Summary of Doctoral Dissertation

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3D Reconstruction of Typhoon and Isolated Cumulonimbus Clouds Using Satellite, Airborne and Ground Cameras
（衛星、航空機および地上での撮像に基づく台風と積乱雲の 3 次元構造推定）

Typhoons and torrential rain are weather phenomena that inflict damages and casualties, especially in the heavily populated East and South-east Asian countries. Because of this, measuring their intensity accurately can help mitigate the hazards that they bring. However, the analysis of typhoon (size, shape of clouds and development rate) is difficult to perform because of its chaotic behavior and environmental factors that affect it. According to studies, the essential parameters to estimate typhoon intensity from remote sensing are cloud morphology, cloud-top height, and cloud profiling information across the center of the storm. For stronger typhoons, the typhoon eye and eyewall are also more prominent, making them good indicators of typhoon intensity. In addition, typhoons and cumulonimbus clouds that could cause torrential rains have different spatial and temporal scales. This discrepancy in scaling makes it difficult to analyze clouds using a single imaging source. Thermal infrared from meteorological satellites that measures cloud altitude are unreliable because of inconsistent atmospheric temperatures. Furthermore, radar sensors have insufficient spatial and temporal resolution to measure small cloud particles. These show that the current methods have limitations.

In this research, a method was developed to analyze typhoons and isolated cumulonimbus clouds using stereo-photogrammetry from different imaging sources. We reconstructed the world's first three-dimensional model of typhoon (Typhoon Maysak, September 2020) and typhoon eye (Typhoon Trami, September 2018) using stereo-photogrammetry of satellite (Diwata-2) and aircraft images respectively. The result of the stereo-photogrammetric model from satellite images has 1.17 km/pix resolution with 2.64 pix projection error while the result from aircraft images has 6.08 m/pix resolution with 2.37 pix projection error. Multiple isolated cumulonimbus clouds were also modeled through stereo-photogrammetry of images from multiple ground cameras. The resulting 3D cloud resolution from ground observation at Edogawa City last August 14, 2019 has resolution of 1.85m/pix with with 4.34 pix projection error. Another observation was conducted at the same location on September 5, 2020 and the resulting 3D model has resolution of 4.5m/pix with 3.2 pix projection error. Our method has significantly higher resolution since most satellites and sensors have spatial resolution of 1 km at best, with the exception of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Diwata-1.

For each stereo-photogrammetric model, cloud-top altitude was also estimated, and were compared with the cloud-top altitude estimated from Himawari thermal infrared (TIR) and dropsonde data. The resulting altitude from stereo-photogrammetry shows that the cloud-top altitude of Typhoon Trami has approximately 14 km altitude and has huge overlap with the altitude estimate from TIR. However, cloud-top altitude of Typhoon Maysak has erroneous estimate due to large camera rotation angles of Diwata-2 that were not incorporated to the 3D reconstruction. The isolated clouds from the 2019 and 2020 observations at Edogawa City have ctop-top altitudes of 6.2 km and 3.4 km respectively. Both are approximately 2 km higher than their TIR-method cloud estimates. Since ground observations are conducted at Tokyo Bay coastline, the estimate difference is attributed to the effect of surface emissivity that might have contaminated the TIR data. The altitude profile of the models has good details of the cloud structures. Furthermore, this study suggests the idea of analyzing clouds in volumetric perspective and could help improve the accuracy of extreme weather prediction in the future.