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SUMMARY OF DOCTORAL THESIS

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Title: Synthetic Aperture Radar Application for Tropical Peatlands Monitoring Activity in Indonesia

（インドネシアにおける熱帯泥炭地管理のための合成開口レーダー画像の応用に関する研究）

Tropical peatlands acknowledged as one of key ecosystems among the high-carbon reservoir ecosystems due to their huge carbon and water storage, their effect on coastal ecosystems, and their role in preserving bio-resources and biodiversity. Furthermore, tropical peatlands play an important role in the global carbon balance, and thus have a direct relationship with global climate change processes. Unfortunately, tropical peatlands are now being subjected to a rapid economic development without full consideration to the sustainable management principles and practices of tropical peatlands, which has led to large increases in carbon emission.

Concurrently, the importance of tropical peatlands as a long-term carbon sinks and stores, their tendency to become a short-term source of carbon emission, and their significant role in climate change processes, have been receiving tremendous interest during the past two decades. These concerns should be initially responded to via an accurate inventory of tropical peatlands to obtain a better understanding of the sustainable management principles and practices of tropical peatlands, as well as to improve the foundation of knowledge in tropical peatlands monitoring activity. Nevertheless, tropical peatlands cover relatively large areas and are primarily located in remote areas that are difficult to access. Thus, it is obviously challenging to develop reliable methodologies for monitoring the vast areas of tropical peatlands, especially in Indonesia where the largest portion of the tropical peatlands is located.

Remote sensing (RS) application is recognized as one of the most suitable tool to monitor the vast areas of tropical peatlands, as in situ measurements are generally time-consuming, labor-intensive and limited by accessibility. Furthermore, the recent development of synthetic aperture radar (SAR)-based RS satellites has introduced an advanced prospect that enables continuous monitoring and cloud-free observation in humid tropical regions, particularly for tropical peatlands monitoring activity in Indonesia. The primary objectives of this study are to explore the ability of L-band Advanced Land Observing Satellite (ALOS) Phased Array type L-band SAR (PALSAR) fully polarimetric data for tropical peatlands identification, to evaluate the performance of L-band ALOS PALSAR dual-polarization and fully polarimetric data for tropical peatlands classification, as well as to investigate the potential of C-band dual-polarization Sentinel-1 data for peat depth classification, in response to the emerging SAR-based RS applications for tropical peatlands monitoring activity.

The first topic of this study was carried out to investigate the use of L-band ALOS PALSAR fully polarimetric data for identifying tropical peatlands in two study areas situated in Kahayan River catchment area, Central Kalimantan Province, Indonesia. Specifically, three polarimetric decomposition (PD) theorems and the radar vegetation index (RVI) were evaluated for their capability to identify tropical peatlands characteristics from the viewpoint of L-band SAR fully polarimetric data. This study has suggested that SAR-based RS application serves as an efficient tool in tropical peatlands identification, such that the combination of classes derived from unsupervised classification of polarimetric features of Freeman-Durden tree-component decomposition integrated with

the broad-interval (calculated by mean and standard deviation values) class of RVI value that generated from L-band ALOS PALSAR fully polarimetric data was successfully identified the existence of tropical peatlands. Thus, the tropical peatlands identified in study area 1 yielded a producer's accuracy (PA) of 75.8% and a user's accuracy (UA) of 80.9%, whereas those in study area 2 gave accuracies of 77.6% and 76.0% for PA and UA, respectively.

The second topic of the present study evaluated the performance of L-band ALOS PALSAR dual-polarization data, fully polarimetric data, and their data combinations for tropical peatlands classification in Siak River transect, Riau Province, Indonesia. Thus, polarimetric features derived after PD theorems, backscatter coefficients measurements, and the RVI were evaluated to classify tropical peatlands using the decision tree (DT) classifier. This study has found that the classification results of the dual-polarization data were inferior to the fully polarimetric data, indicating that the fully polarimetric data were more suitable for classifying tropical peatlands. Furthermore, the integration of topographic-derived data in the SAR-based tropical peatlands classification was found to be effective in improving the classification accuracy, whereby in this study, the feature "distance to river" increased the classification accuracy by nearly 10% for overall accuracy (OA) and 15% for Kappa coefficient (K) when integrated with the polarimetric features derived by the combination of dual-polarization and fully polarimetric data by means of the DT classifier. Additionally, the seasonal variation of tropical peatlands was discovered, in which the existence of tropical peatlands in a land use/cover without the presence of vegetation was not influenced by the seasonal condition. In contrast, the existence of tropical peatlands in a land use/cover with the presence of vegetation was influenced by the seasonal condition.

The third topic of this study examined the potential of C-band dual-polarization Sentinel-1 data for peat depth classification on oil palm plantations in Siak Regency, Riau Province, Indonesia. Particularly, the ground-range radar cross section (σ^0) and slant-range perpendicular radar cross section (γ^0) for both polarization channels — vertical transmit-horizontal receive (VH) and vertical transmit-vertical receive (VV) — of Sentinel-1 data were compared and evaluated, on monthly basis, during 2015, for discriminating peat depth classes using the DT classifier. This study has suggested that γ^0 features yielded better performance in discriminating peat depth classes. By applying γ^0 features, the distance factor (DF) values of the initial class pair increased as much as 11.5% and 13.3% for VH and VV polarizations, respectively. Furthermore, the classification results gave the best accuracy for the very deep-peat class, with 76% and 67.86%, of PA and UA, respectively, followed by the shallow-peat class that yielded a PA of 64% and UA of 80%. Subsequently, the deep-peat class produced a PA of 58% and UA of 59.18%, whereas the medium-peat class yielded the lowest PA and UA, of 54% and 49.09%, respectively. In addition, the seasonal variation of rainfall intensity was discovered to be influencing feature selection for peat depth classification. Thus, the combination of γ^0 features derived in the much rain months was selected for separating the shallow- and medium-peat classes, whereas those derived in the less rain months was selected for discriminating the deep- and very deep-peat classes.

To conclude, the present study has been successfully developed methodologies for tropical peatlands identification by means of L-band SAR fully polarimetric data, for tropical peatlands classification by using L-band SAR dual-polarization and fully polarimetric data, as well as for peat depth classification on oil palm plantations by utilizing C-band SAR dual-polarization data. In general, the results and findings of this study could aid in increasing the foundation of knowledge regarding the tropical peatlands monitoring activity, involving the use of both L- and C-band SAR data, as an initial response to actualize the sustainable management principles and practices of tropical peatlands in Indonesia. Finally, this study might serve as a contribution to the development of the emerging SAR-based RS applications for monitoring environmental issues in agriculture, especially in the studies of tropical peatlands monitoring activity.

Keywords: ALOS PALSAR, Sentinel-1, dual-polarization, fully polarimetric, polarimetric decomposition, radar vegetation index, decision tree classification