# DETECTION OF GROUNDWATER DISCHARGE POINTS IN COASTAL REGIONS AROUND MT. CHOKAISAN, JAPAN BY USING LANDSAT ETM+ DATA

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**ABSTRACT:** The flow of freshwater into the sea, termed as submarine groundwater discharge, is a key factor for understanding the hydrological cycle in both the sea and land regions. The numerous positions from which freshwater gushes out or its quantity impedes the understanding of its properties. Therefore, this study detects groundwater discharge points arising due to the difference in freshwater and seawater by using the multispectral Landsat ETM+ signals. A case study in coastal regions around Mt. Chokaisan, Japan is performed. This study comprises three procedures: (1) computer simulation of the flow of submarine groundwater discharge in the study area, (2) performance of preliminary experiment on the band properties of the Landsat ETM+, (3) detection of the difference in water properties by using the Landsat multispectral bands. Our experimental results obtained by the Landsat ETM+ are in considerable agreement with the realities in the study area.

**KEY WORDS:** Submarine groundwater discharge, Coastal regions, Freshwater, Landsat ETM+

## 1. INTRODUCTION

Remote sensing is a powerful technique for monitoring environmental changes. Presently, various remotely sensed data are used depending on the purpose. Only sea surface information is obtained by remote sensing; however, multispectral band properties acquired from the Landsat-7 are sufficient for determining the differences between seawater and freshwater. In particular, the features extracted from the multitemporal scenes of Landsat will help determine the conditions responsible for the differences in water qualities in coastal regions. Freshwater discharged in coastal regions has been frequently used for sustaining marine resources (Marui, A., 1997). It is difficult to understand the properties of freshwater due to the various freshwater source locations and its variable quantities.

Therefore, this study detects groundwater discharge points arising due to the difference in freshwater and seawater in coastal regions around Mt. Chokaisan, Japan by using the Landsat ETM+ (Enhanced Thematic Mapper, plus) signals. This study comprises three procedures. First, a computer simulation was performed in order to examine whether the estimate of groundwater discharge points with the Landsat ETM+ was possible. Second, preliminary experiment regarding the band properties of the Landsat ETM+ was conducted. Seawater temperature measurements and the knowledge acquired by an expert regarding the submarine groundwater discharges in the study area were also obtained. Third, the cluster technique using the Landsat multispectral bands revealed the difference in the sea surface information arising due to the difference in water properties.

## 2. STUDY AREA AND MATERIALS

### 2.1 Study area

In Japan, submarine groundwater discharges exist in the Japan Sea around Mt. Chokaisan, Akita and Yamagata Prefectures. The basin system seldom develops on the seaside of Mt. Chokaisan, such that freshwater gushes out from both the land and coastal regions. Some land areas with freshwater springs have been investigated (e.g., Hida, N. and Yoshizaki, M, 2001); however, in the coastal regions, the details regarding their properties have not yet been clarified.

### 2.2 Seawater temperature measurements

The freshwater temperature of the groundwater discharge was measured on January 26 and July 31, 2004, October 30, 2004, August 10 and October 29, 2005, August 11, 2006, August 10, 2007, February 10, June 22 and August 5, 2008. These measurements revealed that the average temperature was about 10 ℃ throughout the year. In order to understand the seawater information with regard to the Japan Sea, the Sea Surface Temperature (SST) data (Akita Prefectural Institute of Fisheries Web site) were used. The SST measured in March, August, and September was 9 ℃, 28 ℃, and 26 ℃, respectively. In summer, the difference between the SST and the temperature of freshwater from submarine groundwater discharge is extremely large; this indicates that the properties of waters that arise due to the differences in water temperatures can play a key role in estimating submarine groundwater discharge points.

### 2.3 Landsat ETM+ data

Multispectral data consisting of eight spectral ranges has been acquired using the ETM+. The Landsat ETM+ data (Path-Row: 108-33) acquired on March 23, 2001 (i.e., March data) and September 2, 2002 (i.e., September data) were used. In the eight kinds of band data, six kinds of band outputs (i.e., bands 1 to 5, and 7) with the ground resolution of 30 meters were utilized for the study.

### 2.4 Realities acquired by experts

In order to detect the groundwater discharge points by using the Landsat ETM+, an interview to the expert of hydrology in the study area was performed. The acquired knowledge is summarized as below:

(1) When it judges from the scale of Mt. Chokaisan, the areas of the submarine groundwater discharge exist ranging from land regions to the several-hundred meters offing.

(2) The groundwater which gushes out has affected information of sea water surface, and the conditions are able to be observed from the land regions.

(3) Groundwater discharge point is not single, but are scattered in coastal regions.

Fig.1 shows groundwater discharge points in coastal regions; Kosagawa, Misaki and Kamaiso are the areas where the groundwater gushes out. Fukiura is a river with fresh water.

## 3. COMPUTER SIMULATION OF THE FLOW OF SUBMARINE GROUNDWATER DISCHARGE

### 3.1 Simulation conditions

To examine the possibility of estimating the groundwater discharge points with the Landsat ETM+, a computer simulation of the flow of submarine groundwater discharge was performed. The basic equations of calculation were the equation of continuity, Navier-Stokes equation, and the transport equation of heat (Kawamura, T., 1996; Kawamura, T., 1997). Semi-implicit pressure-linked equation (SIMPLE) (Nakayama, A., Kuwahara, F., and Kyo, K., 2002.) was used to solve these equations. A staggered grid was used for variable arrangement. The simulation conditions considering those in the study area and properties of the Landsat ETM+ are summarized in Table 1. Fig.2 shows a simulation conditions for the flow; the number of flow points is set as 3.

### 3.2 Simulation results

Fig. 3 gives the simulation result in case 1 to 3. The flow velocity of one submarine discharge of underground waters at 1.5 m/s has affected the SST located at the sea level to 0.3 meters point. When the flow velocity of two submarine discharges of underground waters are 0.9 m/s or more, the SST falls. For the case 3, indicating three submarine discharges set, 0.8 m/s is sufficient for the SST falls. Figs.4 and 5 illustrate the simulation results for the flow of submarine ground water discharge of case 2 by using 0.9 m/s and case 3 by using 0.8 m/s, respectively. Those results are in agreement with those obtained by a ground survey.

Therefore, the results suggest a possibility that the interaction of two or more submarine groundwater discharges might affect the sea surface information arising due to the difference in freshwater and seawater, and that the landsat ETM+ with the ground resolution of 30 meters would detect the groundwater discharge points.

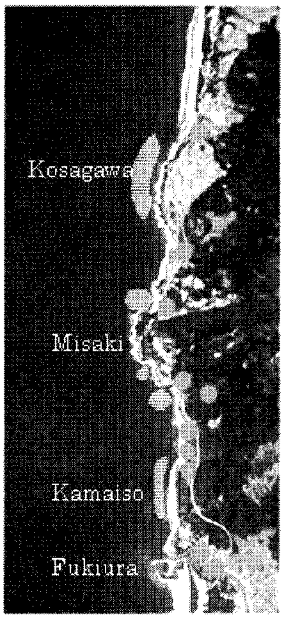



Fig.1 Groundwater discharge points in coastal regions.

Table 1 Simulation conditions.

| | |
|---|---|
| **Range** | **30 m × 10 m (x-z)** |
| **Grid interval** | **30 × 20** |
| **Month** | **September** |
| **Sea Surface temperature** | **26 ℃** |
| **Water temperature of** | **10 ℃** |
| **Velocity of current** | **0.25 m/s** |
| **Velocity of flow** | **0.1 ~1.5 m/s** |
| **Time interval** | **$\Delta t = 2.0$, $t = 1400$ (s)** |
| **Number of flow points** | **case1:1<br>case2:2<br>case3:3** |

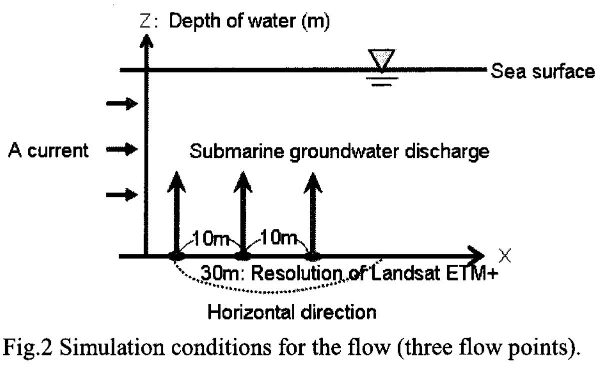



Fig.2 Simulation conditions for the flow (three flow points).

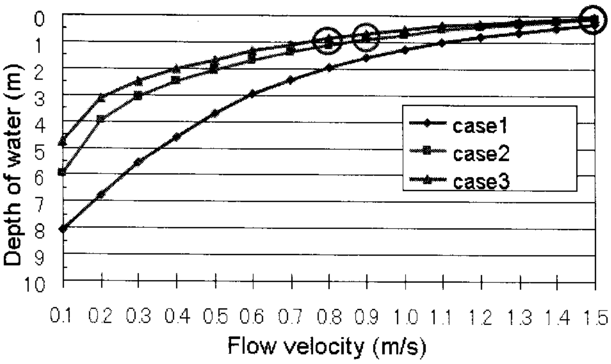



Fig.3 Relationship between the gush flow velocity and the temperature fall ranges.

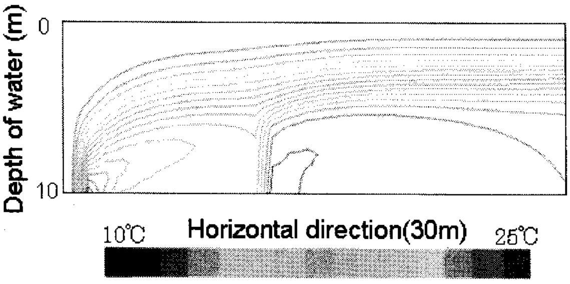



Fig.4 Simulation result of case 2 (0.9 m/s)

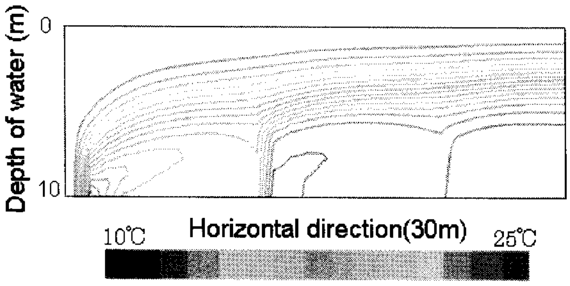



Fig.5 Simulation result of case 3 (0.8 m/s)

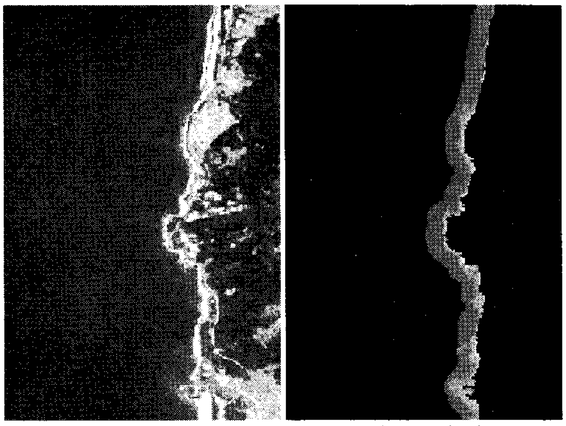
## 4. DATA ANALYSIS

### 4.1 Preprocessing

The preprocessing consists of (i) geometric correction, (ii) masking processing, and (iii) atmospheric correction. First, for the September and the March data of the Landsat ETM+, ten ground control points (GCP) were selected and then geometrically corrected by using the second order conformal transformation (Takagi, M. and Shimoda, H., 2004). The RMS error using this process was computed to be 0.19. The resampling process employed cubic convolution (Takagi, M. and Shimoda, H., 2004).

Second, the range of the Digital Numbers (DNs) in the sea regions is smaller than those in the land regions; masking process was performed for both the land regions and the sea regions of the 500 meters or more offing depending on the knowledge acquired by the experts. Fig.6 gives the study area obtained by masking procedure.

Finally, by using the 3rd band signals of ETM+, atmospheric correction (Takagi, M. and Shimoda, H., 2004) of the 1st and 2nd band data which is a visible wavelength band was performed.



(a)Landsat ETM+ (b) Masked image

Fig.6 Study area obtained by masking procedure.

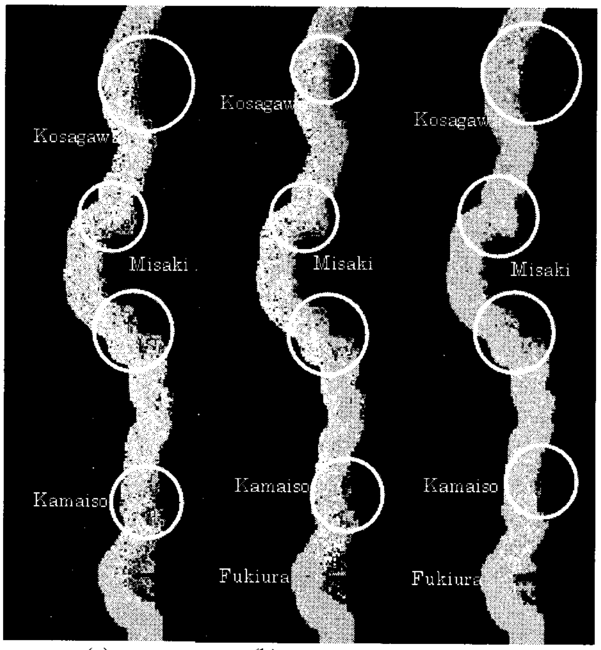
### 4.2 Classification maps drawn by K-means clustering

Based on the experimental results regarding the band properties, the multispectral band properties of the Landsat ETM+ acquired during different seasons were used in order to understand the differences in sea surface information corresponding to the differences in the water properties. The differences of the DNs in the two scenes, acquired in September and March, were used as the features for the clustering beside band properties in the original outputs. Classification maps with regard to the Japan Sea were drawn by the K-means clustering algorithm (Takagi, M. and Shimoda, H., 2004).

## 5. RESULTS AND DISCUSSION

Fig.7 (a) shows the classification result due to the 1st band of the September data (k=10). The remarkable features of this map in costal regions, which are different from the other areas in the Japan Sea, are classified as red-colored regions. However, the features are much larger than the areas of groundwater discharge indicated by the experts. For the March data, there exist many unknown pixels, such that the points with freshwater springs could not be distinguished. These results suggest that simple band data was unable to extract the gush points of the submarine groundwater discharge in the study area.

The gush points of the submarine groundwater discharge were estimated by the use of the combination data of the September multispectral signals. For six kinds of band outputs (i.e., bands 1 to 5, and 7), the properties of three groups: the 1st, 2nd and 5th, the 1st, 2nd and 7th, and the 1st, 2nd, 5th and 7th band data ware relevant to the points with freshwater springs. Fig.7 (b) shows the classification result due to the original properties of 1st, 2nd and 5th bands obtained in September by using k=10, indicating the best result in k= 3 to 20. When compared with the knowledge acquired by the experts, the resulting regions were found to have a high possibility of submarine discharge of underground water gushing out.




(a) (b) (c)

Fig.7 Classification results using the Landsat ETM+.
(a) 1st band in September; (b) 1st, 2nd and 5th band in September; (c) 1st, 2nd and 5th band in the differences computed from the two scenes and their original properties obtained in September.

(a) Corresponds to Fig7 (b) (b) Corresponds to Fig7 (c)

Fig.8 Magnified images obtained from Fig.7.

In this study, the differences computed from the two scenes (i.e., the September and the March data) regarding the above three groups of band data and their original properties obtained in September were utilized for the classification. A classification is also performed by the K-means clustering and then the result obtained due to the properties of 1st, 2nd and 5th bands is shown in Fig.7(c) (k=10). Coastal regions with groundwater gushing out are classified as the same cluster; it is good to understand the details of sea surface information in local regions. Fig.8 shows the magnified image of Fig.7 (b) and (c) in coastal region around Misaki. It is found that Misaki has many groundwater discharge points; the conditions are well classified as red-colored regions. The use of the above combination data of multitemporal signals is able to extract features appeared in the water difference.

The results suggest that the both differences computed from two scenes regarding the above combination data and original properties of the above bands obtained in September are in use for determining the points of groundwater discharge in coastal regions.

## 6. CONCLUSIONS

This study has detected the groundwater discharge points in the coastal regions around Mt. Chokaisan. The following conclusions were obtained:

The simulation results suggest that the existence of two or more gush points enables the determination of the location of groundwater springs by using the Landsat ETM+ with the ground resolution of 30 meters.

Properties of the Landsat ETM+ acquired during different seasons were able to retrieval the sea surface information arising due to the difference in freshwater and seawater.

The properties of three band groups: the 1st, 2nd and 5th, the 1st, 2nd and 7th, and the 1st, 2nd, 5th and 7th band outputs acquired in September were useful in understanding the differences in sea surface information corresponding to the differences in the water properties.

K-means clustering due to both the differences computed from the two different scenes regarding the above combination data and the original signals acquired in September was performed; the clustering results in the coastal regions agreed with the findings acquired by the ground survey and the knowledge acquired by the expert.

## ACKNOWLEDGMENTS

The authors thank Ms. C. Ishizawa and Mr. T. Takahashi, Akita University, for their help in conducting the experiments. The authors also thank Professor Emeritus N. Hida for his helpful comments. This study has been supported by a Grant-in-Aid for Young Scientists (B) (No. 18760295) from The Ministry of Education, Culture, Sports, Science and Technology, Japan.

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