Data Assimilation of GPS Precipitable Water Vapor into the JMA Mesoscale Numerical Weather Prediction Model

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1. Introduction

One of the most important objectives of mesoscale numerical weather prediction (NWP) is the precise identification of the timing and location of heavy rainfall, and NWP improvement is essential to enable quantitative forecasting of extreme precipitation with a lead time. The Japan Meteorological Agency (JMA) operates a mesoscale model (MSM) with a horizontal resolution of 5 km to forecast mesoscale events over the country's islands. The MSM operationally produces 15-hour forecasts four times a day (at 00, 06, 12 and 18 UTC initial times) and 33-hour forecasts four times a day (at 03, 09, 15 and 21 UTC initial times) to assist forecasters in issuing weather warnings. As a data assimilation system for the MSM, the nonhydrostatic mesoscale four-dimensional variational data assimilation system (JNoVA) was newly implemented in April 2009 in place of the hydrostatic Meso 4D-Var system.

Atmospheric delay in GPS (Global Positioning System) signals caused by precipitable water vapor (PWV) is one of the most important data types for improvement of MSM precipitation forecasts considering that moisture observations are insufficient compared with other meteorological variables. Since 1994, the Geographical Survey Institute (GSI) of Japan has deployed a nationwide ground GPS network called GEONET, which covers the entire Japanese archipelago and comprises more than 1,200 ground receivers a mean distance of 15 – 25 km apart (Figure 1). Although GPS data are primarily implemented for monitoring crustal deformation, they are also useful as water vapor sensors. Several studies have shown that water vapor information retrieved from GEONET has a positive impact on numerical weather prediction (NWP). JMA commenced operational use of GPS-derived PWV in NWP with JNoVA on October 28, 2009. Precipitation forecasting was improved by taking moisture information as an initial condition of the MSM.

2. Quality control

As Japan is characterized by steep mountainous terrain and MSM employs smoothed topography, large discrepancies exist between the GPS antenna height and the corresponding MSM surface height in mountainous areas. In order to adjust differences in the PWVs between the first guess and the GPS, the first guess PWV is interpolated or extrapolated from the model surface to the actual terrain surface as follows:
(1) If the model surface is higher than the actual terrain surface, the model PWV is extrapolated to the actual terrain surface by assuming that the specific humidity between the two surfaces is equal to that in the lowest model layer.
(2) If the model surface is lower than the actual terrain surface, the model water vapor between the two surfaces is subtracted from the model PWV.

Quality checking is mainly based on the presentable errors of the GPS PWV data. Observed GPS PWV data are discarded unless all of the following conditions are satisfied:
(1) The actual surface elevation is less than 500 m.
(2) The absolute value of the elevation difference between the model surface and the actual surface is less than 200 m.
(3) The observed GPS PWV is between 1 mm and 90 mm.
(4) The absolute value of the PWV departure is less than 8 mm from the first-guess value after height correction.

The horizontal grid spacing of the inner model of JNoVA is 15 km, but the spatial density of GEONET stations is higher than this in some places. In order to avoid over-fitting, GEONET station thinning is performed so that the spatial density of GPS observations becomes coarser than 30 km. Since JNoVA assimilates observational data with one-hour slots in a three-hour assimilation window, we evaluated the GPS-derived PWV for each clock hour.

3. Impacts of experiment

The experiment for the three-hourly forecast-analysis cycle was performed without and with GPS PWV data for the period 17 – 25 July 2006. During this period, 33-hour forecasts were made four times a day at 03, 09, 15 and 21 UTC.

Figure 2 shows the root mean square errors (RMSE) for the surface relative humidity of the 33-hour forecasts for the experimental period. The surface relative humidity errors for these forecasts taking GPS PWV to an initial condition are remarkably small.

Figure 3 shows that the GPS PWV has a significantly positive impact on precipitation forecasting. An improvement of the equitable threat score for the three-hour accumulated precipitation forecast is seen for moderate rain.

Figure 4 shows a case of heavy rain during the experimental period. Figures 4b and 4c show the forecast for three-hour accumulated precipitation amounts starting from analysis without and with GPS PWV, respectively. Figure 4a shows the corresponding observation for radar-raingauge analyzed precipitation. Without GPS PWV data, the amount shown in the precipitation forecast in the rainfall area of Japan's Yamaguchi Prefecture was much smaller than that of actual observation. With assimilation of GPS PWV (Fig. 4b), more precipitation is predicted and the precipitation pattern is closer to the results of observation.

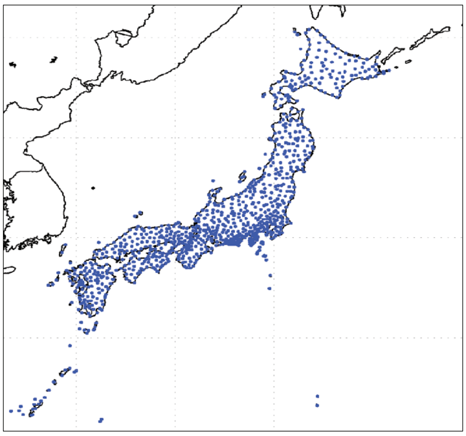

Fig. 1 Locations of GEONET sites over all the islands of Japan

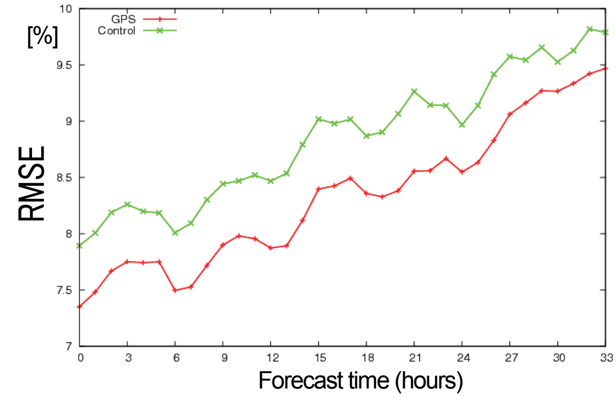

Fig. 2 RMSE of surface relative humidity for 33-hour forecasts for the period from 17 to 25 July 2006. This verification was used against hourly observations of relative humidity [%] by domestic SYNOP stations (at about 70 locations) and the calculated RMSE for observations in the forecast time. Forecasts starting from analysis with (red line) and without (green line) GPS PWV data are displayed.

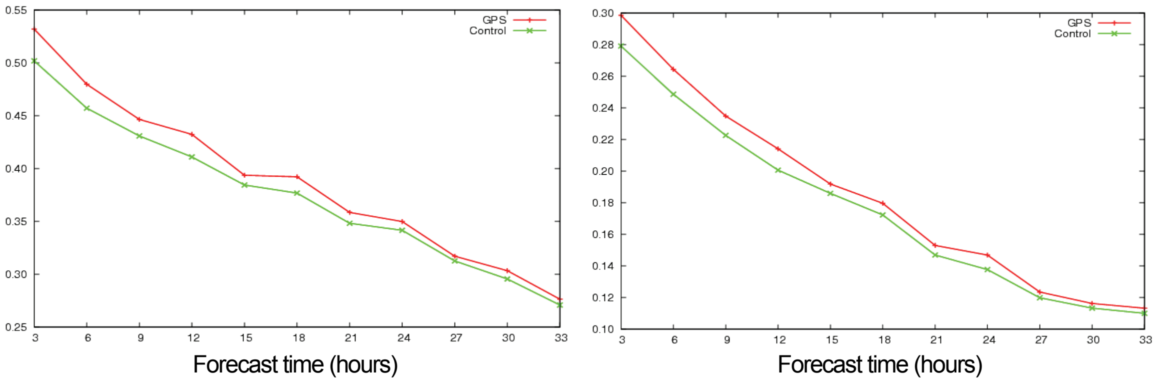

Fig. 3 Equitable threat score of 3-hour accumulated precipitation for 33-hour forecasts over Japan starting from analysis with (red lines) and without (green lines) GPS PWV data for the period from 17 to 25 July 2006. The threshold values are 1 mm (left) and 10 mm (right) with a verification grid distance of 10 km.

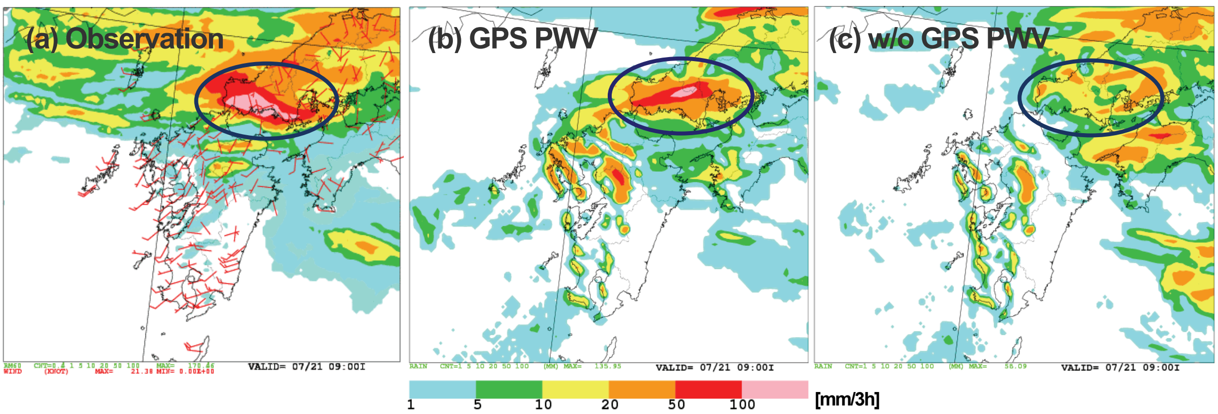

Fig. 4 Forecast FT = 00 – 03 and observations of three-hour precipitation amounts at an initial forecast time of 21 UTC on 20 July 2009. Left: radar-AMeDAS observations; center: forecast starting from analysis with GPS PWV; right: forecast starting from analysis without GPS PWV