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Abstract of Doctoral Dissertation

Degree requested: Doctor of Science Applicant's name: Syachrul Arief

Meteorological application of a dense GNSS network utilizing atmospheric delay gradient and crustal subsidence: The 2018 disastrous rain episode in SW Japan

(大気遅延勾配と地殻上下変動を利用した稠密 GNSS 網の気象学的応用：平成 30 年 7 月豪雨の事例研究)

Abstract

Heavy rain from late June to early July 2018 brought disastrous flood in Southwest (SW) Japan, especially in Kyushu. By using a dense array of Global Navigation Satellite System (GNSS) receivers in Japan GEONET, I study this episode with two different space geodetic approaches, i.e., measurements of atmospheric water vapor and crustal deformation due to surface water load.

The first approach is the recovery of Precipitable Water Vapor (PWV) using the zenith wet delays (ZWD). Because atmospheric water vapor concentrates in relatively low altitudes, ZWDs often represent the elevation of the observing stations rather than the relative humidity of the air column above the stations. To overcome the difficulty, I reconstructed ZWDs converted to sea-level values by spatially integrating the tropospheric delay gradient (azimuthal asymmetry of water vapor) vectors from coastal GNSS stations. I also calculated convergence of such delay gradients, equivalent to water vapor convergence (WVC) index proposed by Shoji (2013). I found that extreme rainfall occurs in the region and time where both the sea-level ZWD and the WVC index are high. I confirmed this was the case also for similar disastrous heavy rain episodes in SW Japan in 2017 July and 2019 August.

Next, I studied vertical crustal movements associated with surface water loads brought by heavy rainfall, using the official F3 solution of the GEONET station coordinates. Rainwater would act as the surface load and depress the ground to a detectable level. I removed common mode errors by adjusting ~100 reference stations to the median positions over ~1 month period using the Helmert transformation. I confirm land subsidence of up to ~ 2 cm in some areas where major flooding occurred. Land subsidence was observed to recover with a time constant of 1-2 days, which reflects the rapid drainage of rainwater into the sea due to the large topographic slope of the Japanese Islands and the proximity of the flooded areas to the sea. Then, I estimated the distribution of surface water load over the entire SW Japan using the GNSS station subsidence as the input. The estimated distribution of surface water resembled to the rainfall distribution from the AMEDAS rain gauge data from Japan Meteorological Agency (JMA).

We then compared the amount of water of the 2018 heavy rain episode using the three ways, i.e. (1) spatially integrated PWV, (2) cumulative rainfall from AMEDAS rain gage, and (3) surface water distribution estimated from crustal subsidence. Cumulative rain was larger than atmospheric PWV, which is reasonable considering that the atmospheric water vapor only represents the capacy of the "bucket" to carry sea water to land. Regarding the comparison of the rain gauge data and the surface water estimated from crustal subsidence, the latter largely exceeded the former. One possibility is that the Amedas rainfall data are underestimated. In general, AMEDAS stations tend to be built in low-altitude valleys, and may not represent true amount of rainfall over the whole land. Another reason would be that surface water may indicate cumulative rain over the multiple days.

I performed similar studies using GNSS data taken at stations in Indonesia. I processed the raw GNSS data to determine ZTD and PWV values using open-source software packages such as goGPS. I validated the estimated tropospheric parameters with those from other research centers, such as University of Nevada Reno (UNR). Next, I appled the methods to the disastrous heavy rain events that caused floods in Jakarta in early January 2020. I confirmed the PWV time series and crustal subsidence associated with this event.