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Title	<Abstracts (PhD thesis)>A study of water vapor variability associated with deep convection using a dense GNSS receiver network and a non-hydrostatic numerical model
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Citation	Sustainable humanosphere : bulletin of Research Institute for Sustainable Humanosphere Kyoto University (2016), 12: 25-26
Issue Date	2016-11-15
URL	http://hdl.handle.net/2433/225913
Right	
Type	Departmental Bulletin Paper
Textversion	publisher

Kyoto University

ABSTRACTS (PH D THESIS)

A study of water vapor variability associated with deep convection using a dense GNSS receiver network and a non-hydrostatic numerical model

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The characteristics of water vapor variability associated with the initiation and evolution of deep convection were investigated by using Global Navigation Satellite System (GNSS) meteorology technique and a meso-scale non-hydrostatic numderical model (NHM). The local scale spatio-temporal variability of precipitable water vapor (PWV) was analyzed by using a dense GNSS receiver network installed around Uji, Kyoto, with inter-station distances of about 1-2 km. The PWV data were used to validate the NHM results and to investigate the optimum scales of water vapor measurement for predicting deep convection by conducting a data assimilation experiment. Next, an observational campaign was conducted in Indonesia to elucidate the feasibility of GNSS meteorology and meso-scale NHM in the tropical region.

First, observational system simulation experiments (OSSE) were performed to investigate the improvement of local-scale PWV measurement due to increased horizontal resolution of GNSS-derived PWV. Local-scale PWV fluctuations were smoothed out previously, because all slant path delays above a low elevation (5°−10°) cut off were averaged to estimate a single PWV value in the conventional procedure. In this study, only high elevation Quasi-Zenith Satellite System (QZSS) (higher than 80°) and GPS (higher than 60°) were selectively used to estimate PWV. The simulation result showed that meso-γ scale PWV fluctuations can be observed by this method.

Secondly, a case study was conducted to understand the mechanisms of PWV variation during a heavy rainfall event on 14 August 2012 in Uji, by comparing the GNSS-PWV and the downscaled 250 m mesh model data. Although a simulated convection was initiated at slightly different place and time from the observation result, the model successfully simulated the observed rapid increase of PWV prior to the surface rainfall. In the model, the local PWV maximum began to form about 16 min before the surface rainfall due to wind convergence near the ground. Five minutes later, free convection was initiated at approximately 1 km elevation by the preceding surface wind convergence. Due to the existence of a stable inversion layer between 2.2 and 3.5 km elevation, the shallow free convection took 11 min to rise above the inversion layer to form a deep convection. It was found that low-level wind convergence caused the local increase of PWV prior to generation of deep convection.

Third, the high-resolution PWV data derived from the Uji network were assimilated to a nested NHM-LETKF system, and the optimum scales of water vapor measurement for predicting deep convection was investigated. From the analysis of the observed Zenith Wet Delay derived from the Uji network, it was found that horizontal scale of water vapor variability became small (1.9-3.5 km) when it rained around the Uji network. The data assimilation experiments showed that simulation accuracy of one hour accumulated rainfall amount was most improved when the PWV data were assimilated with horizontal resolution of 3.5 km that was consistent with the observed horizontal scale of the water vapor valiability. In addition, it was found that influence of observation error correlation of PWV can become smaller by

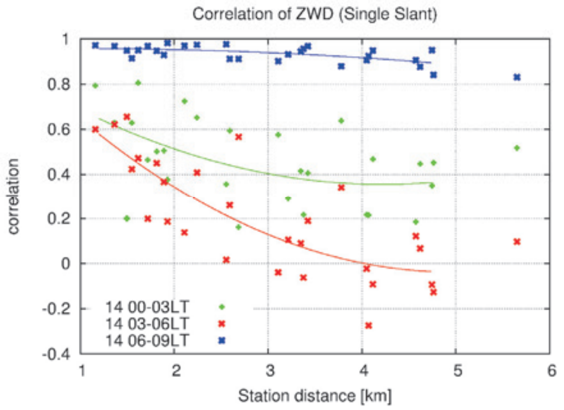

Figure 1. Horizontal distance dependency of correlation of ZWD converted from highest elevation single slant delays derived from the Uji network during rain-free (blue), weak rain (green), and heavy rain (red) periods. Curves are fitted second degree polynomials.

assimilating PWV which were converted from highest elevation single slant delays instead of using conventional PWV data. Analysis of the assimilated model data revealed that the observed local PWV increase at the north edge of the rain band was formed by wind convergence above planetary boundary layer induced by clockwise rotating vertical wind shear.

Based on these outcomes, the studies using GNSS meteorology method and NHM were applied to Indonesia which is the most active convective region in the world, because GNSS receiver networks are rapidly being constructed whereas operational meteorological networks are insufficient. An intensive observation campaign using GNSS receivers, radiosondes, and X-band Doppler radar was carried out in 2013 in the Bandung basin which is as small as about 20 km. Relations between water vapor variability inside the small basin and convective initiation was investigated by analyzing the observation data and downscaled NHM data. The model results successfully reproduced the observed deep convection and showed that static stability around the southern slope of the basin decreased due to moisture transport from the bottom basin by a thermally-induced circulation that formed low-level wind convergence with deepened moist convective mixed layer at the southern basin and decreased moisture at the northern basin. The simulated local-scale water vapor variability was also observed by the GNSS receiver network. It was suggested that water vapor at the bottom basin in the morning and low-level wind convergence induced by the local circulation are important for convection initiation in Bandung.

This is the first study that demonstrated that high-resolution PWV data assimilation with inter-station distances of less than 10 km can improve simulation accuracy of localized heavy rainfall. The revealed characteristic scale of water vapor variability and optimum scale for PWV assimilation was about 3.5 km. The use of a dense GNSS receiver network and high elevation GNSS satellites like QZSS is the best way to retrieve the local scale water vapor variability and it is important to assimilate the high resolution PWV data into a numerical weather prediction model.