

Identification of Shallow Submarine Hydrothermal Activity Using Multispectral Satellite Images

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ABSTRACT

Processing of multispectral images allows identification of areas with shallow submarine hydrothermal activity. Temperature data over time were processed based on data from MODIS (Moderate-resolution Imaging Spectroradiometer) images of the Punta Mita area in Mexico, where active hydrothermal vents discharge thermal water at a temperature of 85°C at a 10 m depth. This was done to demonstrate that detectable temperature anomalies on the ocean surface are related to the presence of hydrothermal shallow vents on the sea floor. Results showed that temperature anomalies due to the discharge of hydrothermal fluids at shallow depths are large enough to be observed by satellites. The temperature of the area where submarine vents are located is consistently higher than the surrounding area by at least 1°C. The analysis was performed based on data for 288 days, including daily and seasonal variations that do not mask the temperature anomaly.

1. INTRODUCTION

Sea surface temperature is an important parameter in oceanographic studies, and it is routinely measured using infrared brightness data provided by numerous satellites. However, specific studies require distinct levels of accuracy and spatial and temporal resolution. The information contained in multispectral images has been utilized to determine absolute and relative values of temperature in different water bodies, including oceans and lakes (Anding and Kauth, 1970; McMillin, 1975; Donlon et al., 2007; Trunk and Bernard, 2008; Crosman and Horel, 2009; Merchant *et al.*, 2009). The identification of thermal anomalies is especially important for the exploration of shallow hydrothermal vents, but the restricted area affected by these features requires a spatial resolution of a few hundred square meters and a temporal resolution of at least one day to verify the seasonal and daily variations that may affect the surface temperature and the atmospheric effects.

Most satellites include sensors to detect electromagnetic radiation in the thermal infrared frequencies; however, the atmospheric effects that cause absorption of radiation in these frequencies are difficult to quantify. Therefore, several methods are used to calculate *brightness temperature*, which is computed from the measured emitted radiance (assuming black body radiation). One of the most widely used methods is the split-window technique, in which the brightness temperature is computed for two bands with different amounts of known absorption (Anding and Kauth, 1970). For instance, temperature estimation can be based on the brightness temperature from bands 3 and 4 of the AVHRR images, and on bands B13 and B14 of ASTER images (McLain et al., 1985). This method has

been applied successfully to a large area in western Mexico with the aim of defining an upwelling zone (Galindo et al., 2001).

2. STUDY AREA

Punta Mita was selected as the study area because intense shallow hydrothermal venting occurs there at present. The location of the study area is shown in the map in Figure 1. Hydrothermal activity at Punta Mita consists of fluid discharge (gas and water) at 85°C from a NE-SW-trending fissure that is hosted in basaltic rocks and is partially covered by unconsolidated platform sediments. This activity affects an area of <1 km² at a depth of ~10 m (Prol-Ledesma et al., 2002).

It is located about 500 m off the coast of Punta Mita in the northern part of Bahía de Banderas in the state of Nayarit. The area lies near the NW limit of the Jalisco Block and in the western end of the Mexican Volcanic Belt. It is affected by the tectonic extension that results from the displacement of the Rivera Plate. In this area, anomalously high heat flow values have been calculated (Prol-Ledesma and Juárez, 1986). This high heat flow causes a high geothermal gradient that heats deeply penetrating meteoric water.



Figure 1: Location of the study area of PM – Punta Mita. Surface temperatures were calculated using the brightness measured by multispectral satellite images.

3. METHODOLOGY

The work was focused on the verification of the occurrence of a surface thermal anomaly related to the presence of shallow vents on the ocean floor. This problem was approached by constructing a time-series of the temperature values calculated for pixels representing grid blocks of the zone where the shallow vents are found in the Punta Mita area.

MODIS (*Moderate-resolution Imaging Spectro-radiometer*) images of the Punta Mita area (with 250 m spatial resolution) were available for only 288 consecutive days, so this time period was used to calculate the temperature variations. Atmospheric and radiometric corrections were performed on the images before they were georeferenced to locate the pixel that contained the area where hydrothermal vents were observed. Temperatures were calculated using the SeaDAS (*The SeaWiFS Data Analysis System*) software. Windows with a size of 7x7 pixels were extracted from the images, and the time series for the central and surrounding pixels were obtained.

4. TEMPERATURE CALCULATION IN THE PUNTA MITA AREA

Temperature determination was performed for a 7x7 window from 288 MODIS images that contain the area of the active vents at the center. The temperature was calculated for the pixel that corresponds to the location where hydrothermal venting has been reported, and the average temperature was also computed for the surrounding pixels in the window. The calculations were performed on different dates and a time series was built. The variation of surface temperature with time is plotted in Figure 2 and shows that the temperature of the central pixel is consistently higher than the average of the surrounding pixels.

This plot indicates that the discharge of hot water (85°C) at a depth of about 10 m affects the ocean surface temperature. Thus, satellite imaging may be a useful technique of locating temperature anomalies.

5. DISCUSSION

The time series of the temperature in the Punta Mita area includes data for almost one year and covers the seasonal variations that would affect the temperature distribution. It

can be seen in the plot in Figure 2 that the temperature of the area containing the hydrothermal vents is consistently higher than that of the surrounding pixels, as the difference between the temperatures was positive for 287 of 288 days in spite of the seasonal and daily variations. There is no clear explanation of the conditions that caused the negative difference on that day, as no strong variations were reported in wind or ocean currents for that day. It is assumed that it was probably due to local atmospheric conditions.

This method may be able to be applied to search for undiscovered shallow submarine vents, especially to locate coastal hydrothermal systems for exploitation. Further application of this method is intended to locate shallow vents in the northern Gulf of California, where exploitation of the submarine resources is planned for the near future (Hiriart et al., 2009).

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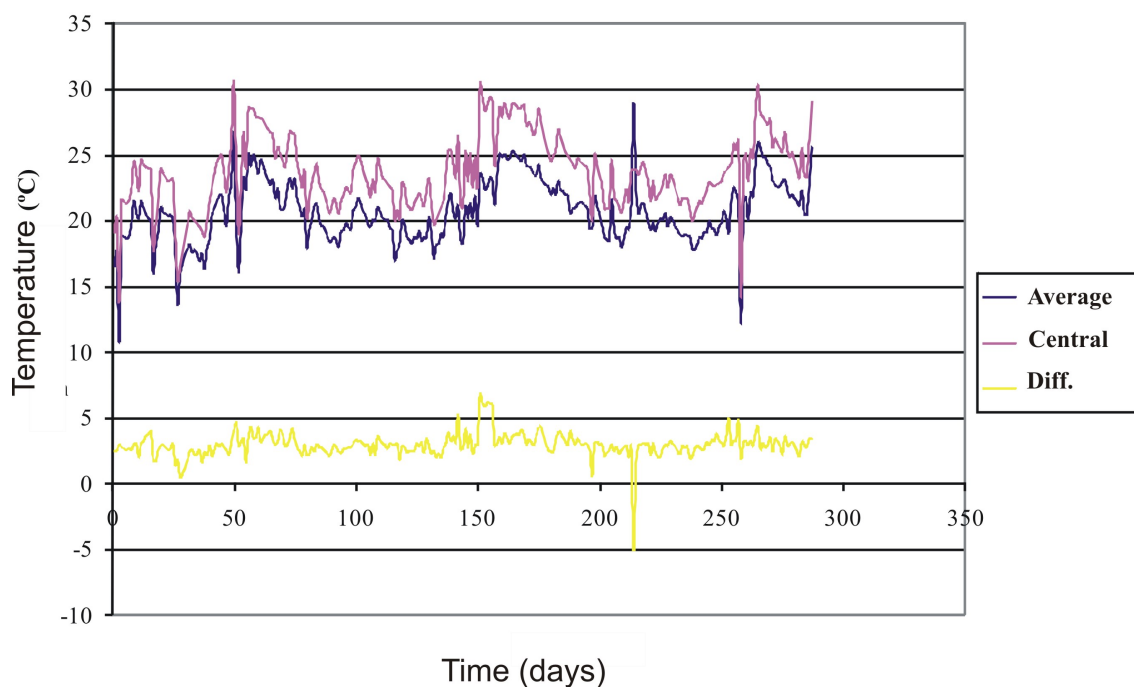


Figure 2: Plot of the calculated temperature for the central pixel (hydrothermal vents) and the average over the 7x7 pixel window. Central – the average temperature in the central pixel containing the hydrothermal vents; Average – the average temperature for the 48 pixels that surround the vents in the 7x7 window; Diff. – The difference between the Central temperature and the Average temperature.

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