This project is a joint program with the Research Center for the Pacific Islands in Kagoshima University. The project seeks to enhance the self-reliance of Yap Islands in Micronesia. Remote sensing is an effective procedure simultaneously to analyze and to monitor environmental changes because of its potentials to cover a large area and generate time series analysis. Many researchers have been undertaking studies using satellite data. Especially, it was clarified that the water depth, shallower than 20m can be estimated by satellite data. If the distribution of water depth map can readily indicate a waterway easily for a native person and also evaluate the rising sea surface for purpose of understanding the greenhouse effect. And if a method of classification the land can be achieved, it will be possible to evaluate and analyze biomass and surface temperatures on the ground and thus the potential of yield of several crops. Our primary results highlights these methods to be effective for the Yap Islands.

**Abstract**

Remote sensing technique is an effective technology for monitoring and analyzing environmental changes on the Earth surface. We have tried to clarify environmental changes in Yap islands using satellite data, especially, on the distribution of water depth around the Yap islands and land classification. To serve our purpose, a sea-truth and ground truth data were collected, using a portable spectrometer and a digital camera.

Key words: remote sensing, water depth, land classification, monitoring

**Principle of the Evaluating of Water Depth**

It is assumed that the extinction coefficient of the sea water $\alpha$, is homogeneous vertically at a point. At the sea surface, radiance intensity, $I_0$, become $I_1$ at the bottom. $I_1$ are expressed as $I_1=I_0e^{(-\alpha h)}$, where $h$ is the depth. As the radiance $I_1$ is reflected by the sea-bed, $I_1$ becomes $I_2$, $I_2=\alpha I_1$, where $\alpha$ denotes bottom reflection coefficient. When the radiance reaches at the sea surfaces, the intensity becomes $I_3$, $I_3=I_2e^{(-\alpha h)}$. Then $I_3$ is expressed as $I_3=I_0e^{(-2\alpha h)}$. $I_3/I_0$ is the reflectance at the sea surface. If the extinction coefficient of the water collected at the
Yap and reflectance are measured, the depth will be evaluated.

Sea Truth

Actual sea depths were measured by throwing a rope from our boat at several points. Spectral reflectances were measured by a handheld spectroradiometer (Model: 2703, Abe-sekkei Co. Japan), ranging from 400 nm to 1050 nm at 25 nm intervals. Sea sediments were collected at the same points and spectral reflectance was measured by the handheld spectroradiometer. Seawater, in the middle depths, was collected at the same time, and extinction coefficients of water at several wavelengths, from 400 nm to 1100 nm, were measured by the spectrometer (Model: 121-0001, Hitachi Co.). These points were recognized and recorded by handheld GPS instruments (Model: GPS-315, Magellan Co.).

Ground Truth

Spectral reflectances of the leaves of several crops and trees, grown in the Yap islands, were measured by handheld spectroradiometer. Making a land classification map for Yap islands, several points were surveyed. The data were recorded by digital camera and video camera. The points were recognized and recorded by handheld GPS instruments.

Image Analysis

In recent times, many satellites have been observing the Earth surface. Satellite data for the West Pacific have been received mainly at bases in Hatoyama, Japan, Beijing, China etc. Few data based on observing Yap islands have been available. Moreover, reflected and emitted radiation from ground objects cannot penetrate clouds. For these reasons, we determined to use the

Fig. 1. Measured points in Yap.
satellite data of Landsat-2/MSS (L-2/MSS) and MOS-1/MESSR.

L-2/MSS data consist of 4 bands; Band-4 is from 0.5\( \mu m \) to 0.6\( \mu m \), Band-5 is from 0.6\( \mu m \) to 0.7\( \mu m \), Band-6 is from 0.7\( \mu m \) to 0.8\( \mu m \), and Band-7 is from 0.8\( \mu m \) to 1.1\( \mu m \). MESSR consist of 4 bands, too, but the regions are slightly different, Band-1 is from 0.51\( \mu m \) to 0.59\( \mu m \), Band-2 is from 0.61\( \mu m \) to 0.69\( \mu m \), Band-3 is from 0.72\( \mu m \) to 0.80\( \mu m \), and Band-4 is from 0.8\( \mu m \) to 1.1\( \mu m \). The resolutions are 80m and 50m for L-2/MSS and MESSR, respectively.

**Spectral reflectance of sea-sediment**

Spectral reflectance of several sea-sediments, collected at many positions, is shown in Fig.2. In the case of sea-grass, the spectral reflectance curves have a low peak at 575 nm, a red-edge between 600nm to 700nm and a higher reflectance in the infrared region. This is the same tendency as for plants grown on land. For mud and sand, spectral reflectance increased with increased wavelength. These results are the same as on bare land.

Coral and sea-grass are randomly distributed on the seabed around these islands. Moreover, we found sludge in some parts of the area. If the seabed was classified into several categories, it become possible to estimate sea-depth by adapting the reflectances of each category.

These measured reflectances were divided into corresponding bands of satellite calculated. The result is shown in Table 1.

![Fig. 2. Reflectance on several measured points.](image-url)
Changes of spectral reflectance with sea depth

Relationships between the spectral reflectance of sand and mud, which correspond to Landsat-2/MSS and water-depth, are shown in Figs. 3 and 4, respectively. These relationships are indicated by the following equations.

On sand

\[ y = -0.3718x + 16.444, \quad R^2 = 0.9743 \]

\[ y = -0.5308x + 20.270, \quad R^2 = 0.9643 \]

\[ y = -0.2804x + 10.863, \quad R^2 = 0.9480 \]

\[ y = -0.1358x + 7.8323, \quad R^2 = 0.6736 \]

Table 1. Characteristics of measured points

<table>
<thead>
<tr>
<th>Point</th>
<th>Depth (m)</th>
<th>Sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>St-5</td>
<td>1.1</td>
<td>Sand + Sea grass</td>
</tr>
<tr>
<td>St-12</td>
<td>1.75</td>
<td>Sand</td>
</tr>
<tr>
<td>St-14</td>
<td>8.0</td>
<td>Mud</td>
</tr>
<tr>
<td>St-18</td>
<td>2.5</td>
<td>Sand + Mud</td>
</tr>
<tr>
<td>St-19</td>
<td>9.0</td>
<td>White sand</td>
</tr>
<tr>
<td>St-21</td>
<td>2.4</td>
<td>Clay</td>
</tr>
<tr>
<td>St-22</td>
<td>21.0</td>
<td>Coral + Sand</td>
</tr>
<tr>
<td>St-26</td>
<td>6.5</td>
<td>Coral</td>
</tr>
<tr>
<td>St-30</td>
<td>13.5</td>
<td>Mud + Clay</td>
</tr>
</tbody>
</table>

Fig. 3. Relationships between reflectance and depth at each MSS Band on sand.

Changes of spectral reflectance with sea depth

Relationships between the spectral reflectance of sand and mud, which correspond to Landsat-2/MSS and water-depth, are shown in Figs. 3 and 4, respectively. These relationships are indicated by the following equations.

On sand

\[ y = -0.3718x + 16.444, \quad R^2 = 0.9743 \]

\[ y = -0.5308x + 20.270, \quad R^2 = 0.9643 \]

\[ y = -0.2804x + 10.863, \quad R^2 = 0.9480 \]

\[ y = -0.1358x + 7.8323, \quad R^2 = 0.6736 \]
On mud

B4: y=-0.0715x+6.4792, \( R^2 = 0.5901 \)
B5: y=-0.0993x+6.8819, \( R^2 = 0.7596 \)
B6: y=-0.0672x+4.7687, \( R^2 = 0.8609 \)
B7: y=-0.0095x+5.6078, \( R^2 = 0.0306 \)

Where \( y \) is the mean reflectance of each MSS band and \( x \) is depth. The decreasing rate in the case of sand is larger than in the case of mud. These results correspond to the principle of evaluating the water depth.

**Extinction coefficient of the seawater**

The absorbencies of the collected water were changed at wavelength and collection points as shown in Fig.5. As wavelength increase absorbance decreases. At 900 nm, it shows the bottom for all curves as the typical absorbance of the water. From this curve, the extinction coefficients of seawater corresponding to the L-2/MSS band was calculated as shown in Table 2.

Table 2 shows the extinction coefficient collected on Yap and at Izumi, Kagoshima, Japan, for corresponding bands with L-2/MSS and L-5/TM, respectively. It is evident from Table 2 that the values of extinction coefficients decrease with increasing wavelength, which accords with the Rayleigh Scattering Theory.

**Distribution of the water-depth**

The distribution of sea-water-depth at Izumi, Kagoshima Japan using L-5/TM data is shown in Fig.6. White and black color indicate shallow and deeper waters, respectively, from 0 to 20 m.

![Fig. 4. Relationships between reflectance and depth at each MSS band on mud.](image-url)
The sea-truth points were recorded by GPS and actual depths were also measured. The linear regression coefficient between depth and indices (color) was 0.8562. This procedure shows the potential for measuring the sea-depth around Yap islands.

**Spectral reflectance of crops**

Spectral reflectances of the leaves of crops and trees grown in Yap islands are shown in Fig. 5. Changes of absorbance at each wavelength on collected sea water.

**Table 2. Extinction coefficients of seawater**

<table>
<thead>
<tr>
<th>On Yap ('99 Oct.) for L-2/MSS</th>
<th>Extinction coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band</td>
<td>Wavelength</td>
</tr>
<tr>
<td>Band-4</td>
<td>500(\sim)600nm</td>
</tr>
<tr>
<td>Band-5</td>
<td>600(\sim)700nm</td>
</tr>
<tr>
<td>Band-6</td>
<td>700(\sim)800nm</td>
</tr>
<tr>
<td>Band-7</td>
<td>800(\sim)1100nm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>On Izumi ('98 Oct.) for L-5/TM</th>
<th>Extinction coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band-1</td>
<td>450(\sim)520nm</td>
</tr>
<tr>
<td>Band-2</td>
<td>520(\sim)600nm</td>
</tr>
<tr>
<td>Band-3</td>
<td>630(\sim)690nm</td>
</tr>
<tr>
<td>Band-4</td>
<td>760(\sim)900nm</td>
</tr>
</tbody>
</table>

The sea-truth points were recorded by GPS and actual depths were also measured. The linear regression coefficient between depth and indices (color) was 0.8562. This procedure shows the potential for measuring the sea-depth around Yap islands.
Fig. 6. Distribution of the water depth using L-5/TM (1997 Oct).

Fig. 7. Spectral reflectance on several crops.
Fig. 7. In the visible region, differences of spectral reflectances are not recognized and lower reflectance for all crops. However, peaks occurred at about 575 nm. On the other hand, higher reflectances in the near-infrared region were shown with different crops. These results show the possibility of land-classification using satellite data.

Conclusion

Sea truth and ground truth show the possibility of estimating the sea-depth around the Yap islands and also land-classification using satellite data.

We are now in the process of collecting satellite data from NASA in USA and NASDA in Japan. We hope to succeed in making visual maps which will indicate environmental changes over the passed during 30 years.

References


