°C; normal sea-surface temperatures for December are 25–30°C (Roden, 1961). These higher, more characteristic temperatures were noted by ships in the areas surrounding the upwelling (dark areas in Fig. 2). These temperatures are in general agreement with the digitized data provided by the SR aboard NOAA-2. Historical data (Wyrski, 1964) indicate that the Gulf of Tehuantepec has a permanent shallow thermocline, and since the mixed layer depth rarely exceeds 25 m, cooler water of 22°C or less would need to be brought up from only 35–40 m at this time of year. There would be no problem in mixing water to that depth under abnormally high wind conditions. As reported by ship observations, sea-surface temperatures along the maximum wind axis in the upwelling were consistently cooler than the air temperatures by 1–2°C during each Tehuantepecer. The upwelling widens southward for 500 km (Fig. 2), indicating that outward diffusion of water was taking place along the wind axis. The
distinct western boundary of the upwelling (Fig. 2) coincides with the position of the Tehuantepec Submarine Ridge, suggesting topographic control of the limits of upwelling.

b. Gyres

A readjustment of nearshore currents and associated surface temperatures began on 23 December. After three weeks of nearly continuous northers and resulting upwellings, the winds effectively ceased. From a previous mean velocity of 10 m s\(^{-1}\) the winds in the Gulf of Tehuantepec became very light, variable in direction, and often calm for the remainder of the month— they were conspicuous only in their relative absence.

Fifteen hours had passed from the time the northers fully abated to the time of acquisition of the first VHRR infrared image in the sequence shown in Fig. 3. As a result of the wind cessation, the coastal currents were no longer diverted to seaward by the wind-induced upwelling, and they began a return to the historical average December circulation shown in Fig. 1. During this process a large circular anticyclonic gyre 200 km in diameter developed near the coast in the western part of the Gulf (Fig. 3). The cooler recently-upwelled water became entrained with a clockwise motion into the adjacent warmer water to the north by the readjusting currents and served as a tracer on the infrared imagery. In this area the cool water began to moderate and approach the surface temperature of the surrounding water; this is indicated in Fig. 3 by the intermediate gray tone of the water within the boundaries of the gyre. Progressing through 27 December in the sequence shown in Fig. 3, the warm water began its movement at the northern edge.
Fig. 3. Sequence of alternating daytime and nighttime VHR-R images of southern Mexico and the adjacent Pacific Ocean. The thermal patterns delineate a large anticyclonic gyre immediately west of the Gulf of Tehuantepec.
of the gyre and extended along the eastern margin as it widened and apparently overrode the cooler water. The boundary of the gyre was defined on the imagery by the readjusting currents only as long as there was a thermal contrast detectable by the VHRR-IR sensor. Surface temperatures taken from ship weather observations provided by NOAA’s Environmental Data Service are, for the most part, inconclusive; the patterns so obvious in the imagery (Fig. 3) are not completely brought out by the five-day composite analysis of selected ship temperatures in Fig. 4 (a five-day composite was used in order to permit full coverage of the Gulf of Tehuantepec). The only distinctive feature seems to be the filament of cooler water (20–24°C) that defines the southern margin of the gyre in Fig. 3.

Similar gyres, although smaller and less well-developed, were observed between the five incidences of upwelling whenever satellite coverage permitted. The presence of even moderate northerly winds at these times tended to prolong the upwelling process and to inhibit significant gyre formation. A large gyre also developed in this area after another Tehuantepecer in early March 1974. Because a gyre was observed on several occasions when winds either abated or ceased entirely, it is hypothesized that the gyre is a regular transitional phase between the extreme upwelling events and the normal winter circulation and temperature distribution off the coast of southern Mexico.

3. Conclusions

It is apparent from this brief discussion that the VHRR, with its relatively high (1 km) resolution and daily repeatability, may offer a way to improve the prediction and management of the yellowfin and skipjack tuna resources in the eastern tropical Pacific Ocean. One potential application might be to direct the fleet to possible harvests as indicated by the sea-surface temperature distribution, particularly along water mass interfaces where phytoplankton productivity (and hence feeding activity) is likely to be high.

When increased computer capability becomes available for rectification and mapping of VHRR data, the accuracy and utility of the data and imagery should increase for both oceanographic and fisheries requirements.

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REFERENCES