3D Reconstruction of Typhoon Trami Using Air-borne images And Isolated Cumulonimbus Clouds Using Multiple Ground Cameras

*Meryl Regine Llenaresas Algodon[1], Yukihiro Takahashi[2], Mitsuteru Sato[2], Hisayuki Kubota[3], Jun Matsumoto[4], Kazuhisa Tsuboki[5], Hiroyuki Yamada[6]

1. Hokkaido University, Graduate School of Science, 2. Hokkaido University, 3. Hokkaido University, Faculty of Science, 4. Tokyo Metropolitan University, 5. Nagoya University, 6. University of the Ryukyus

Typhoons and torrential rains are weather phenomena that cause flooding and landslides, especially in the East and South-east Asian countries that are exposed to these extreme weather phenomena. In addition, the frequencies and intensities of typhoons and torrential rains are getting higher due to warming temperature. Because of this, measuring their intensity accurately can help mitigate the hazards that they bring. However, 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 for estimating 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. 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 typhoon eye and isolated cumulonimbus clouds using stereo-photogrammetry aircraft, and cameras located on the ground. The cloud-top altitude was then estimated from stereo-photogrammetric models and validated using Himawari-8 TIR and dropsonde data. For the aircraft reconnaissance, images of Typhoon Trami, a Category 5 typhoon that hit Japan last September 2018, was also captured using a monocular camera in the aircraft. Using stereo-photogrammetry, the first 3D model of a typhoon eye was reconstructed. The result of the stereo-photogrammetric model from the aircraft images has an area coverage of approximately 2,080 km2 with a ground resolution of 6.08 m/pix and a 2.37 pix projection error. The orthomosaic has a latitude range of 20.4°N to 20.9°N and a longitude range of 128.8°E to 129.6°E. The resulting altitude from stereo-photogrammetry shows that the cloud-top altitude of Typhoon Trami is approximately 14 km and has a huge overlap with the altitude estimate from TIR. The altitude profile from the stereo-photogrammetry has sufficient resolution to see the stair-step structure within the typhoon eye. This structure visualizes the eyewall replacement cycle of typhoons.
Multiple isolated cumulonimbus clouds were also modeled through stereo-photogrammetry of images from 5 ground cameras. The first ground observation was conducted at Edogawa City last August 14, 2019. Only 3 images were utilized for the reconstruction of the stereo-photogrammetric model. It has a resolution of 1.85m/pix with a 4.34 pix projection error and an area coverage of 151 km2. The estimated cloud-top altitude from the model is 6.2 km which is higher than its TIR estimate of 3.7 km. Unlike all the other data, this observation was also detected by a radar located in Matsudo City which is 18 km away from the target cloud. The cloud height estimated from the radar ranges from 691m to 2.05 km. Due to low temporal resolution, it is difficult to measure the exact cloud height range of the target cloud using the ka-band radar. Based from the undetected cloud at elevation angle 10°, we can assume that its cloud-top altitude is lower than 3.20 km.
Another observation was conducted at the same location on September 5, 2020 and the resulting 3D

model has an area coverage of 4.27 km2 with a ground resolution of 1.85 m/pix and a 3.2 pix projection error. The estimated cloud-top altitude is 3.4 km, 1.7 km higher than its TIR estimate.
From the results, our method shows significantly higher resolution than other imaging sources 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. This enables the reconstruction of the stereo-photogrammetric model using our imaging sources. In addition, the stereo-photogrammetric model of the isolated cumulonimbus cloud shows the continuous cloud height range unlike the TIR which estimates just the cloud-top altitude.This research was supported by SATREPS, funded by Japan Science and Technology Agency (JST) / Japan International Cooperation Agency (JICA).

Keywords: 3D Reconstruction, Typhoon Monitoring