Assimilation of Precipitable Water Observations During the Atmospheric Radiation Measurement Program Water Vapor Intensive Observation Period September 1996

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Introduction

In the development of an Integrated Data Assimilation and Sounding System (IDASS) in support of the Atmospheric Radiation Measurement (ARM) Program, assimilation of the Global Positioning System (GPS) precipitable water (PW) data collected in the Water Vapor Intensive Observation Period (WVIOP) of September 1996 over the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site is one of the main tasks. A four-dimensional variational data assimilation system (4DVAR) based on the Penn State/National Center for Atmospheric Research (NCAR) mesoscale model (MM5) with many physics options is now available. Our objectives in this paper are to

1. compare the measurements between GPS and microwave radiometer
2. assess the impact of the GPS PW data assimilation on moisture analysis
3. assess the impact on short-term prediction.

Data and Model

During the WVIOP-96, there were 15 GPS stations located within Kansas and Oklahoma (Figure 1). The PW data are available at 30-minute intervals during the WVIOP. At the SGP Central Facility (SGP), PW data measurements from the microwave radiometers (MWR) are also available (Jim Liljegren of Pacific Northwest National Laboratory and Ed Westwater of the National Oceanic and Atmospheric Administration's Environmental Technology Laboratory [ETL]). Figure 2 shows PW evolution at SGP0 on the selected 6 days from GPS, ARMMWR, and ETLMWR. GPS compares favorably with the microwave radiometer measurements in general. The ability for GPS to provide stable measurements under all weather situations is apparent.

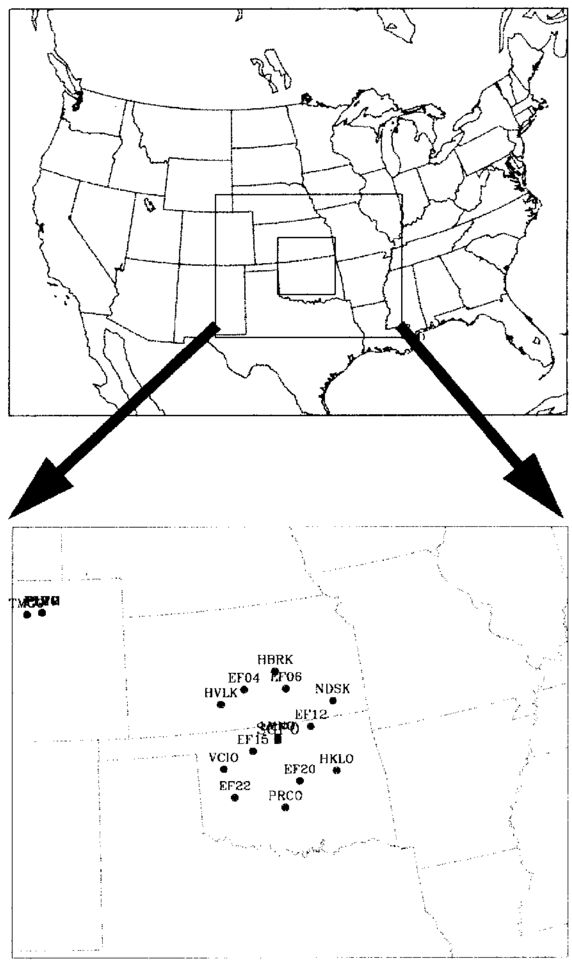


Figure 1. Location of the GPS observation network, and the domain for the MM5 PW data assimilation experiment.

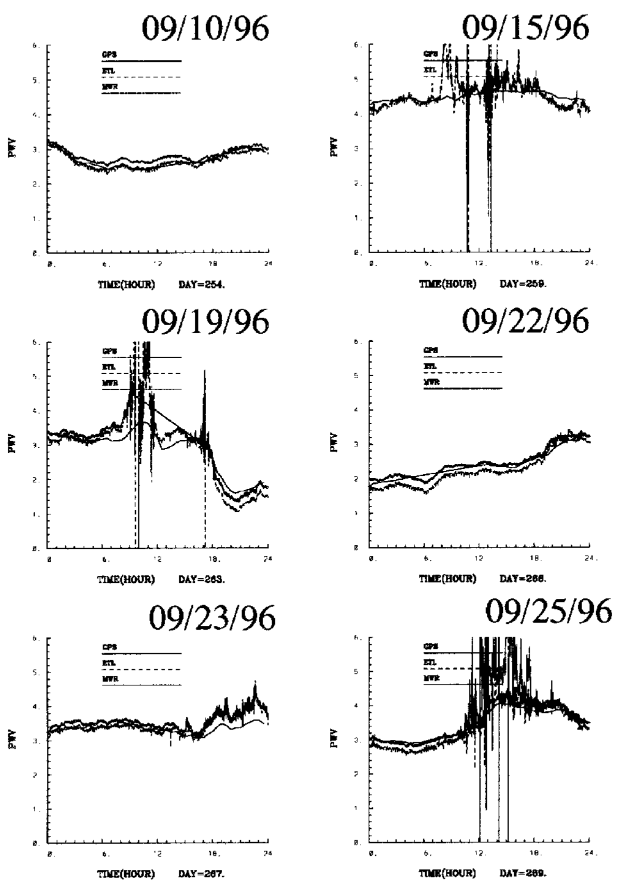


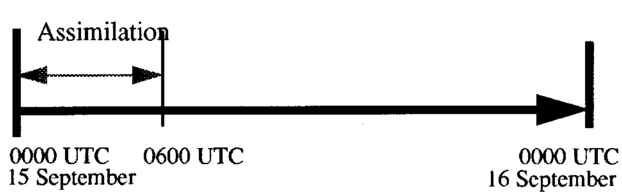
Figure 2. Comparison of the PW time series on 6 selected days at station SGP0; short dash line for ARMMWR, long dash line for ETLMWR, and solid line for GPS.

Case and Experiment Design

Synoptic Case

We have selected the base of September 15, 1996. Intense convection took place over the GPS network from 0900 UTC to 1800 UTC 15 September 1995 (Figure 4).

Experiment Design



We performed GPS PW data assimilation during the 6-hour period of 0000 UTC to 0600 UTC 15 September 1996 and assessed its impact on short-term forecast of the convection. All experiments were conducted over a 20-km domain and were derived by the hourly lateral boundary condition provided by the 60-km model. The GPS PW data at 13 times (30-minute intervals) between 0000 and 0600 UTC 15 September and the gridded analysis at 0000 UTC 15 September were used in MM5-4DVAR. Three experiments were conducted: NO4DVAR in which no GPS data were assimilated and two 4DVAR experiments with different physics packages, 4DVAR_A and 4DVAR_C.

Physics	4DVAR_A	4DVAR_C
Cu. param.	Grell	Kuo-Anthes
Grid-scale precip.	Dudhia's	Large-scale cond.
PBL scheme	Bulk	Bulk
Surface fluxes	On	Off

Results

The cost function and the norm of gradient decrease rapidly during the minimization process. This shows that the MM5 4DVAR system can successfully assimilate the GPS PW data into the model.

The following table shows the absolute bias errors and the RMS errors of PW during the periods of 0-6 h (assimilation period), 7-24 h (purely forecast period) and 0-24 h (total forecast period) for Exp. NO4DVAR, 4DVAR_A, 4DVAR_C against the GPS PW observations over 15 stations.

Exp	Error	0-6 h	7-24 h	0-24 h
NO4DVAR	|Bias|	0.865	2.772	2.238
	RMS	1.582	3.814	3.189
4DVAR_A	|Bias|	0.247	1.655	1.260
	RMS	0.615	3.639	2.792
4DVAR_C	|Bias|	0.325	1.347	1.060
	RMS	1.282	3.549	2.915

Figure 3 shows the PW for Exp. NO4DVAR, 4DVAR_A and 4DVAR_C, and their differences from the GPS PW observations. The difference between the GPS PW observations and the model is considerably smaller in the 4DVAR experiments. This shows that the MM5 4DVAR assimilation of GPS PW data significantly improves the moisture analysis. In Exp. 4DVAR_A, the PW field at 0600 UTC 15 September fits the observations very well. For example, a high PW value of 50.23 mm was observed at EF22 located in the southwest of the domain, and Exp. 4DVAR_A gave a small error of 0.23 mm.

NO4DVAR

4DVAR_A

4DVAR_C

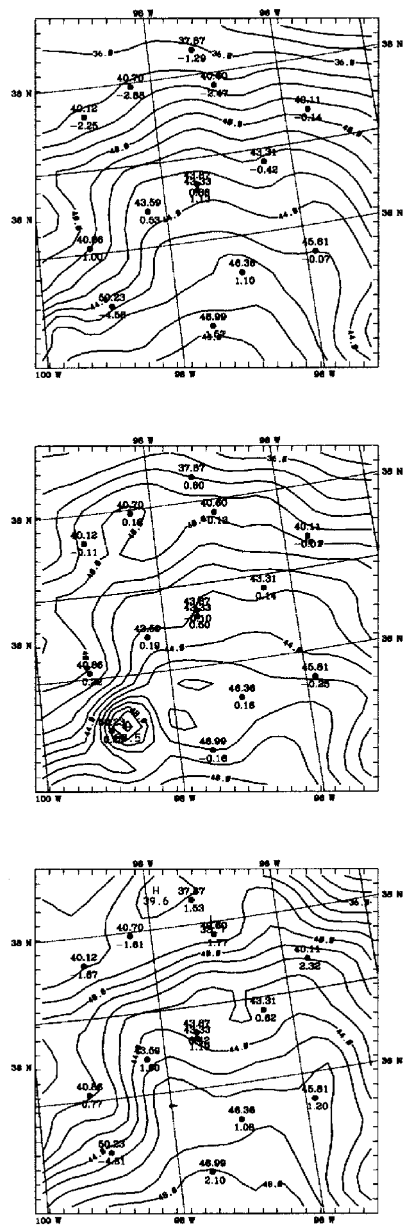


Figure 3. Precipitable water at 0600 UTC 15 September 1996 for Exp. NO4DVAR, 4DVAR_A and 4DVAR_C. The number above • indicates the GPS PW observations, and the number under • indicates the differences between model and observations.

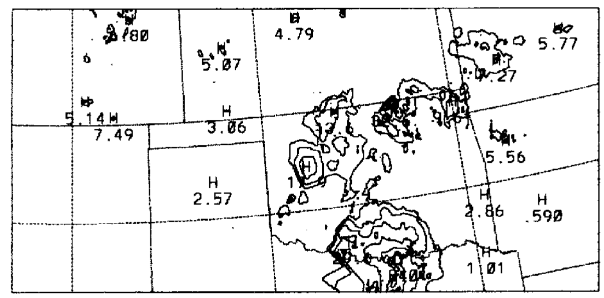


Figure 4. Observed hourly rainfall ending at 1200 UTC 15 September. Contour levels are 2.5, 5, 10, 20, 30, 50 mm.

Figure 5 shows the hourly rainfall forecast ending at 1200 UTC 15 September 1996 for Exp. NO4DVAR, 4DVAR_A and 4DVAR_C. This is 6 h into the forecast after the end of the assimilation period. The forecast model used the same physics as that in Exp. 4DVAR_A. With the optimal initial conditions from 4DVARs, the model squall line (represented by the hourly rainfall) over the Kansas and Oklahoma region moved faster than that of NO4DVAR and compared more favorably with the observed hourly rainfall (Figure 4).

We would like to emphasize that any improvements from the 4DVARs experiments come only from the incorporation of 15 GPS PW observations over the Kansas-Oklahoma network.

Despite the different physics package used in 4DVAR_A and 4DVAR_C, the results are very similar. This is very encouraging, because the computing cost (CPU time) for the 4DVAR with the simpler physics package (Exp. 4DVAR_C) is about 30% less than that with the more complicated physics (4DVAR_A). Our results suggest that simpler physical parameterization can be used during the assimilation period, and more sophisticated physics can be used in the forecast period, to save the computational expense for 4DVAR.

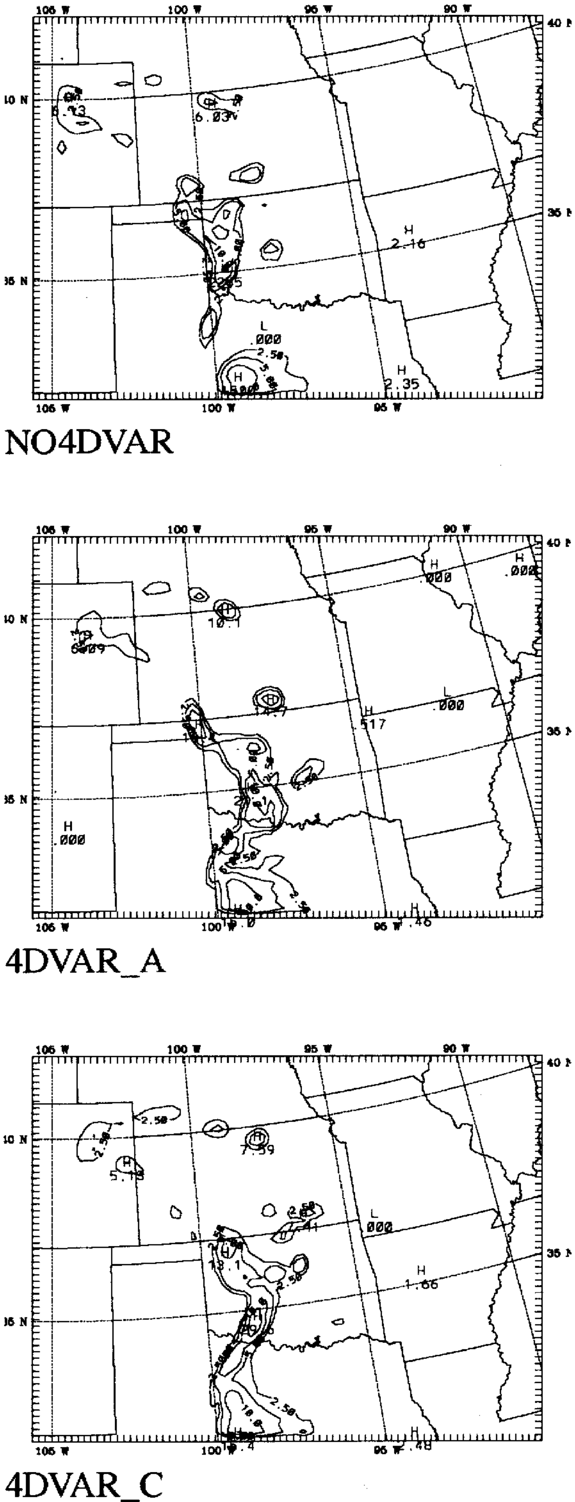


Figure 5. Hourly rainfall forecast ending at 1200 UTC 15 September for Exp. NO4DVAR, 4DVAR_A and 4DVAR_C. Contour levels are same as Figure 4.

Summary

1. The GPS measurements compare favorably with the microwave radiometers. The GPS receivers provide data in all weather conditions, while microwave measurements are contaminated in cloudy and precipitating weather.

2. The MM5 4DVAR system can successfully assimilate the GPS PW data at 30-minute intervals.

3. The assimilation of GPS PW data improves the moisture analysis and improves the prediction of a squall line over the Kansas-Oklahoma region.

4. Although 4DVAR with the complicated physics package gave the better fit to the GPS PW data, the forecasts starting from the optimal initial condition from 4DVARs are not strongly sensitive to physical parameterization used in the MM5 adjoint. Therefore, simpler physical parameterization may be used in the assimilation period to reduce the computational cost of MM5 4DVAR.