An assimilation experiment of GPS-derived water vapor observations on a local heavy rainfall event

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1. Introduction

The Meteorological Research Institute of the Japan Meteorological Agency (JMA) has been developing a nonhydrostatic cloud-resolving 4DVAR assimilation system (NHM-4DVAR; Kawabata et al. 2011) based on the JMA operational mesoscale model (NHM). The aim of this development is to investigate mechanisms of strong convection. A forward model of NHM-4DVAR is a full nonlinear JMA-NHM (Saito et al. 2007), while the tangent linear and the adjoint models consider perturbations to the dynamics and the warn rain cloud microphysics process. Horizontal resolution is 2 km.

In this paper, an assimilation experiment on a local heavy rainfall event occurred on 19 August 2009 in Okinawa Island, Japan is presented, and comparisons of assimilation methods of GPS data (precipitable water vapor (PWV), GPS zenith total delay (ZTD), and GPS slant total delay (STD)) data are discussed.

2. GPS-derived water vapor observations

First, slant total delay amounts of radio waves from GPS satellites to receivers are observed at each GPS observation site (STD). It is possible to observe several STDs at one GPS observation site at the same time. These data are mapped to the zenith direction and averaged (ZTD). Since radio-wave delay is affected by dry atmosphere and water vapor (Eq. 1) and these delays are separated, we can obtain information on accumulated wet atmosphere (PWV). Figure 1 illustrates above methods. PWV and ZTD have information on water vapor in the zenith direction only above the observation site, while are affected by several factors of atmospheric conditions (pressure, temperature, and water vapor). On the other hand, STD has vertical and horizontal information of several factors of the atmosphere. This characteristic of STD is advantageous to reproduce small scale phenomena (e.g., cumulonimbus), especially, for a high resolution assimilation system.

We have developed the assimilation method of STD; Delay amount is calculated with Eq. (1) at each model grid box and integrated along a radio wave path. Since the model top height of NHM-4DVAR is about 20,000 m, we assume that delay amount above the model top level

$$(n-1)\times 10^6 = K_1\left(\frac{P_d}{T}\right) + K_2\left(\frac{P_v}{T}\right) + K_3\left(\frac{P_v}{T^2}\right) \quad \text{.......... (1)}$$

n: refractivity, Pd: partial pressure of dry atmosphere, Pv: partial pressure of water vapor, T: temperature, K1, K2, K3: constants.

decreases exponentially and becomes zero at 200 km height Moreover, we introduced the observational error of STD depending on elevation angle of slant path.

Figure 2 show an example of delay amount at each model grid calculated with Eq. (1). These are distributed along radio slant path. Here, cold colored points show small amount of delay and locate in high levels, while

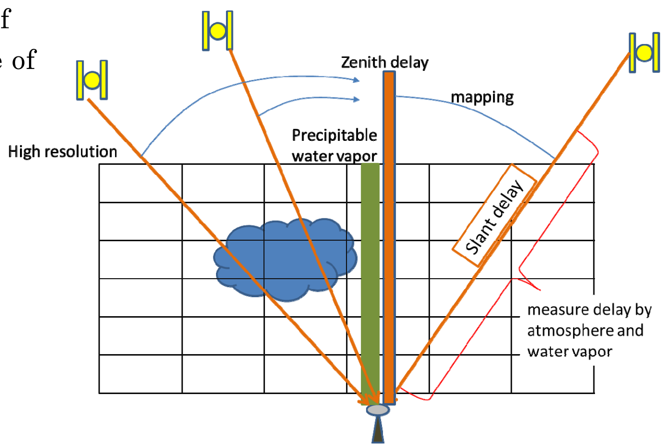

Figure 1. schematic of GPS-derived water vapor observations.

warm colored points show large amount of delay and locate in low levels. In addition, they distribute horizontally wide, thereby, STD provides horizontal and vertical atmospheric information.

3. Assimilation experiment

Impact test of GPS observation assimilation was conducted for a local heavy rainfall event on 19 August 2009 in Okinawa Island, Japan. A 1-h assimilation window was set from 11 to 12 JST (Japan Standard Time). After the assimilation, we conducted a 3-h forecast from 11 to 14 JST. GPS observations were processed according to Shoji (2009). Hereafter, the case in which first-guess field was used is called as 'BCK', the case in which GPS precipitable water vapor was assimilated is called as 'PWV', the case in which GPS zenith total delay was assimilated is called as 'ZTD', and the case in which GPS slant total delay was assimilated is called as 'STD'.

Figure 3 shows 1-h accumulated rainfall amount at 14 JST. In observation (Fig. 3a), intense rainfalls over 20 mm h^{-1} is seen in the southwest of Okinawa Island, corresponding rainfall areas are forecasted in STD (Fig. 3b). Only weak rainfalls are seen in PWV (Fig. 3c), though rainfall distribution of PWV and ZTD are slightly improved compared with BCK (Fig. 3d). Namely, two intense rainfall cells southwest of Okinawa Island are seen in the observation and PWV, but only one cell is seen in BCK. Result of ZTD was similar to that of PWV (not shown). From these results, we can say that assimilation of GPS observation improves the heavy rainfall forecast. Especially, STD data have a positive impact on intensity on the heavy rainfall forecast in a high resolution assimilation system.

Reference

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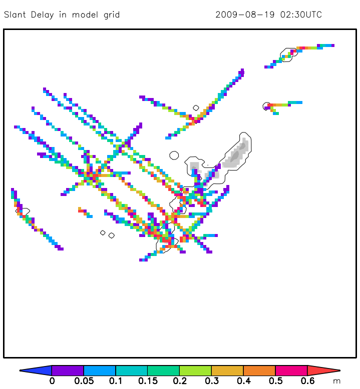

Figure 2. Horizontal distribution of delay amount on model grids. Delay amount on each model grid calculated with Eq. (1). Cold colored points show small amount. Warm colored points show large amount.

(a) (b) (c) (d)

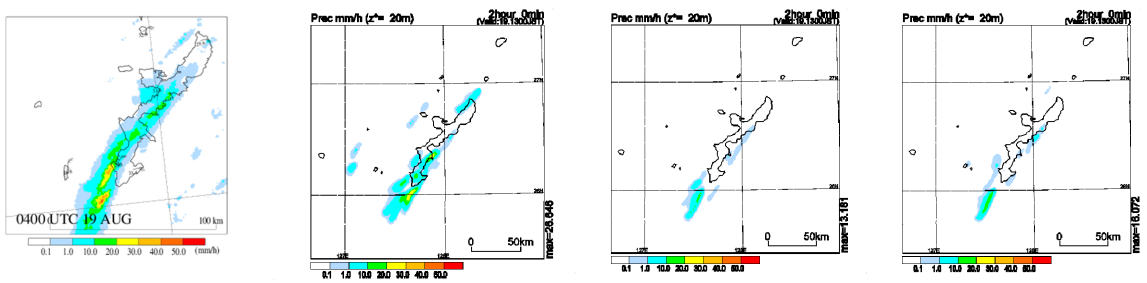

Figure 3. 1-h accumulated rainfall amount of (a) Observation, (b) STD, (c) PWV, (d) BCK.