Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

AAS24-P06 Room:Convention Hall Time:May 21 17:15-18:30

Basic research of now-casting system for severe storms by using a dense GPS network

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The frequency and intensity of torrential rains are increasing. Though localized horizontal inhomogeneities of water vapor distribution were observed prior to such kind of rainfalls in historical cases, these phenomena occur suddenly and have a horizontal scale of a few kilometers. So, local heavy rainfalls are difficult to predict by current weather forecasting systems or models.

The integrated amounts of water vapor along to the zenith direction (or PWV, precipitable water vapor), can be estimated from the troposphere-induced delays in GPS signals (GPS meteorology). PWV estimation by GPS meteorology, using the nation-wide Japanese GPS network: GEONET cannot achieve enough horizontal resolution to predict local heavy rainfalls since the network is deployed with inter-station distances of about 20 kilometers.

We propose the system for real-time monitoring of high accuracy PWV horizontal distribution with a few kilometers scale which is considered to be beneficial to predict localized heavy rainfall by using a dense GPS network.

We deployed a dual-frequency GPS receiver network for PWV estimation around Uji campus of Kyoto University with inter-station distances of a couple of kilometers. We executed an observation campaign on July and August 2011 to test the accuracy of GPS-derived PWV, by comparison with radiosondes, LIDAR and radiometer. PWV comparison between GPS and LIDAR showed a significant difference: 4.0 mm in RMSE due to the height limit of LIDAR observations. GPS-derived PWV difference with radiosondes and radiometer was at most 3.00mm in RMSE.

We have developed the basic components of a system for monitoring, interpolating, and visualizing PWV derived from the GPS receiver network. Semi-real time data from dual frequency GPS receiver network can be visualize.

The impact of real-time satellite orbits and clocks, such as IGS ultra-rapid products which are needed if we run this system for real-time analyses was tested. The error introduced by the use of ultra-rapid orbits and clocks was considered to be avoidable by differential positioning.

For turning this system to practical use, we can reduce cost for GPS network significantly, at least about 70%, if single frequency receiver could be deployed instead of dual frequency receiver. However, in single frequency receiver processing ionospheric delay information is required to achieve high accuracy troposphere-induced delay solution because small scale perturbation of ionospheric delay between two GPS stations cannot be removed even with differential processing.

We thus investigated the performance of a local ionosphere model, which is needed to build up the system with single frequency GPS receivers, generated with the dual frequency GPS stations around the single frequency receiver network.

The results showed that interpolated ionospheric model at 10-20km scale, using stations in the GEONET, can work as well as an ionospheric model generated by dense GPS network used in this work. Even when TEC(total electron content) in ionosphere varies much, difference of estimated troposphere-induced delay between single frequency analysis with ionospheric model and dual frequency analysis was less than 4.5 mm in RMSE. Since this amount of deference in delay of GPS microwave is equal to 0.7 mm difference in PWV, it seems to be possible to build now-casting system for severe storms by using single frequency GPS network.

From 30 minutes before the time of sunset/sunrise estimated at the height of the ionosphere to 30 minutes after that time, the error of the ionospheric model was observed to change significantly. These results suggest that there is about 1 hour latency from the time which sunray starts or ends up to light ionosphere to the time which TEC variation becomes much, at the estimated height of ionosphere.

Keywords: Extreme weather, GPS meteorology, Precipitable Water Vapor, Severe storms, Now-casting, Ionospheric disturbance