

Analysis of the PWV variations observed by a hyper-dense network of GNSS receivers prior to localized rainfall

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Sudden and localized heavy rainfall events are posing increasing danger to urban areas, not only for the generation of floods, but also for the possibility to trigger landslides and damage crucial infrastructures. Numerical weather prediction models need to be supported by observations with sufficiently high spatial resolution, in order to be able to successfully forecast such localized precipitation events. To this aim, a crucial parameter to be monitored is the amount of precipitable water vapor (PWV), as well as its spatial distribution over the area of interest, and its variation over time. The Global Positioning System (GPS), which is one of the Global Navigation Satellite Systems (GNSS) currently available, has been increasingly used not only for positioning, but also for the remote sensing of physical parameters useful in Earth sciences. The PWV, or integrated amount of water vapor along the zenith direction, can be estimated by GPS (or GNSS) meteorology, which is a method that associates the amount of water vapor to the tropospheric delays which affect the signals of positioning satellites.

We deployed a dual-frequency (DF) GNSS network around Uji campus of Kyoto University, Japan, with inter-station distances of about 1-2 km. By using this network, we built a basic system to observe PWV fluctuations occurring within a small horizontal scale (less than 10 km), which are then analyzed to identify possible precursors of local torrential rain. Results from two observation campaigns (executed in the summer of 2011 and 2012) to retrieve and study GPS-derived PWV showed that its difference from other meteorological instruments was at most 2 mm in RMSE. We analyzed the variations of PWV detected when localized heavy rain was observed on July 9 and 25, 2012. Both the averaged value and the variance of PWV among GNSS stations increased before a nearby meteorological radar detected the rain clouds. In the latter case, the relative value of PWV among stations was larger than 5 mm.

For turning this system into practical use, e.g. for supporting a heavy rain early warning system, real-time satellite orbit and clock products are required. To estimate and correct the error of predicted satellite clock information, we used stations from the existing nation-wide GPS network in Japan (GEONET), with long baselines (~100 km). The difference between the real-time PWV and that obtained in post-processing by means of precise orbit and clock products was 1.5 mm in RMSE.

Furthermore, the cost-effective deployment of hyper-dense GNSS networks over urban areas would benefit from the usage of inexpensive single-frequency (SF) receivers. We implemented and tested a software application that estimates and interpolates the ionospheric delay from DF stations surrounding the hyper-dense network, in order to compensate SF observations for the effect of the ionosphere, according to a method called SEID (Satellite-specific Epoch-differenced Ionospheric Delay), which was originally developed at the GFZ in Potsdam, Germany. By applying SEID for SF PWV retrieval, the error in terms of PWV with respect to the DF solution was about 1.6 mm in RMSE. The PWV horizontal distribution obtained by SF analysis with this model could detect localized PWV inhomogeneity emerging prior to a rainfall which occurred within a small horizontal scale (less than 10 km).

Keywords: GNSS, GPS, PWV, precipitation, tropospheric delay, ionospheric delay