Summary

Dissertation Title: Investigation of the Variability of Chlorophyll-a over the Spring-Neap Tidal Cycle in the Turbid Ariake Bay, Japan, by the Improved *MODIS Ocean Color Data*

(改良した MODIS 海色データによる日本の高濁度海域有明海でのクロロフィル a の大潮小潮周期変動の研究)

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Red tides occur widely in coastal waters, and they are often harmful to the local fisheries and sometimes human health. Chlorophyll-a (Chl-a) is a common indicator of phytoplankton biomass, and thus satellite Chl-a is expected to be useful for detecting and monitoring red tides to mitigate the harmful impacts as it allows for synoptic view of the red tides from space. In the turbid Ariake Bay, Japan, red tides occur frequently and often damage the local fisheries, especially the Nori (Porphyra; Rhodophyta) production. Therefore, it is helpful to use satellite Chl-a to detect and monitor red tides in Ariake Bay. However, the accuracy of satellite Chl-a for coastal waters is affected by failure of atmospheric correction and inadequacy of standard in-water algorithm, and thus it needs to be improved. Spring-neap tides, total suspended matter (TSM) and river discharge are suggested as important controlling factors for the variability of Chl-a in Ariake Bay based on mostly field observations. However, the variability of satellite Chl-a over the spring-neap tidal cycle has not been investigated in Ariake Bay yet. Accordingly, we conducted the followings: 1) Improve the accuracy of MODIS-Aqua Chl-a in the turbid Ariake Bay (Chapter 2). 2) Investigate the variability of Chl-a over the spring-neap tidal cycle in the turbid Ariake Bay, using a 16-year (2002-2017) of improved MODIS-Aqua dataset (Chapter 3).

In Chapter 2, the accuracy of MODIS-Aqua Chl-a for the turbid Ariake Bay was improved by addressing both the atmospheric correction and in-water algorithm. Due to the existence of aerosols in the atmosphere and turbidity of the water, the standard atmospheric correction of MODIS often causes under- or over-estimation of remote sensing reflectance (Rrs) in the blue bands. With the data of Ariake Bay we applied the recalculation method of Hayashi et al. (2015) developed for Ise and Mikawa Bay to conquer the underestimation of Rrs by the absorptive aerosol. This method assumes that the error in Rrs(λ) is linear between the wavelength of 412 to 547 nm and the error in MODIS Rrs(547) was negligible. We improved this method by applying it not only for the underestimation but also the overestimation of Rrs. Furthermore, the standard in-water algorithm for MODIS Chl-a, OC3M, is affected by suspended sediment and coloured dissolved organic matter (CDOM) in coastal waters, which results in over- or under-estimation of Chl-a. Therefore, a new empirical switching algorithm was generated based on the relationship between in situ Chl-a and the band ratio of max(Rrs(443), Rrs(488))/Rrs(547) used for OC3M. The criterion of Rrs(667) of 0.005 sr^{-1} was used to evaluate the extent of turbidity for the switching algorithm. The results showed that the switching algorithm is better than OC3M, as the root mean square error (RMSE) of estimated Chl-a decreased from 0.414 to 0.326. The accuracy of MODIS Chl-a was improved by combination of recalculated Rrs and the switching algorithm, and RMSE decreased from 0.610 to 0.287. For an independent validation dataset, the accuracy of recalculated MODIS Chl-a was also improved and the RMSE decreased from 0.412 to 0.335.

In Chapter 3, the variability of Chl-a over the spring-neap tidal cycle in Ariake Bay was investigated with 16-year of improved MODIS dataset. Composites for the four tidal stages, namely spring to neap, neap, neap to spring, and spring tide, and the spatial-average were

produced, and annual and seasonal climatology and the individual cycle were analyzed. The Chl-a peaks generally occurred during the neap and neap to spring tide when TSM was low, and Chl-a decreased in spring tide when TSM was high. Spatially averaged Chl-a was inversely correlated with TSM, and it is expected that the light availability controlled by the tidally resuspended TSM was the important factor for the variation in Chl-a over the spring-neap tidal cycle. In addition, Chl-a was highest in summer when river discharge was also the highest, suggesting that river discharge was an important factor for the seasonal variation in Chl-a.

The results of this study generally suggested the followings: 1) The accuracy of MODIS-Aqua Chl-a for the turbid Ariake Bay was effectively improved by a combination of the simple Rrs recalculation method and the local switching algorithm. 2) The variability of Chl-a over the spring-neap tidal cycle was revealed by 16-year of improved MODIS-Aqua dataset. 3) Ocean color satellite data can be used to understand the variability of Chl-a over the spring-neap tidal cycle in coastal bays.