論 文 の 要 旨

題 目　Development of New Water Quality Algorithms using Hyperspectral Data in Optically Complex Waters
（光学特性が複雑な水域における超多波長反射率データを使った新しい水質推定手法の構築）

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Water is closely relative to our lives, to realize the monitoring and management of water quality for both inland and sea water is of great significance. Water quality parameters such as Chlorophyll-*a* (Chl-*a*), Total suspended solids (TSS) are important indicators to assess water quality, and sea surface salinity (SSS) is one of the key variables for monitoring and modeling ocean circulation. A variety of researches have been carried out to develop methods for detecting these water quality parameters using remote sensing methods in optically complex waters. However, there is not a unified algorithm applied for all kinds of waters due to the characteristic of regional dependency.

The objectives of this study are: (1) to develop models to estimate Chl-*a* and TSS in irrigation ponds in Higashihiroshima using *in situ* hyperspectral reflectance data and several regression analyses including (a) a simple linear regression at each waveband of reflectance and the first derivative reflectance (FDR); (b) all available two-band combination spectral indices (RSI and NDSI); and (c) a PLS regression with full spectra and ISE selected spectra (ISE-PLS) using original reflectance and FDR datasets (Chapter 3); (2) to evaluate the ISE-PLS method's accuracy to confirm the potential application to estimate Chl-*a* in the Seto Inland Sea comparing with several traditional approaches using *in situ* hyperspectral reflectance data (Chapter 4); (3) to test the applicability of $a_y(440)$ as a proxy for SSS in the bio-optical model, further, to establish the model for estimating SSS using *in situ* reflectance and water quality datasets in the Seto Inland Sea (Chapter 5); (4) to evaluate the bio-optical model developed with the Second generation Global Imager (SGLI) bands for SSS estimation in the Seto Inland Sea using *in situ* measurement data (Chapter6).

In Chapter 3, the author established quantitative models for estimating the Chl-*a* and the TSS concentrations in irrigation ponds in Higashihiroshima, Japan, using field hyperspectral measurements and statistical analysis. Field experiments were conducted in six ponds and spectral readings for Chl-*a* and TSS were obtained from six field

observations in 2014. For statistical approaches, two spectral indices were used, the RSI and the NDSI, and a PLS regression. The predictive abilities were compared using the coefficient of determination (R^2), the root mean squared error of cross validation (RMSECV) and the residual predictive deviation (RPD). Overall, ISE–PLS, using FDR, showed the best predictive accuracy for both Chl-*a* (R^2 = 0.98, RMSECV = 6.15, RPD = 7.44) and TSS (R^2 = 0.97, RMSECV = 1.91, RPD = 6.64). The important wavebands for estimating Chl-*a* (16.97% of all wavebands) and TSS (8.38% of all wavebands) were selected by ISE–PLS from all 501 wavebands over the 400–900 nm range. These findings suggest that ISE–PLS based on field hyperspectral measurements can be used to estimate water Chl-*a* and TSS concentrations in irrigation ponds.

Harmful algal blooms (HABs) occur frequently in the Seto Inland Sea, bringing significant economic and environmental losses for the area, which is well known as one of the world's most productive fisheries. In Chapter 4, the author developed a quantitative model using *in situ* hyperspectral measurements in the Seto Inland Sea to estimate Chl-*a* concentration, which is a significant parameter for detecting HABs. Spectra and Chl-*a* data were obtained at six stations from 12 ship-based surveys between December 2015 and September 2017. In this study, the ISE-PLS regression method along with several empirical and semi-analytical methods such as ocean chlorophyll (OC), three-band model, and two-band model algorithms were used to retrieve Chl-*a*. Results showed that ISE-PLS using both the water-leaving reflectance (R_L) and FDR had a better predictive ability with higher R^2, lower root mean squared error (RMSE), and higher RPD values (R^2 = 0.77, RMSE = 1.47 and RPD = 2.1 for R_L; R^2 = 0.78, RMSE = 1.45 and RPD = 2.13 for FDR). However, in this study the OC algorithms had no predictive ability and the three-band and two-band model algorithms did not perform well in areas with lower Chl-*a* concentrations. These results support ISE-PLS as a potential coastal water quality assessment method using hyperspectral measurements.

SSS is playing a critical role for studying biological and physical processes in the ocean. In Chapter 5, the author established a model for estimating SSS using *in situ* measurement datasets from FY2015 to FY2016 in the Seto Inland Sea. To estimate SSS, a bio-optical model combined with the CDOM absorption coefficient at 440 nm ($a_y(440)$) was performed. Results showed that the estimated $a_y(440)$ had a reversely linear relationship with *in situ* SSS using winter datasets (R^2=0.66), which indicated the $a_y(440)$ is potential for modeling to estimate SSS, furthermore, the bio-optical model can be used for water quality assessment in Seto Inland Sea.

In Chapter 6, the author evaluated the bio-optical model combined with GCOM-C/SGLI bands to estimate SSS in the Seto Inland Sea. The *in situ* spectral and SSS data for the year of 2015 were analyzed using a two-band ratio and a bio-optical model. In the bio-optical model, the absorption of Gelbstoff in 380 nm (g_{380}) was utilized to build the relationship with SSS. According to the spectral pattern, the dataset were separated to two kinds of types (i.e., Type A and Type B). Results showed the estimated Chl-*a* had a linear relationship with observed Chl-*a* both for Type A and Type B dataset (R^2 = 0.69 for Type A and R^2 = 0.76 for Type B), and the estimated g_{380} also showed a linear relationship with observed SSS for both type of dataset (R^2 = 0.43 for Type A and R^2 = 0.64 for Type B), which showed the proposed bio-optical model based on SGLI bands has a potential predictive ability for Chl-*a* and SSS estimation in the Seto Inland Sea.