Determination of Upwelling in the Southern Central Vietnam Sea using Satellite Imagery

Nguyen Tu Dan, Tran Anh Tuan and Trinh Hoai Thu
Dept. of Remote sensing and GIS,
Institute for Marine Geology and Geophysics - VAST
18 Hoang Quoc Viet Rd. Cau Giay, Hanoi, Vietnam
tudan@vista.gov.vn

Abstract: Based on sea surface temperature (SST) map derived from NOAA imagery, an algorithm for determination of upwelling water in the Southern Central Vietnam Sea has been developed.

The upwelling in this area is formed during summer by the influence of the near shore water current from the North to the South and the southwest current to the sea, which is caused by the southwest monsoon.

Study on the upwelling is aimed at supporting researches on Ocean environment in general and aquaculture in particular.

Keywords: Upwelling, Sea surface temperature, NOAA-AVHRR.

1. Introduction:

The South Vietnam sea area is located in the tropical monsoon region and deeply influenced by two main monsoon seasons: the northeastern (dry season) and southwestern (rainy season). The sea area is characterized by complicated bathymetry, with the bottom depth ranging from some tens meters up to 4000 meters. During rainy season, the runoff streams from the continent considerably affect marine waters near the eastern South Vietnam's coast, while it is not alike during dry season. The hydrology and the current in Central Vietnam Sea depend mostly on the monsoon and the regional sea current regime. Due to these natural conditions, the study area has quite complicated temperature-salinity regimes and current system, which serve as a premise for the creation of upwelling.

The upwelling process is caused by the variation of temperature and salinity fields of seawater in both vertical and horizontal directions. This variation is related with the physical processes in the surface of seawater, which are involved in the interaction between coastal circulation, coastal and sea bottom relieves.

The study of upwelling distribution and activities is aimed at supporting researches on Ocean environment in general and aquaculture in particular.

One of the effective methods to detect the location and migration of upwelling centers is to determine the temperature field of sea surface by satellite imagery.

2. Method for determination of sea surface temperature field from high resolution NOAA satellite imagery

To date, the NOAA satellites are equipped with Advanced Very High Resolution Radiometer sensors (AVHRR), covering five channels of wavelengths with the following spectral characteristics:

- Channel 1: 0.58-0.68 μm (visible channel)
- Channel 2: 0.72-1.10 μm (visible-near infra-red channel)
- Channel 3: 3.55-3.93 μm (Middle infra-red channel)
- Channel 4: 10.30-11.30 μm (Thermal infra-red channel)
- Channel 5: 11.50-12.50 μm (Thermal infra-red channel)

Among these, channels 1 and 2 are mainly used for study of weather change and vegetation distribution, while channels 3, 4 and 5 are used for obtaining the distribution of temperature of Earth's surface and in the atmosphere below clouds.

Calculation from the 3, 4 and 5 channels will assign each pixel a value of temperature in Kelvin degree (^{0}K). The sea surface temperature can be calculated from NOAA-AVHRR images by the following formula (PCI 6.3 User Guide, 1998):

$$SST\ (^0C) = A^*(T_4-T_5)+B^*T_4+C^*(T_4-T_5)*(Z-1)+D$$

Where: A, B, C, and D are the constants proposed by McClain E.P. (1981);

Z is the satellite zenith angle coefficient:

T_4 and T_5 are temperature values at the channels 4 and 5 (in ^{0}K).

Hence, the calculation of sea surface temperature in ^{0}C involves the following steps:

a. Calculation of temperature (in ^{0}K) in the channels 3, 4 and 5 using spectral correction parameters for NOAA images.

Using the correction parameters determined for NOAA images, the spectral correction is carried out. This process converts the digital number values (DN) of image to physical units. Results of conversion process are the percentage values of reflectance at two visible channels (1,2) and the values of temperature (in Kelvin degrees) at thermal channels (3,4,and 5).

To date, a program for automatically pre-processing was developed at Center for Remote sensing and Geomatics (CIAS). The program uses the EASI commands to combine and execute PCI's modules for pre-processing of high-resolution NOAA images. The input data are the HRPT_raw type of NOAA images or HRPT_level 1B (using World Fire Web), and *.TLE files. The program automatically runs through all pre-processing steps and saves computed results. The run time is approximately 15 minutes, and the results can be viewed on screen.

b. Calculation of satellite zenith angle.

Given the following input values:

X is the pixel's coordinate by column,
SatAltitude is the satellite altitude (833.3 km),
EarthRadius is the Earth's radius at equator (6378.135 km),

Scanning angle of the satellite can be defined as:

*SatScanAngle = (1024-x)*55.3846 degrees/1024.0*

Then, the Sin of satellite's zenith angle can be defined as:

Sin (SatZenAngle) = Sin (SatScanAngle)(SatAltitude+ EarthRadius)/ EarthRadius*

Where the value of *SatZenAngle* can vary from 0 to +68 for all points of two hemispheres.

c. Calculation of temperature (in ^{0}C) at each pixel by McClain formula (PCI 6.3 User Guide, 1998):

$$T\,(^0C) = A^*(T_4 - T_5) + B^*T_4 + C^*((T_4 - T_5)*(Sec.SatZenAngle - 1)) + D$$

Where: *T* is the temperature values in Celsius degrees,

T_4 and T_5 are temperature values in Kelvin degrees at the channels 4 and 5,
A, B, C, D is McClain coefficients for day or night times,
Sec.SatZenAngle is the Sec of satellite's zenith angle

According to Kidwell Katherine B. (1995), the McClain coefficients applicable for NOAA-14 are:

	A	B	C	D
Day time coefficients	2.139588	1.017342	0.779706	- 278.43
Night time coefficients	2.275385	1.029088	0.752567	- 282.24

As for NOAA-12:

	A	B	C	D
Day time coefficients	2.579211	0.963563	0.242598	-263.006
Night time coefficients	2.384376	0.967077	0.480788	-263.94

The NOAA-AVHRR images are acquired daily at CIAS, Vietnam. Therefore, it is possible for us to obtain the picture of sea surface temperature at the moments remotely sensed images were shot. However, for further use in research and production, these images need to be converted to raster format (as image files) and vector format (as contour maps). Hypothetically, average temperature values are calculated for each image unit during a certain time period, say, daily, weekly, monthly, annually or many years. In fact, since Vietnam belongs to a group of tropical countries with high humidity, cloud cover is a serious constrain to the use of remotely sensed images, especially during wintertime, when clouds may obscure the large area of interest. Due to this fact, the original images should be selected for save processing time.

The flow chart in figure 1 shows the processing steps involved in a process of compilation of sea surface temperature map from NOAA-AVHRR imagery.

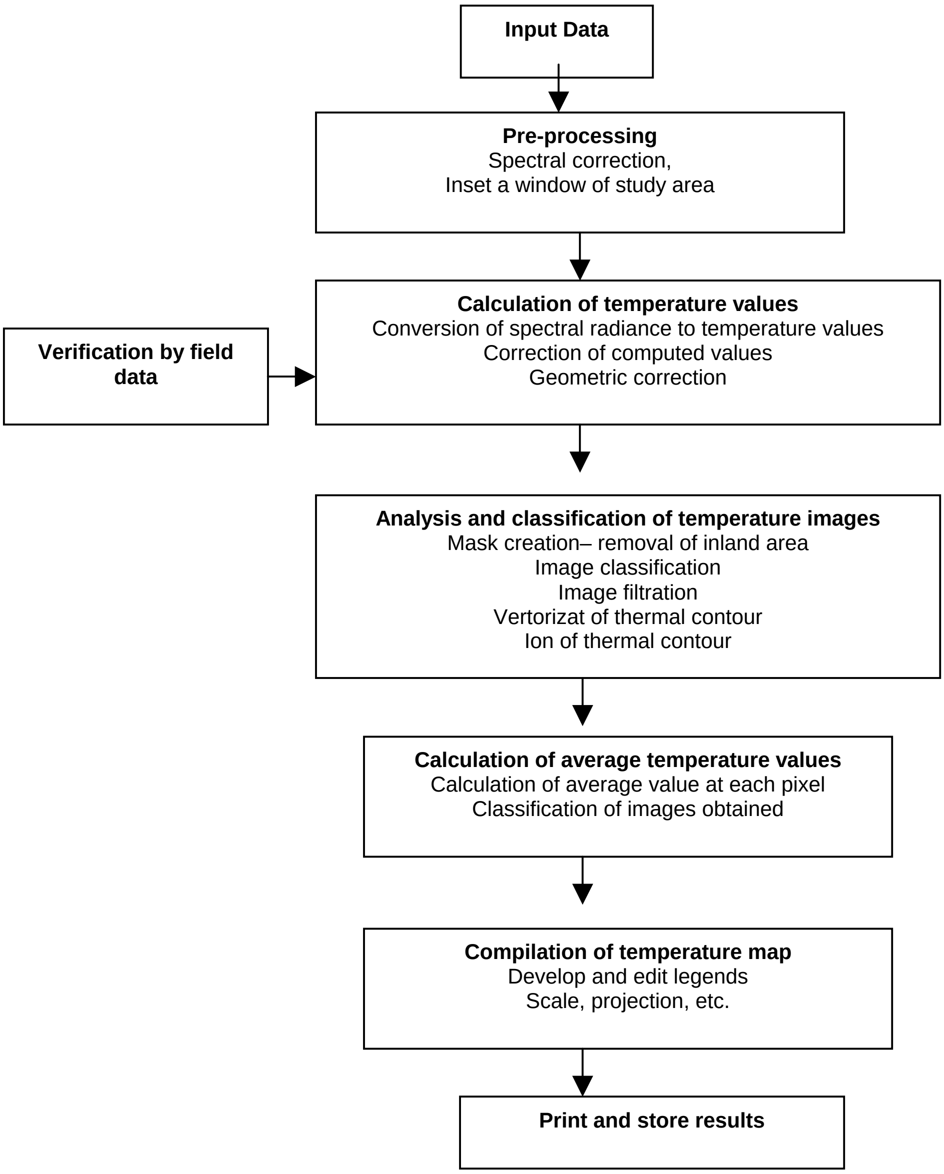


Figure 1. Flowchart showing process of compilation of sea surface temperature map

In contrast with observational data, temperature images provide the spatial distribution of temperature field over a large area. However, for research and production purposes, it is very important to verify these images and compare them with actual data obtained by in suit measurements.

3. Detection of upwelling centers and their activities in Vietnam sea area using temperature images and surface circulation data

This paper uses documented data on surface current system in the study area, published by Nguyen Tien Canh and Nguyen Van Viet (1998). The authors have used the dynamic method to study the system of surface current in South Vietnam sea, based on the observational data obtained during 1979-1988 within framework of a joint Vietnam-Russian project for marine research between the Institute of Fishery Research (Vietnam), and TINRO (Pacific research Institute for Fisheries and Oceanography, Russia).

a. Overview of thermal and surface circulation characteristics of the study area

The study area has quite complicated temperature-salinity regimes and current system.

Near shore, the surface temperature varies from 20 - 22^{0}C in winter and from 26 - 28^{0}C in summer. In contrast, deeper areas have lesser difference of temperature between the two seasons: the average temperature in winter ranges from 26 to 27^{0}C, and in summer from 29 to 30^{0}C. The area of lowest temperature is observed near the Southeast coast of Central Vietnam, with temperature not exceeding 27^{0}C according to long-term statistical data, and at some places down to 24-26^{0}C according to cruise data obtained by the USSR ships. This is probably due to the upwelling activities caused by southwest monsoon. During northeast monsoon, the distribution of surface temperature is clearly affected by cold airflows, as the thermal contours are bent in the NE-SW direction, forming the low temperature zones of 25^{0}C, some time of 22^{0}C. In the southern and southeastern parts of the study area, the surface temperature is spatially stable and rather warm: of 25 - 27^{0}C during February and 26 - 29^{0}C during November. On can observe that off-shore, the influence of northeast monsoon is not as strong as in the near shore area, where the low temperature zones reach to the 5th parallel.

The results of study on surface current system show that, during northeast monsoon, from December to January, the sea current moves in the NE-SW direction. Equatorial circulating flows coming from the north and near shore flows caused by northeastern monsoon are met in the East Vietnam Sea and become one main stream, going to the south. While passing by the Central Vietnam coast in direction parallel to the coastline, this stream can have maximum speed of 60-70 cm/sec. Maximum speed of flows are observed in the middle of winter (December-January), coinciding the strongest northeast monsoon. During April, the transitional period from northeast and southwest monsoon seasons, circulating flow caused by the northeast monsoon grows weak, and the big anticlockwise circulation whirl in the middle of the East Vietnam Sea becomes two smaller ones, which located near the northern and southeastern coasts. During the southwestern monsoon, the main stream is affected by runoff flows from the continent, tends to change its direction perpendicular to the coastline. A number of anticlockwise circulation whirls with different sizes appear in the off shore area, which form the flows having opposite direction with those of northeastern monsoon season. During the period of strongest southwest monsoon (July - August), the near shore main stream has average speed of 30 cm/sec. The flow considerably decreases in September, and the first signs of the northeastern monsoon circulation start.

b. Detection of upwelling centers in the study sea area

The upwelling phenomenon is caused by the dispersion of seawater layers and the vertical movement of seawater columns, affected by the interaction of sea bottom relief and horizontal movement of sea flows. During an upwelling, water rises up from the depth to surface, and although the upwelling size is limited, it may affect the oceanographic conditions within hundreds nautical miles. Water also rises up by dispersion of sea flows. The whirls of different sizes can lead to upwelling. Upwelling supports the exchange of temperature, salinity and other bio-chemical elements between the water layers and therefore is potential for the organic productions. Study of the upwelling phenomenon, its structure, intensity and migration due to hydrographic conditions, therefore is of high scientific and practical significance.

The comparison between monthly actual data and daily temperature images can give us clearly the law of temperature distribution and migration of the upwelling centers. As a rule, temperature at center of upwelling is lower than in adjacent areas due to the rising of cold water from under, while the salinity and nutrient content are higher. That is the reason why the upwelling is related to much kind of marine resources.

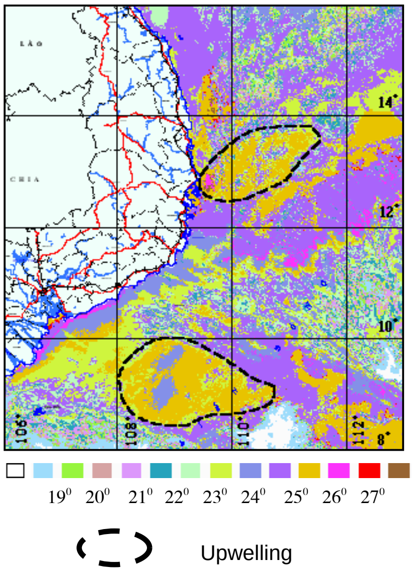
Based on results of this study, we would like to emphasize a rule for determining upwelling places by using temperature images: an upwelling usually has the form of a concentric circle, with contour lines showing increasing temperature from the center. This can be used as a criterion for detection of upwelling centers.

4. Conclusion

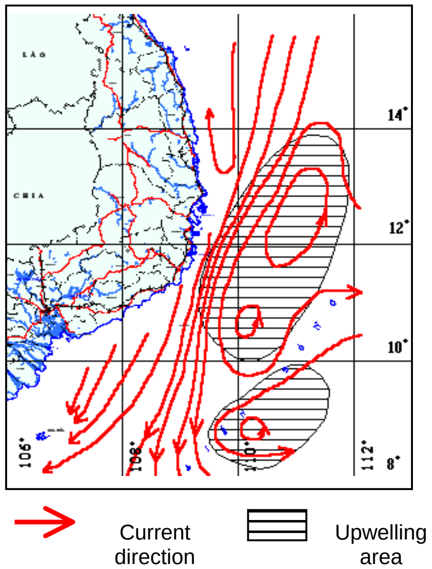
In order to determine the upwelling centers, scientists usually use current maps in combination with data on salinity and temperature. This paper shows the application of satellite data to detect the upwelling centers by analyzing temperature field of sea surface. The results show that existing upwelling are migrating spatially. Thus, the continuously observation during successive days or months can define the activities and migration of upwelling centers. Some largest upwelling centers in Vietnam Sea are illustrated in figs. 2, 3.

Figure 2: Upwelling centers determined by daily imagery and by monthly observational data:

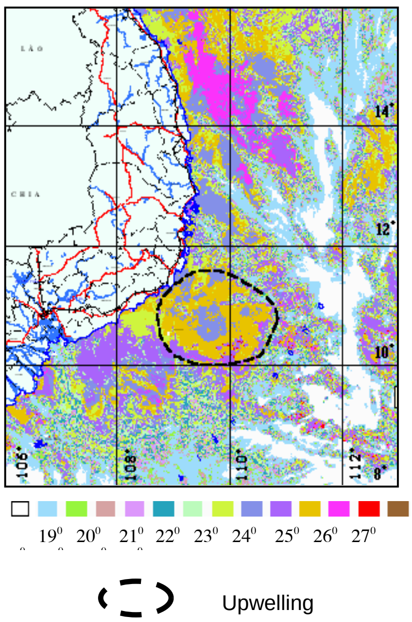
a. Upwelling centers by analyzing temperature field using NOAA-AVHRR satellite image of February 25th, 1999



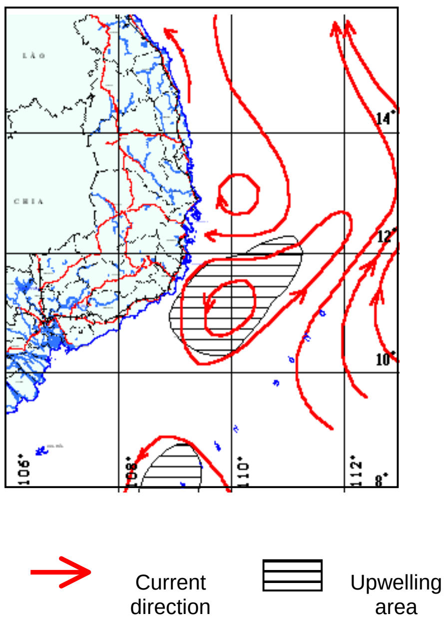
b. Current direction and upwelling centers during February 1998



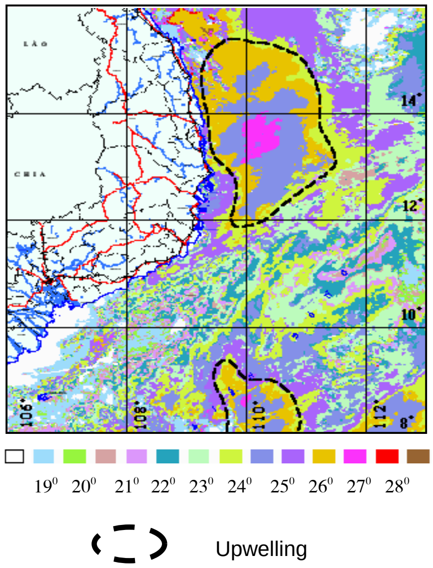
c. Upwelling centers by analyzing temperature field using NOAA-AVHRR satellite image of Mars 5th, 1999



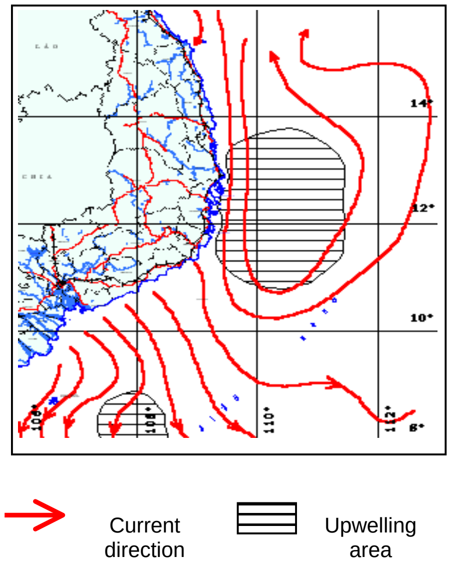
d. Current direction and upwelling centers during Mars, 1998



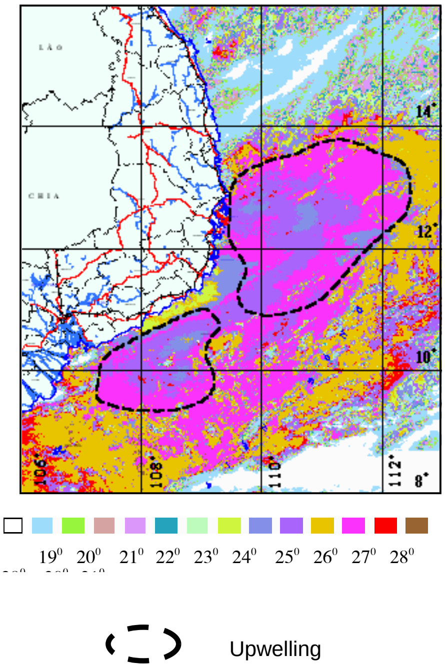
e. Upwelling centers by analyzing temperature field using NOAA-AVHRR satellite image of July 9th, 1999



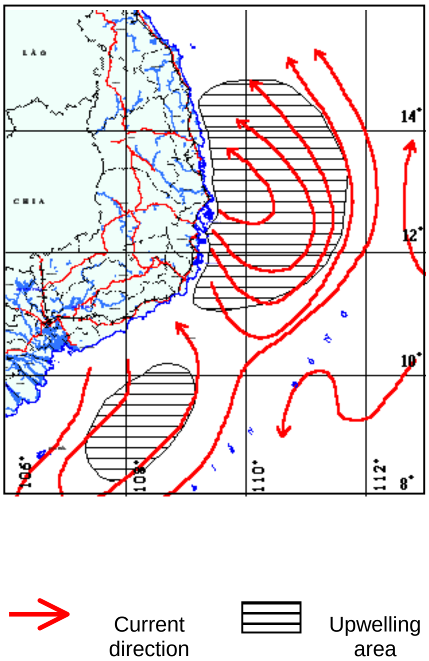
f. Current direction and upwelling centers during July 1998



g. Upwelling centers by analyzing temperature field using NOAA-AVHRR satellite image of August 12th, 1999



h. Current direction and upwelling centers during August 1998



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