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Estimation of Several Kilometer Scale PWV Distribution using GNSS Slant Path Delay for Monitoring of Cumulus Convection

SHOJI, Yoshinori[1*]

[1]Meteorological Research Institute

A procedure for estimating precipitable water vapor (PWV) distribution around each ground-based station of the global navigation satellite system (GNSS) on a scale of several kilometers is presented. This procedure utilizes the difference between zenith total delay above a GNSS station and zenith mapped slant path delay (SPD). By assuming an exponential distribution for the horizontal water vapor gradient, this difference can be used to estimate the PWV gradient in each SPD direction. Shoji (2013) proposed the WVI index, which is defined as the standard deviation of the PWV_{SPD}. The retrieved PWV gradient in this study can be regarded as another utilization of PWV_{SPD}. In the WVI index, ray path direction data is not utilized. The PWV gradient proposed in this paper utilizes both the deviation of PWVSPD and information on its direction.

The procedure was tested for an estimation of the PWV variation associated with the parent storm of an F3 Fujita scale tornado that occurred in Ibaraki prefecture on May 6, 2012. Differential reflectivity observed by a dual-polarimetric radar showed the existence of a developed parent cloud approximately 1 h before the tornado occurred. A high-resolution numerical weather model simulation showed the existence of a strong PWV gradient around the parent cloud, made evident by the co-existence of a strong updraft and downdraft within an approximately 5-km radius. The PWV gradient calculated using the GNSS observation network with an average spacing of approximately 17 km could not detect such a small-scale, strong PWV gradient. The PWV gradient estimated using the proposed procedure revealed a strong PWV gradient and its enhancement. In this case, higher order inhomogeneity component of each SPD played a critical role.

However, the gradient was weaker than the NWP simulation. This might be partly because of the insufficient observation density. Horizontal scale of the higher order inhomogeneity component of each SPD is about several kilometers and we adopt distance cutoff of 5 km. In order to analyze several kilometer scale PWV distribution, we need denser GNSS network with at least 10 km horizontal spacing. Another possible reason for the weaker gradient may be insufficient and inhomogeneous coverage of GPS satellites. As of 2012, carrier waves transmitted from six to twelve GPS satellites could be observed simultaneously at each GNSS site in Japan. This might be insufficient for estimating the water vapor gradient in all directions. Also, we need to carefully check the quality of each SPD. In this study, following Shoji (2013), the effects of the satellite clock error and multipath (reflected wave) are tried to eliminate. However it is difficult to distinguish atmospheric signal with those noises, especially under local severe weather.

The number of GNSSs has been increasing. As of December 2013, 24 satellites of the Russian GLONASS are in operation. The European Union's GNSS (Galileo) is in the experimental phase and China is also developing an independent GNSS system named COMPASS. Furthermore, a number of space-based augmentation systems (e.g., Japan's QZSS) and regional navigation satellite systems (e.g. the Indian Regional Navigation Satellite System, or IRNSS) will contribute further satellites and signals to the multi-constellation GNSS. In the next step of this study, we will assess the impact of the increased number of SPDs on multi-GNSS.

Keywords: Mesoscale meteorology, Watervapor, Global Navigation Satellite System