Impact of assimilating the ground-based GPS PWV measurements with 3DVAR system for IHOP 12 June 2002 case

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1. Introduction

In the United States, the ground-based GPS PWV (precipitable water vapor) measurements are available hourly in real-time (about 50-min after the observed time) from three networks: SOUMInet, FLSnet, and CORSnet. There are total of 199 observed sites, but usually there are about 100 observations reported from these networks at each time period (Fig. 1). To exploit the information from this new type of observations, the MM5 3DVAR system, which is a new developed analysis tool, is used to assimilate this non-conventional GPS PWV measurement along with other conventional data.

A convective case (12 June 2002) during the IHOP IOP was chosen to assess the impact of the ground-based GPS PWV measurements on the NWP forecasts. A series of numerical experiments were conducted to identify effects from the GPS PWV data, 3DVAR assimilation system, and the assimilation strategy.

2. Ground-based GPS PWV data

The hourly GPS PWV data are provided by UCAR/GST (GPS Science and Technology group) starting from 21 April 2002 in real-time mode. In addition to the PWV and its observation error, the wet-delay, dry-delay, K-factor, as well as the surface pressure, temperature and relative humidity at the site, are also provided in this data. But in this study, we just assimilated PWV with its reported error.

First, we did a validation study for this new type of data with the MM5 model simulation, and to see if there is new information contained in this data. Figure 2 is a scatter gram between the observed GPS PWV and the model simulated PWV during a 24-h period from 12 UTC 12 to 12 UTC 13 June 2002 within our experimental model domain (Fig. 3).

![Figure 2. The scatter gram between GPS PWV observations and MM5 simulation. The coordinates have been scaled: the origin (0.0) equivalent to PWV = 2.1 mm, and the value of 1.0 equivalent to PWV = 57.8 mm. The line regression is the thick solid line. The total number of samples is 1013, and the correlation coefficient $r = 0.964$.](image)

From this figure, the observed GPS PWV has a high correlation with the MM5 simulation, but the model simulation has a small positive bias for the large values of PWV. GPS PWV mean is 29.83 mm and MM5 is 31.04 mm. The standard deviations for GPS
PWV and MM5 are 13.48 mm and 14.60 mm, respectively. On average, NWP may not gain too much from the ground-based GPS PWV data since the correlation coefficient has already been 0.964.

Figure 3 shows GPS PWV observations at 1200 UTC 12 June 2002, and the differences (O-B) between the observations and the Eta analysis (used as the background in 3DVAR).

Figure 3 shows that mostly the Eta analysis gave PWV few mm moister than the observed one over Oklahoma and Kansas area, but still some structures in the difference field (Fig.3b). Bearing in mind that Eta analysis has already blended the information from all upper air and surface observations, we expect that assimilation of the GPS PWV via 3DVAR would correct some PWV errors existed in the background.

3. Convective case on 12-13 June 2002

At 2200 UTC 12 June 2002, a convective line appeared from west Oklahoma to Texas panhandle. Two hours later, the squall line was well-developed from southeast Kansas to Texas panhandle. Figure 4 shows the hourly precipitation ending at 0000 UTC 13 June 2002 based on NCEP/OH Stage IV 4-km GRIB data of multi-sensor analysis. The maximum amount of rainfall reached 69.4 mm located at the middle of Kansas-Oklahoma border. Then, this rain-band moved southeastward, and after 0300 UTC the convection was gradually weakened and disappeared around 1000 UTC 13 June.

4. Experiment design

A set of numerical experiments was carried out: cold-start initiated at 1200 UTC 12 June, and 3-hourly cycling run started at 0000 UTC 12 June.
3DVAR experiments:
3DVALL: Both conventional and GPS PWV assimilated.
3DVPWV: Only GPS PWV assimilated.
3DVCON: Only conventional data assimilated.
3DV12C: 12-h cycling period with 4 3-h 3DVAR cycling.

The Eta analysis and forecast were used as the background fields in 3DVAR experiments, and provided the lateral and low boundary conditions for model forecasts. The first 3 experiments intends to identify the effects from GPS PWV data and 3DVAR analysis, and the last experiment is used to optimally use the frequent GPS PWV data in improving the convection forecast.

The model physics are exactly same in all experiments, which are MRF-PBL, Dudhia’s radiation scheme, multiple soil layers, Kain-Fritsch-2 cumulus parameterization scheme, and Goddard mixed phase scheme with graupel.

5. Results

To examine the results from the experiments, we use two approaches: 1) to compute the RMS errors verified against the observed GPS PWV during the 24-h forecast period; 2) to compute the threat scores of precipitation forecast verified against the NCEP/OH Stage IV hourly precipitation analysis.

1. RMS errors for PWV forecasts

The Figure 6a showed the PWV RMS errors during the 24-h forecast period for Set-1 of experiments. Except few hours (10-h, 11-h, and 23-h), the initial condition from 3DVAR analysis gave the lower errors than the control run (CONTRL). The lowest 24-h mean error, 5.07 mm, was resulted by assimilation of ALL the observations (3DVALL) and the highest one, 5.47 mm, from the Eta analysis (CONTRL). Assimilation of ONLY the CONVENTIONAL data with 3DVAR (3DVCON) reduced the error to 5.11 mm although the conventional data information should already been blended in the Eta analysis. This means that 3DVAR could extract more useful information from the same data. This may benefit from a) the analysis was completed directly in the model -coordinate; b) the dynamic constraints were implemented; c) the background and observation error statistics were used. Suppose that the Eta analysis has already blended all the conventional data information, in Exp. 3DVPWV, we only assimilated GPS PWV data with 3DVAR. The error is also reduced to 5.35 mm. It is clear that assimilation of the GPS PWV with 3DVAR system at the initial time 1200 UTC 12 June is not only reduced the PWV errors in analysis but also improved the PWV accuracies during the forecast period.

Figure 6b demonstrated the effects from the 3-h 3DVAR cycling runs assimilating the GPS PWV observations at multiple time periods. At the initial time, the 3DVAR analysis is closer to fit the GPS PWV, through four previous 3-h 3DVAR cycles, the error was reduced to 4.08 mm. Except the forecast hours 6 to 12, Exp. 3DV12C gave the lower RMS errors than those from the cold-start runs. Over 24-h averaged, the RMS error reduced to 4.99 mm, especially during the second half of 12-h forecast the errors are much lower than those from 3DVALL and CONTRL. Through the cycling run, the previous observed information (here mainly from GPS PWV data), and the information from model integration during 0000 to 1200 UTC 12 June are included in the
background fields at the initial time, 1200 UTC 12 June. Also there are more hydrometeor fields are included in the background although they were not updated by analysis.

Definitely more experiments are needed to understand the reasons why and how 3DVAR cycling runs improved the forecasts, such as why the errors between 6-h to 12-h forecasts so large? Anyway, the preliminary results from the cycling run 3DV12C showed a positive impact.

2. Threat scores for precipitation forecasts

(The work is still going on, and the results will be presented in Workshop.)

6. Summary and conclusions

In this study, the hourly ground-based GPS PWV data were collected during the year of 2002. The validation study was conducted with the MM5 model simulation for IHOP 12 June 2002 case. For a 24-h period from 1200 UTC 12 to 1300 UTC 13 June 2002, the observed GPS PWV data have a high correlation with the model simulation, but still has more useful information contained in it.

A series of numerical experiments were carried out to assess the impacts of assimilating the ground-based GPS PWV data with the 3DVAR system. From the verifications against the observed GPS PWV data, assimilation of GPS PWV data improved the accuracies of PWV forecasts. The 3DVAR system can extract more information from the same dataset than the Eta analysis while both GPS PWV observations and 3DVAR system play roles in this improvement of the accuracies.

To exploit the frequent availability of the ground-based GPS PWV observations, the 3-h 3DVAR cycling runs are also conducted.

In future, there are several aspects of work need to be done:

1. to refine the 3DVAR system for the fine grid (10-km or less) mesoscale model. Right now the background error statistics in these experiments is just adapted from the real-time forecast system without any tuning. Also the GPS PWV observation errors were used as it is, did not have tuned. We believe that as our experiences accumulated with the 3DVAR system, there are still rooms to improve our results.

2. to try to assimilate other more data from the ground-based GPS observations, such as wet-delay, dry-delay as well as the surface pressure, temperature, and relative humidity. Meanwhile, there are other types of the frequent observations available from Metar, wind profiler, etc., a synergetic use of all these high frequent measurements to improve the forecast of the convective events is a challenge work.

3. to refine the 3DVAR cycling procedure to optimally exploit information from the frequent GPS PWV observations, etc..

References: