F-5.3.1 Studies on the Algorithm for Long-term Monitoring of Coral Reef from High Resolution Satellite Images

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Total Budget for FY1997-1999 7,773,000 Yen (FY1999 2,414,000Yen)

Abstract The algorithm for detecting long-term variation of coral reef was developed from LANDSAT-TM images. The spatial and time domain anomaly of logarithm of pixel value is good for correction of air condition, sun angle, and tidal level change. The most weighty variation around Ishigakizima Island was related to the coral bleaching arose in 1998.

Key Words Satellite Image, Coral area, Visual Image, Monitoring, Coral Bleaching

1. Introduction

The natural environment around coral community is very weak for human activity, because the important coral community is located in the shallow area. Since 1975, decrease of the coral reefs and change of the coral species was caused by inflow of domestic wastewater and inflow of muddy water by the civil engineering works. Sometimes the coral reefs were destroyed by the public work. The coral reefs are one of the most sensitive ecosystems to long-term climate change. Corals are especially sensitive to elevated sea surface temperatures. It is necessary to rapidly extract situations such as decrease of the coral reefs and change of the species.

It is difficult to monitor widely and uniformly the change in the coral reef area in respect of personnel and cost. In this study, it aims at extracting long-term change in the coral reef area using the satellite visible images. Visible light can penetrate to water and it is available for the watching underwater structure. Visible light is absorbed and scattered in some degree in water. The water depth over the coral reef is greatly different with the location. If the same coral is located on different depth, the coral color is different from the viewpoint of the sky. Due to existing tide, the sea level over the coral reef varies every observation, and the color varies from the viewpoint of the sky. Reproducing original color is necessary to monitoring coral area from satellite.

The analysis was carried out using the LANDSAT-TM images of space resolving power 30m operated from 1984. The SPOT satellite image of space resolving power 20m was not used, since this image has no blue band.

2. **Algorithm**

The information in the visible image of the satellite includes signal from coral and much noise such as sun irradiance, aerosol scattering, tides, and so on. The value of each pixel of the image describes as,

$$Eij(\lambda) = Fij(\lambda)\, tij(\lambda)\, aij(\lambda)\, Rij(\lambda) \quad (1)$$

λ : wavelength , (ij shows the pixel position)

$Eij(\lambda)$: satellite observation value

$Fij(\lambda)$: sun irradiance outside of atmosphere

$tij(\lambda)$: dissipation rate in atmosphere

$aij(\lambda)$: dissipation rate in sea water

$Rij(\lambda)$: seabed reflectance (coral reflectance)

It is possible to consider that each pixel of $Fij(\lambda)\, tij(\lambda)$ is the same in the same band of the same image, since the region in the coral area is not so big. However, it is considered to greatly change by observed time. So, is described with

$$S(\lambda) = Fij(\lambda)\, tij(\lambda)$$

On $aij(\lambda)$ which is the dissipation rate in sea water , is described as

$$aij(\lambda) = \exp(-2\, Kij(\lambda)\, (hij + \eta))$$

η : tide level, hij: depth from sea level to coral

$Kij(\lambda)$: dissipation coefficient of sea water

Dissipation coefficient is generally change by the depth. The coral reef area is generally clear and the dissipation coefficient is nearly the same as dissipation coefficient of pure water, so the dissipation coefficient is regarded as unchanged by the depth in this study. It is note that dissipation quantity by seawater spatially greatly differs by muddy water from river, etc. The dissipation coefficient at the wavelength from 410nm to 500nm is small, and that at the wavelength longer than 500nm is larger near Ishigakizima Island. Band 1 (450nm–520nm, blue band) and Band 2 (520nm-600nm, green band) of LANDSAT/TM is not so much dissipated, and Band 3 (630nm-690nm, red band) is dissipated by seawater. That is to say, it becomes an image that lost the redness with deepening.

Equation (1) is transformed and the time change is considered, as follows,

$$\ln(Eij(\lambda,t)) = \ln(Rij(\lambda,t)) + \ln(S(\lambda,t)) - 2\, Kij(\lambda,t)\, ((hij + \eta(t))) \quad (2)$$

The reflection from the coral reef will be estimated by this equation. The sea area with small changes of water quality away from the river is selected, and $Kij(\lambda,t)$ will be nearly the same in this area. Then, the spatially anomaly operation is carried out to equation (2), as follows,

$$\ln(E_{ij}(\lambda,t)) - [\ln(E_{ij}(\lambda,t))] = (\ln(R_{ij}(\lambda,t)) - [\ln(R_{ij}(\lambda,t))]) - 2\,K0(\lambda,t)\,(h_{ij} - [h_{ij}]) \qquad (3)$$

[...] denotes spatial average. By this operation, it did not need to consider tidal sea level change, level of sun irradiance outside of atmosphere, and dissipation rate in atmosphere. There is small phytoplankton in the coral reef area, and the dissipation coefficient is stable except when the turbid water flows in after rain.

Then, the time oriented anomaly operation is carried out to equation (3), as follows,

$$\ln(E_{ij}(\lambda,t)) - [\ln(E_{ij}(\lambda,t))] - \langle \ln(E_{ij}(\lambda,t)) - [\ln(E_{ij}(\lambda,t))] \rangle$$
$$= (\ln(R_{ij}(\lambda,t)) - [\ln(R_{ij}(\lambda,t))]) - \langle (\ln(R_{ij}(\lambda,t)) - [\ln(R_{ij}(\lambda,t))]) \rangle$$
$$- 2\,(K0(\lambda,t) - \langle K0(\lambda,t) \rangle)\,(h_{ij} - [h_{ij}])$$

Where < > is the time average of the same pixel. Or,

$$V_{ij}(\lambda,t)$$
$$= (\ln(R_{ij}(\lambda,t)) - [\ln(R_{ij}(\lambda,t))]) - \langle (\ln(R_{ij}(\lambda,t)) - [\ln(R_{ij}(\lambda,t))]) \rangle$$
$$= \ln(E_{ij}(\lambda,t)) - [\ln(E_{ij}(\lambda,t))] - \langle \ln(E_{ij}(\lambda,t)) - [\ln(E_{ij}(\lambda,t))] \rangle$$
$$+ 2\,(K0(\lambda,t) - \langle K0(\lambda,t) \rangle)\,(h_{ij} - [h_{ij}])$$

$V_{ij}(\lambda,t)$ includes variation of the reflectance from seabed and change of the dissipation coefficient by turbid water. By applying the EOF (Experiential Orthogonal Function) analysis on $V_{ij}(\lambda,t)$, it is possible to separate change of coral reflectance and water quality change by turbid water.

3. Image Preprocessing

33 scenes of LANDSAT satellite TM sensor images were obtained around Ishigakizima Island. Used bands are Band 1 (450nm-520nm, blue band), Band 2 (520nm-600nm, green band), Band 3 (630nm-690nm, red band), and Band 5 (1,550nm-1,750nm, mid-infrared band). The image size is 2551 pixels and 1991 lines. Bands 1-3 are visible ranges, and underwater information is included, and there is no underwater information in infrared band after band 4.

3.1 Precise GCP matching

Latitude and longitude of the center location of the image is not the same, even if the pass number and the row number of the equal satellite is same, observation time. The image matching was carried out by two techniques:

1. Match up 7 Geomorphologically characteristic sites
2. Cross correlation method with 4 templates

It has shifted to the east west in the largest 741 pixels and north south in largest 86 lines. The distortion of image is less than 1 pixel.

3.2 Cloud, land, lost data area flagging

The detection technique of the cloud zone was examined. The histogram of the radiance of Band 1 is shown in Fig.1. Most pixels have from 44 to 144 DN (digital number) except for 1991/12/2 images with many clouds. Since the cloud radiance changes by condition of sun and atmosphere, the pixel of Band 1 over DN160 is considered cloud. There are many lost data in images before 15 years, and these pixels are marked so that it may not use it. It is

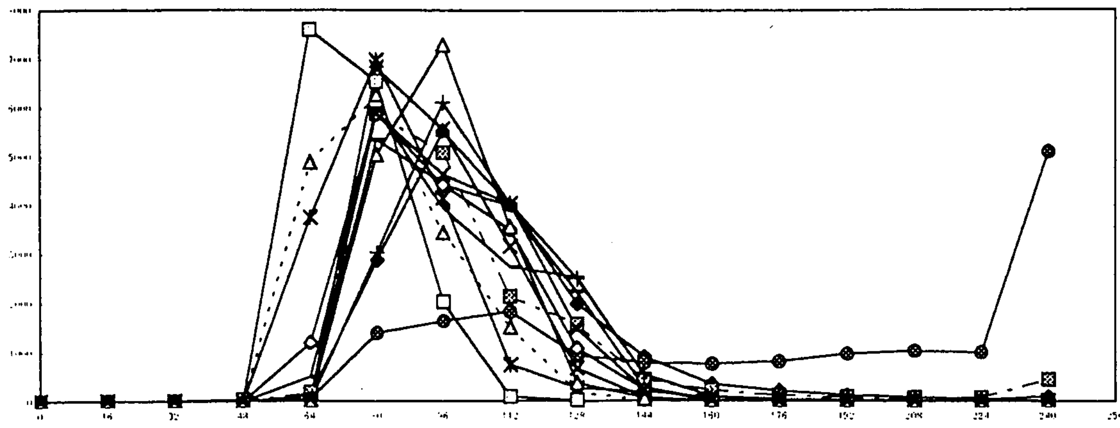

Fig.1 Histogram of Band 1 of LANDSAT/TM

necessary to detect the area to which do not see land and seabed, because the analysis is assumed to be able to detect the seabed signal. Using Band 5 in the mid-infrared band where the signal does not return from the undersea, the mask file for separating the land from the sea area was made. Since it recognizes reservoirs, etc. as sea, and since it recognizes some sea area by the reflection of solar light by the wave as the part land, they were corrected. Mask file for detecting seabed is made Bands 1-2 of the cloud free image taken on May 16th, 1994.

3. Results and Discussion

By establishing observation posts of the total of 25 points, the analysis was carried out in the EOF method. This observation posts decided it referring to the survey points of "Annual Report - 1998 on the Monitoring Coral Reef around Ishigakizima Island"[1]. The number of observation posts decided it less than the number of images used for analysis. The

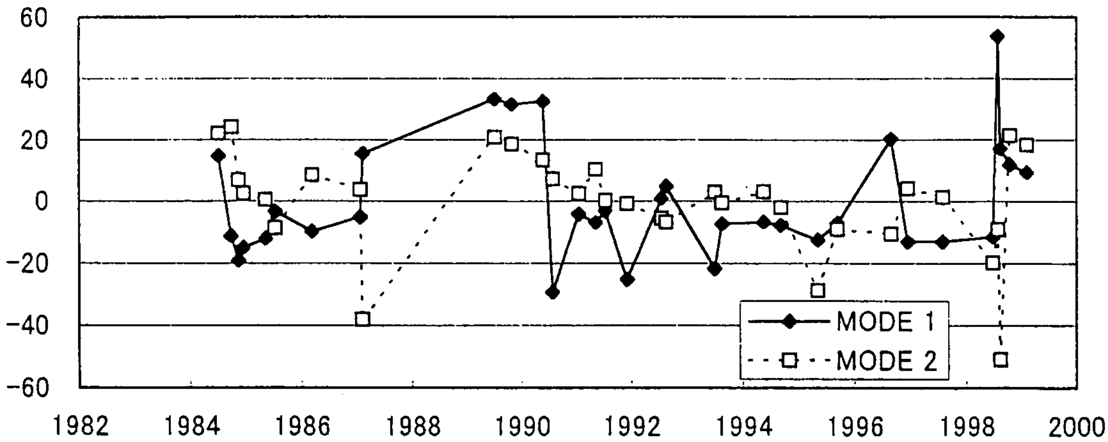

Fig.2 Time Series of MODE 1 and MODE 2

cross correlation coefficient is defined as the average of product of available components of two time series. Therefore, it is important to know where and when the cloud existed. The spatial structure of each mode is not clear by 25 points. The time series got in the analysis according to EOF is respectively independent. The mode expansion was done on each pixel time series, and the spatial distribution of all sea area of each mode was obtained.

The time series of the first and MODE 2 of EOF is shown in Fig.2. There are strong signals in August 1998. The MODE 2 is behind a little comparing with the MODE 1. In 1998, mass coral bleaching was occurred all over the world. This signal is correspondent to the coral breaching in 1998. The MODE 1 has also shown recovery process, after it has the peak especially. The strong signal was also coming out in 1987, 1990, and 1996. The spatial distribution of MODE 1 and MODE 2 is shown in Fig.3. The intensity is high for Band 3 (red band) on MODE 1 and MODE 2. In the MODE 1, the high intensity areas are shown in Urasoko Bay, Maihara, and northwest of Karadake, Sokochi, around Kohamashima Island, near Koharasaki of Iriomoteshima Island, east of nakamasaki of Iriomoteshima. In the MODE 2, the high intensity areas are shown in Urasoko Bay, Maihara, northeast of Karadake, Takasu, and north of Kuroshima Island. The high intensity area of MODE 2 is rather offshore than that of MODE 1. The distribution of ratio of the death coral[1)] by coral bleaching agrees with MODE 1 and MODE 2, especially MODE 2 in Urasoko Bay, Sokochi, and many other places. However, the ratio of death coral agrees with neither MODE 1 nor MODE 2 in Kabira, Yarabusaki, and Maihara.

Average SST (sea surface temperature) in 123-125E and 24-25N around Ishigakizima Island is shown in Fig.4. Air temperature and solar radiation of Ishigakizima Island are shown in Fig.5. Both SST and air temperatures are higher than the normal year in 1998 in the summertime, and it is note that the water temperature has exceeded 30 degree. The SST was also high in 1988 and 1996, and the signal has appeared on 1996 in MODE 1. There is no good image in 1988. SST was higher than normal year from late June through early August in 1998, and it was higher from early June through mid July. Solar radiation is higher than normal year from June through August in 1998, and it is higher from June through July in 1986. The long high solar radiation occurred long period of high temperature.

5. Conclusion and Remarks

Time series and spatial distribution was extracted from images of LANDSAT-TM around Ishigakizima Island. The coral bleaching of 1998 was detected on MODE 1 and MODE 2. There are many other modes, from which various phenomena can be extracted.

The satellite of the high resolution will be launched and available near future. For example, CARTERRA satellite, of which space resolving power is 4m, is now available. It would be able to monitor the coral reef in many high resolution satellites.

Some of used LANDSAT-TM data are the U.S. Gov. possession, and they are kindly provided by Space Imaging EOSAT/NASDA. The sea surface temperature around the

Nansei Islands is kindly provided by Japan Fisheries Information Center. Meteorological data of Ishigakishima Island are kindly provided by Japan Meteorological Agency.

6. Reference

1) Nature Conservation Bureau, Environment Agency (1999) Annual Report - 1998 on the Monitoring Coral Reef around Ishigakizima Island.

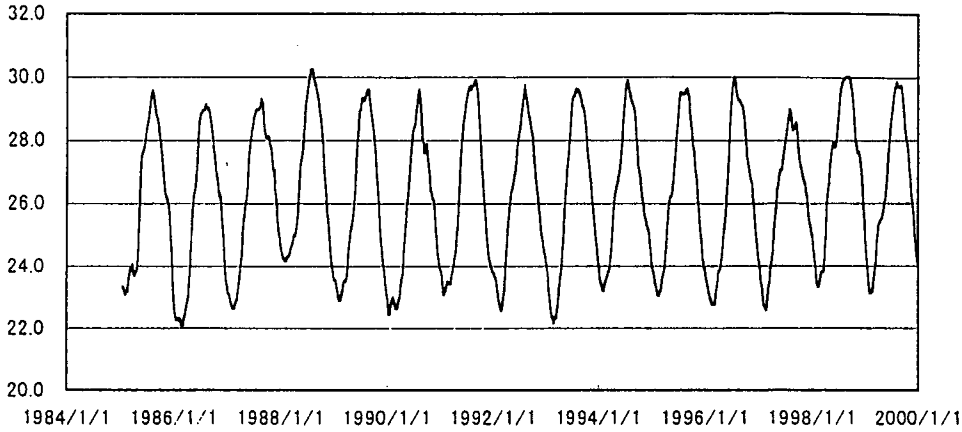

Fig.4 Averaged SST in 123-125E and 24-25N around Ishigakizima Island

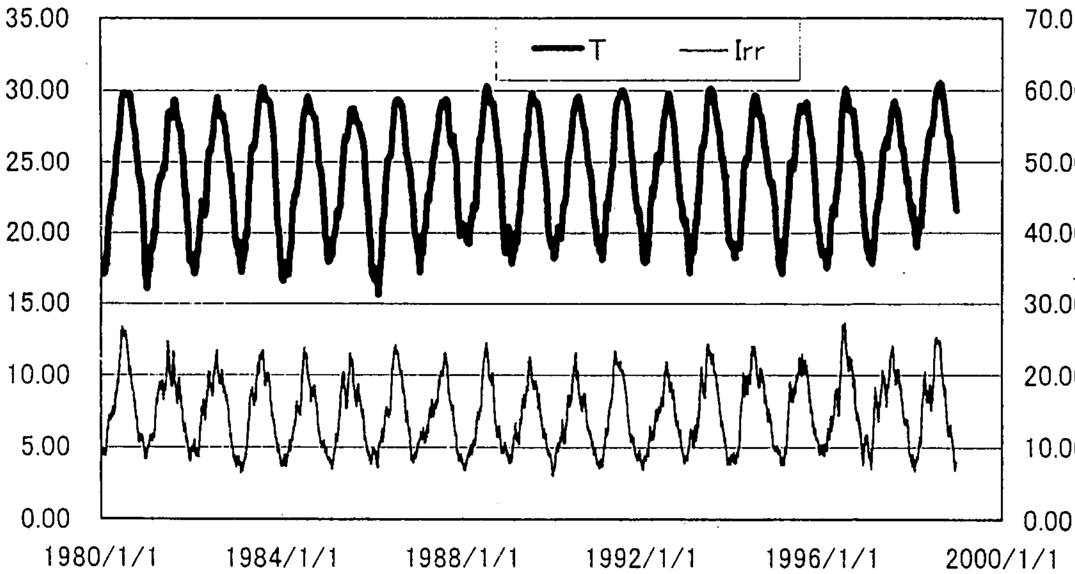

Fig.5 Air temperature and solar radiation of Ishigakizima Island