FOUR-DIMENSIONAL VARIATIONAL DATA ASSIMILATION OF GROUND-BASED GPS WATER VAPOR DATA IN THE JUNE 12TH IHOP CASE

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1. INTRODUCTION

The accurate information on the moisture distribution is critical for the initiation of new convection or enhancement of existing convection (Weckwerth et al. 2005). Ground-based Global Positioning System (GPS) can provide accurate water vapor measurements by retrieving the microwave signal delay between GPS satellites in view and ground stations. In a few recent years, the advance of GPS retrieval techique has enabled to accurately retrieve slant water (SW) which is an integrated water vapor in the direction of each GPS satellite, instead of projecting all available slant water vapor measurements onto zenith and averaging them over a certain period of time to provide precipitable water (Ware et al. 1997; Braun et al. 2001).

International H_2O Project (IHOP_2002; Weckwerth et al. 2004) facilitated intensive observing network of ground-based water vapor remote sensing systems in the Southern Great Plain area. The ground-based GPS network, as one of the numerous observing systems in IHOP_2002, produced invaluable moisture data such as slant water and precipitable water (PW) with high accuracy.

In this study, using the four-dimensional variational data assimilation (FDVAR) system, a few experiments were performed to assess the impact of GPS slant water and precipitable water on the retrieval of horizontal moisture distribution in the squall line area.

2. OBSERVATIONS

On 12 June 2002, mesoscale convective systems are initiated around 2200 UTC across northwestern Oklahoma, which developed to squall line along the surface cold front after a few hours (Figure 1). It is apparent that there is a strong moisture gradient in the convective area. In this study, we focus on the moisture retrieval at convective initiation through data assimilation.

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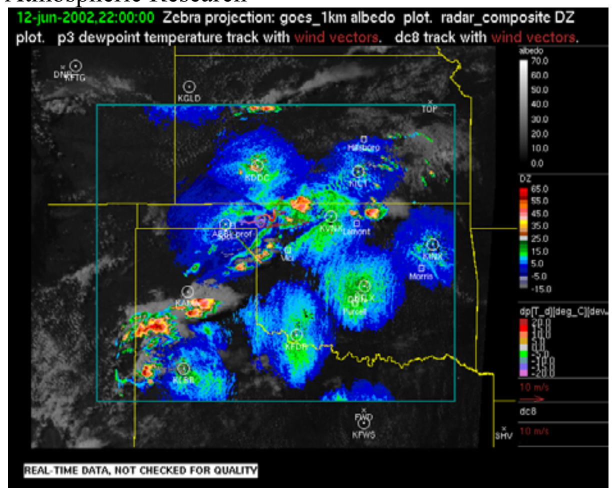


Fig 1. A real-time S-Pol radar composite map valid at 2200 UTC 12 Jun 2002.

The horizontal distribution of the observing systems used in this assimilation study is shown in Fig. 2. Slant water and precipitable water are retrieved at 32 GPS ground stations (blue open circle), u and v wind fields are assimilated at 12 NOAA wind profilers (red cross), and surface dew point temperature data are assimilated at 255 IHOP_2002 mesonet sites (black plus sign).

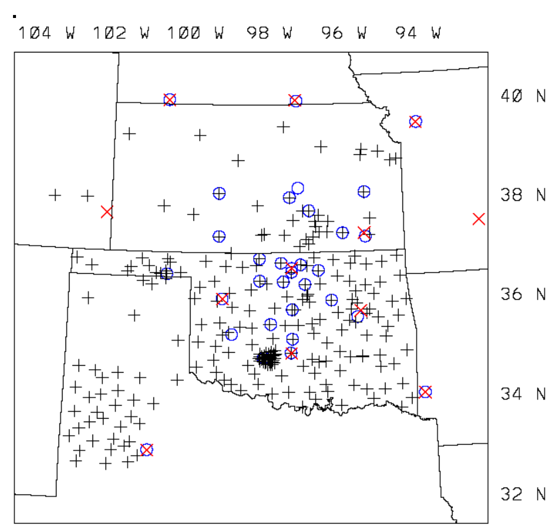


Fig 2. Distribution of the observations. Red cross (x) is wind profiler, black plus (+) is surface dewpoint, and blue circle is ground-based GPS SWD and PW.

Table 1. The observed data assimilated in FDVAR experiments.

Type of data	No. of sites	Data frequency	No. of data (each epoch)
GPS SWD	32	10 min	6~9 (α,θ)
GPS PW	32	30 min	1
Wind profiler	12	1 hour (average)	72 (z)
Surface dewpoint	255	5 min	1

Except the hourly wind profiler (Wprf) observations, all other data is considered as an instantaneous value, as summarized in Table 1. In this study, GPS slant water is assimilated in the slant wet delay (SWD) format, thereby the data is not contaminated by the error of conversion parameter, which is commonly obtained using surface temperature measurement (See equation (2.4) in Ha et al. 2003). Basically SWD can be retrieved every 5 seconds, but in this study, considering the model grid resolution, we assimilated SWD data every 10 minutes. As the number of GPS satellites in view is available up to 9 at any place at any time, 6 ~ 9 SWD data are measured at different azimuth (α) and elevation (θ) angles at each epoch. Figure 3 is a histogram of SWD data illustrating the distribution of slant ray path in terms of elevation and azimuth angles for 2 hours of assimilation window.

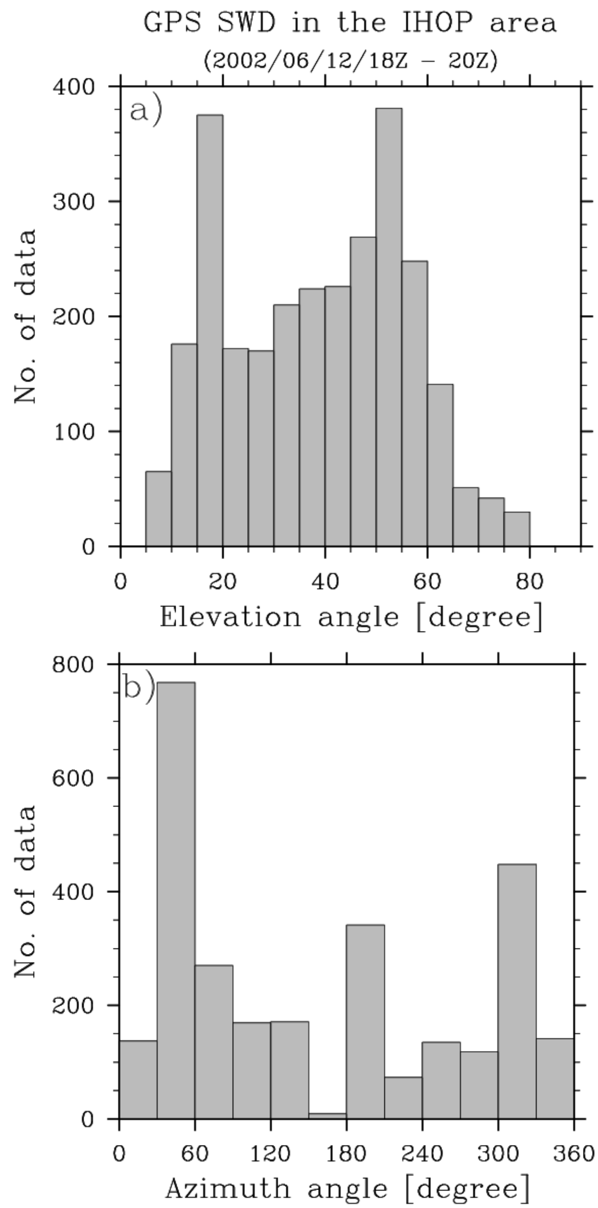


Fig 3. A histogram of GPS SWD data versus (a) elevation angle and (b) azimuth angle.

3. FDVAR EXPERIMENTS

All experiments are conducted over a grid mesh of 70 X 70 with 15-km grid distance and 23 full-sigma levels using the MM5 (Grell et al. 1994). We first perform the "control" run (CTRL) as a standard 9-hr forward model forecast starting at 1800 UTC 12 June 2002 with no data assimilation. This experiment is used as a benchmark for the FDVAR experiments (called as optimal run). In all experiments, the first guess and lateral boundary condition are obtained from the 3-hrly ETA analyses. Also, Goddard microphysics, Kain-Fritsch 2 (KF2) cumulus parameterization, and the National Centers for Environmental Prediction (NCEP) Medium-Range Forecast (MRF) model planetary boundary layer (PBL) scheme (Hong and Pan 1996) are employed in all forward runs.

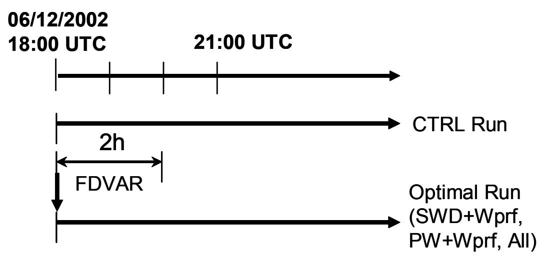


Fig 4. Schematic diagram of experiment design.

As shown in Fig 4, the FDVAR experiments assimilate all available data from 1800 UTC to 2000 UTC to obtain optimal initial condition through the minimization procedure (with 30 iterations) at 1800 UTC. Data frequency in the assimilation is different in each dataset – SWD is assimilated every 10 minutes, PW every 30 minutes, wind profilers every hour, and surface dewpoint every 5 minutes (Table 1). Based on the dataset assimilated in the model, each FDVAR experiments are named SWD+Wprf, PW+Wprf, and All (Table 2).

GPS SWD and PW data are estimated from three-dimensional pressure, temperature, and water vapor mixing ratio as in Ha et al. (2003). Wind profiler data is vertically interpolated into 23 vertical layers before assimilation. Surface dewpoint temperature in the assimilation system is computed from pressure, temperature and water vapor mixing ratio at the lowest sigma level as in Guo et al. (2000). In the assimilation model, Grell cumulus parameterization and bulk PBL are employed.

Table 2. Experiment design.

Experiments	observation data assimilated
CTRL	N/A
SWD+Wprf	GPS SWD, Wind profiler
PW+Wprf	GPS PW, Wind profiler
All	GPS SWD, PW, Wind profiler, Surface dewpoint

4. RESULTS

In this study, all FDVAR experiments successfully converged at 30 iterations in the minimization process (not shown). Now, we verify the resulting assimilated fields against independent observations in Figs 5 and 6. In the time series of the rms error of PW over 32 GPS ground stations shows that SWD assimilation is superior to PW and surface moisture data assimilation throughout the whole forecast hours (Fig 5). In all experiments, rms errors are quickly increased after 7 hour forecast, implying that the forest error is dominant after 7 hours thus the positive impact can effectively last no later than 7 hours. In the verification against wind profilers, it turns out that GPS SWD data assimilation makes most significant contribution to improve the vertical profile of horizontal wind fields as shown in Fig 6. It is noticeable that the improvements are made all through the vertical levels.

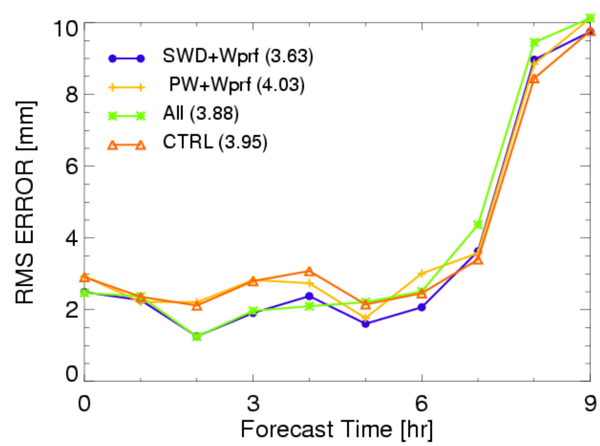
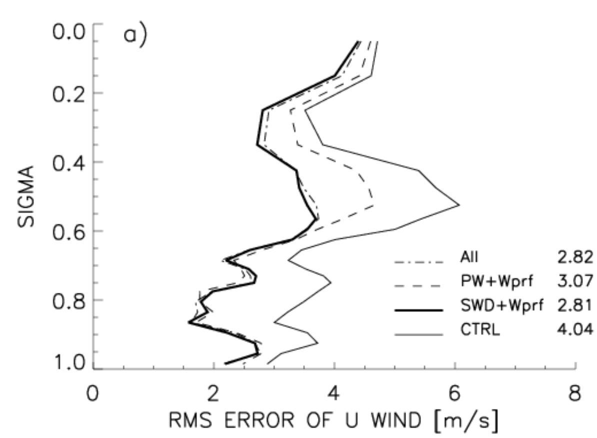


Fig 5. Time series of the rms error of precipitable water over 32 ground-based GPS sites from 1800 UTC 12 to 0300 UTC 13 Jun 2002. The numbers beside the line pattern are the averaged rms errors over 9 hours.



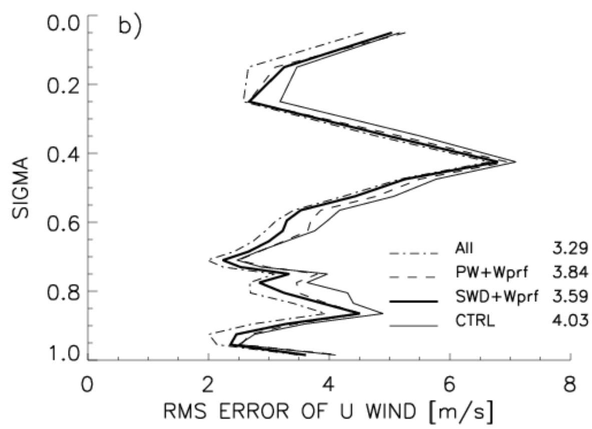


Fig 6. Vertical profile of the rms errors of U wind verifying against the NOAA wind profiler network over 12 sites at (a) 1800 UTC and (b) 2100 UTC 12 Jun, 2002. The numbers beside the line pattern are the vertically averaged rms errors.

5. DISCUSSION AND CONCLUSIONS

A set of mesoscale observations with high spatial and temporal resolution is assimilated in the MM5 4DVAR system (Zou et al. 1997) to examine the relative impact of GPS SWD data on the moisture retrieval. By providing accurate moisture information in the low troposphere in severe weather systems, SWD data makes significant contribution to the improvement of retrieval of spatial moisture distribution, which has potential to the squall line forecast. In this study, it is found that moisture data assimilation has better performance when they are combined with wind profiler data in the assimilation.

6. REFERENCES

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