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IMPACT OF GPS WATER VAPOR DATA ON RUC SEVERE WEATHER FORECASTS

Tracy Lorraine Smith*, Stanley G. Benjamin, Seth I. Gutman, and Barry E. Schwartz
NOAA Research – Forecast Systems Laboratory
Boulder, Colorado, USA
* in collaboration with the Cooperative Institute for Research in the Atmosphere (CIRA)
Colorado State University, Fort Collins, Colorado

1. INTRODUCTION

A primary goal of GPS (Global Positioning System) -based measurements of integrated water vapor (or integrated precipitable water – IPW) is to improve numerical weather predictions of atmospheric water vapor, which will impact such important severe weather indicators as precipitation and instability. Accurate forecasts of water vapor are generally more difficult than those for other parameters such as wind and temperature. One factor responsible for this is that atmospheric moisture is often highly variable in 3-D space and time, more so than wind and temperature. Observations of moisture are inadequate, even in relatively data-rich areas such over as the United States, to fully resolve these variations. Generally, there have been three observational sources for atmospheric moisture: rawinsondes, METARs, and satellite (not available in cloudy areas below cloud top).

Estimates of IPW from GPS signal time delays can complement these moisture observations. GPS-IPW using zenith total delay provides only a vertically integrated value, by definition, but with at least hourly resolution and in all weather conditions, including those with cloud and even precipitation, conditions when observations are most important for forecasts of the atmospheric moisture. The NOAA Forecast Systems Laboratory (FSL) has developed, over the past several years, a GPS-IPW network, which now produces high-accuracy, hourly, near-real-time measurements at more than 130 stations in the U.S. as of 22 May 2002 (Fig. 1).

In this paper, we present the most recent results from a series of GPS-IPW data impact studies performed at FSL with the Rapid Update Cycle (RUC) data assimilation and numerical forecast system. A multi-year parallel cycle with earlier results presented by Benjamin et al. (1998), Smith et al. (2001) and Gutman and Benjamin (2001) has been continued with results from the first half of 2002 now available, and a 5-day test using an advanced 20-km version of the RUC (RUC20) has now been run to evaluate the impact of GPS-IPW data. Here we focus on a case from the RUC20 test with a large severe weather outbreak in the US.

2. THE RAPID UPDATE CYCLE

The RUC is a numerical weather prediction system used over the lower 48 United States and adjacent areas of Canada and Mexico. It features a very high-frequency (1 h) cycle with mesoscale data assimilation and forecast model components. Since 1998, the RUC has run with a 1-h update cycle at the U.S. National Centers for Environmental Prediction (NCEP) with forecasts out to 3 h produced hourly and forecasts out to 12 h produced every 3 h. Each hourly analysis in the RUC uses the previous 1-h forecast as a background, and recent data are used to calculate an analysis increment field which modifies the background. The data cut-off time for the RUC is very short, only +20 min for observations valid at the analysis time or over the previous hour. This requires a very short data latency for potential operational assimilation of GPS-IPW observations, which has been achieved in the U.S. (Gutman and Benjamin 2001).

From 1994-1998, an earlier version of the RUC ran at NCEP, using 60-km horizontal resolution, 25 vertical levels, stable precipitation based on saturation removal, and a 3-h update cycle (designated RUC60 in this paper). In 1998, a 40-km, 40-level version (RUC40) was implemented with a considerable increase in complexity of physical parameterizations including mixed-phase (water and ice can co-exist at the same grid point) cloud microphysics, and a 1-h update cycle (Benjamin et al. 1999). In April 2002, a 20-km 50-level version (RUC20) with further improvements in analysis and model techniques was operationally implemented at NCEP (Benjamin et al. 2002).

3. GPS-IPW DATA IMPACT STUDIES WITH RUC60

Since late 1997, FSL has conducted parallel data assimilation cycles with the RUC60 (60-km horizontal resolution) for the purpose of evaluating the effect of GPS-IPW assimilation on numerical forecasts. The two cycles are run identically except that one assimilates GPS-IPW data every 3 h, whereas the other one does not. Both cycles include assimilation of geostationary satellite (GOES) retrievals of IPW, and observational data from rawinsondes, commercial aircraft, wind profilers, and surface stations (METARs). The assimilation method used in the RUC60 tests is an optimal interpolation (OI) technique. As described by Smith et al. (2001), a two-dimensional analysis of the precipitable water analysis increment field (ΔPW, using differences between observations and the forecast background interpolated to observation locations) is performed as part of the RUC OI analysis. A percentage change in PW is calculated as PW% = ΔPW / PW_{bkg}. This factor is used to modify the water vapor mixing ratio (q_v) at each analysis level. The q_v field

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Corresponding author address: Ms. Tracy Lorraine Smith
NOAA/OAR/FSL R/FS1, 325 Broadway, Boulder, CO 80305-3328.
email :traine@fsl.noaa.gov; RUC info, http://www.ruc.fsl.noaa.gov

modified by the PW analysis is then used as the new background for an analysis using in situ q_v observations.

Previous RUC60 GPS-IPW impact tests for 1998-2000 have shown a modest positive (decreased forecast error) impact from use of GPS-IPW data for short-range forecasts of relative humidity (RH) (Table 1). This impact was found to increase in time as more GPS-IPW stations became available over the U.S., increasing from only 18 in 1999 to over 100 in 2002.

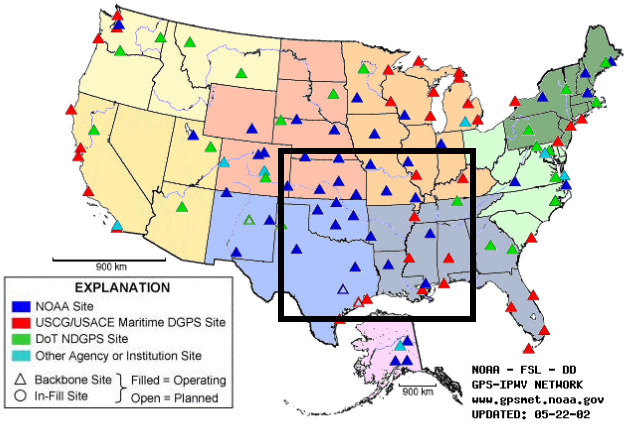

Figure 1. The NOAA GPS network as of 22 May 2002. The black box is the inner verification area containing 17 RAOB sites.

The RUC60 tests have been continued through 2002. The NOAA GPS-Met network with 138 stations available as of 22 May 2002 is shown in Fig. 1. Many of these stations are GPS sites installed for various geodetic purposes for which meteorological observation packages were added.

No. of Stations	18	56	67	100+
Period	1998-99	2000	2001	2002 Jan-Apr
Level (hPa)				
850	1.5	3.8	3.9	7.2
700	1.1	4.1	6.3	6.6
500	0.7	2.1	2.0	0.0
400	0.3	0.1	-0.4	-1.9
Mean 850-500	1.1	3.3	4.1	4.6

Table 1. Percentage reduction of 3-h relative humidity forecast error (using RUC60) from assimilation of GPS-IPW. Forecast error is assessed by computing forecast-observed difference with rawinsonde observations at 17 stations in the south-central U.S. Percentage reduction is error difference (GPS – no-GPS) normalized by forecast error (approximated as 10% relative humidity in this table).

The 2001-02 RUC60 GPS-IPW impact tests show a continued increase in the positive impact over that shown in previous years (Table 1). This continued increase in impact is attributed to the increased number of GPS-IPW stations over the US. No software changes in the RUC60 have been made for any part of the system, including data assimilation and forecast model. Between 2002 and 2000-01, there is a substantial increase in impact at 850 hPa, from about 4% (normalized by total forecast error) to over 7%. The percentage improvement from assimilation of GPS-IPW observations averaged over the 850-500 hPa layer has increased from 1.1% in 1999 to 3.3% in 2000, and now up to 4.6% in 2002 (first four months only).

4. RUC20 IMPACT TESTS

A new 5-day data impact test with the RUC20 system was recently conducted, with parallel cycles conducted with and without assimilation of GPS-IPW observations. The 5-day period chosen was for 25-29 May 2000, a period of active convective weather over the central and eastern United States. During this period, the number of GPS-IPW stations available was 55. In the RUC20 experiment, GPS-IPW observations were assimilated hourly rather than every 3 h as with the RUC60 experiments. The number of other data types assimilated in both RUC20 cycles was also increased over the number of types in the RUC60 experiments. The RUC20 experiments included hourly assimilation of surface and wind profiler data, velocity azimuth display (VAD) data from US Doppler radars, and cloud-top pressure/temperature and cloud-drift wind data from GOES satellites.

The preprocessing for GPS-IPW data is improved for the RUC20 experiment over that performed with RUC60. In the RUC20, corrections are performed for the elevation difference between the GPS site and the model terrain at that point. Also, no modifications are made in the analysis due to precipitable water observations at levels above 500 hPa. This was based on the results shown in Table 1, which shows no consistent positive impact above 500 hPa. This indicates that there is generally no positive correlation between RUC60 forecast error of IPW and that of q_v at levels above 500 hPa. Another assimilation change made with RUC20 is that a multipass iteration is performed for the moisture analysis, repeating the 2-D PW analysis, adjustment of the q_v field using cloud-top data, and the in situ q_v analysis, to force some mutual consistency in the analysis to each of these observation types.

The effect of GPS-IPW assimilation on 3-h RUC20 RH forecasts in 5-day impact experiment is shown in Fig. 2. The effect was strong at 850 hPa, with a 7% reduction in relative humidity forecast error for both the 17 rawinsonde stations in the south central US and even for the full 85-station network over the entire RUC20 domain. The effect of GPS-IPW assimilation was somewhat smaller at higher isobaric levels, especially for the full domain.

The RUC20 data impact experiment also showed a positive impact on precipitation forecasts, as indicated by comparing precipitation equitable threat scores (ETS) from forecasts with and without GPS-IPW assimilation.

Other tests have shown that, in general, the precipitation forecast skill for the RUC20 system is much improved over that of the RUC60 version, due to improved precipitation-related parameterizations, improved data assimilation, and higher spatial resolution. The ETS for 24-h precipitation was calculated by verifying against a 24-h gauge-based precipitation analysis produced daily at NCEP. The 24-h precipitation amounts from the RUC20 were produced by adding two 12-h forecasts.

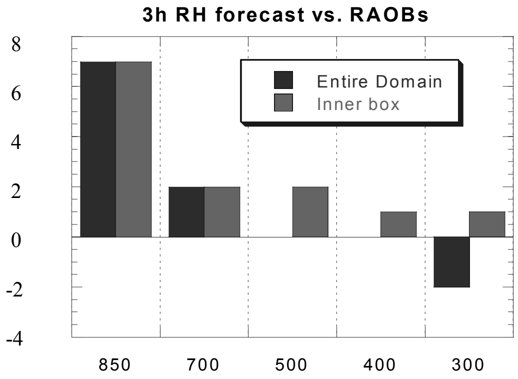

Figure 2. Reduction of 3-h relative humidity forecast error due to assimilation of GPS-IPW observations for 24-29 May 2000 period using RUC20 assimilation system. Vertical axis in percent, horizontal axis is pressure in hPa.

The equitable threat score (ETS) may be interpreted as follows: ETS is higher for an increased number of grid boxes with forecasts accurately showing values at least equal to the observed values at a given threshold. Conversely, ETS is lower as the number of 'false alarm' incorrect forecasts increases for that same threshold. As shown in Fig. 3, the equitable threat score from the RUC20 experiment including hourly GPS-IPW assimilation is slightly higher for all 24-h precipitation thresholds except the 1.5" threshold, for which there were very few observations during this 5-day period. This improvement in precipitation forecasts from assimilation of GPS-IPW over this period is notable in that precipitation is verified over the entire RUC domain.

5. CASE STUDY

On 24 May 2000, an outbreak of severe weather occurred from the central to northeastern U.S. (Fig. 4). Space limits comparisons, but we will contrast 24-h precipitation forecasts from the two RUC20 runs with and without GPS. Examples of important severe weather forecasting fields such as CAPE, CIN, and LI will be shown at the conference. The NCEP gauge analysis of precipitation is shown in Fig. 5. Unfortunately, probably due to the severe weather, data from KY/TN were unavailable for that day. The corresponding 24-h forecast (sum of two 12h forecasts) from the RUC20 GPS run and NOGPS run are shown in Figs. 6 and 7. The influence of the GPS data is more apparent in the forecast of precipitation intensity than in its location, for this case. The analyzed precipitation maximum on the MO/AR border, which is coincident with a large cluster of severe hail and tornado reports is captured much better by the run with GPS data, along with the PA/NY hail region.

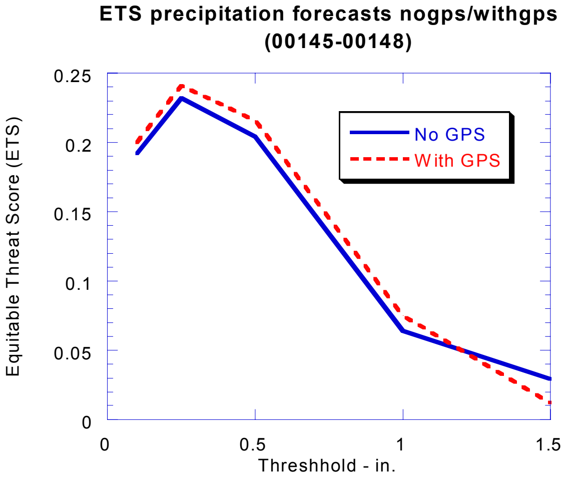

Figure 3. Equitable threat score for RUC20 cycles with and without assimilation of GPS-IPW observations for 24-29 May 2000 period.

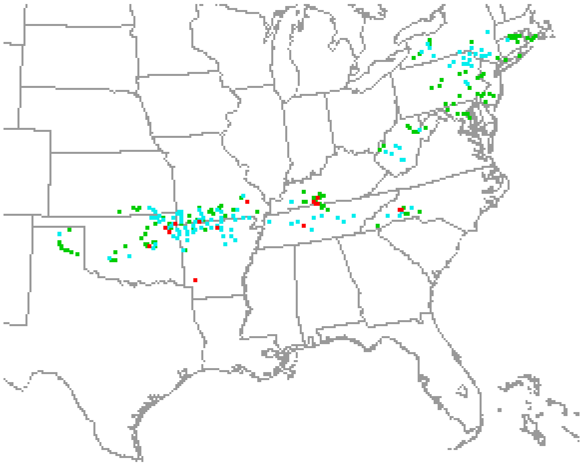

Figure 4. Severe weather reports for 24 May 2000.

6. CONCLUSIONS

Results of recent GPS-IPW data impact tests using 60-km and 20-km versions of the Rapid Update Cycle model/assimilation system show modest improvements in short-range forecasts of atmospheric moisture and precipitation over the United States. The multi-year RUC60 parallel cycle test has been extended into 2002, showing a stronger effect on 3-h relative humidity forecasts in the lower troposphere each successive year. This improvement is attributable to the continued increase in number of GPS-IPW stations over the U,S,, over 100 stations as of early 2002.

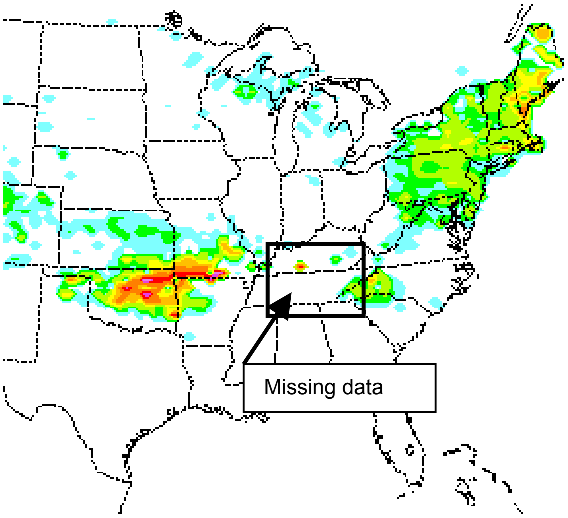

Figure 5. NCEP gauge precipitation analysis for 24 May 2000. Missing data in KY/TN.

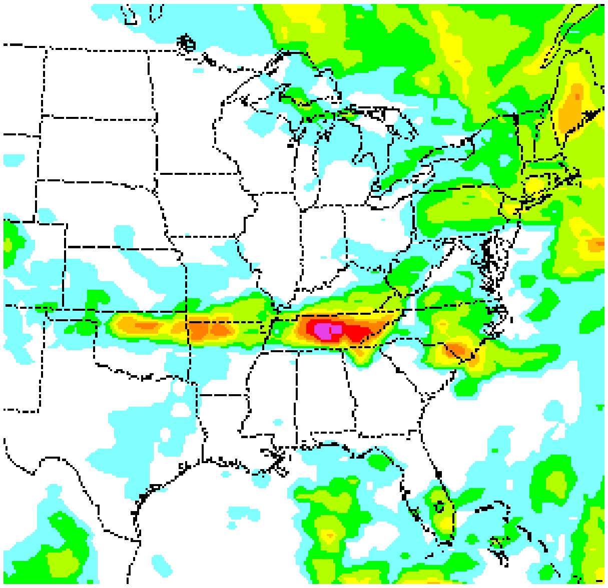

Figure 6. RUC20 precipitation (sum of two 12-h forecasts) for run with GPS 24 May 00.

A 5-day parallel test from 24-29 May 2000 was carried out using a 20-km version of the RUC. This test showed also showed improvements in relative humidity and precipitation numerical forecasts resulting from assimilation of GPS-IPW observations. The impact on precipitation forecasts was stronger than in previous longer-term tests with the 60-km RUC, although this may be related to the shortness of the RUC20 test period. GPS-IPW improved the precipitation forecast of amount and distribution on 24 May 2000, a severe weather day across much of the U.S. The RUC20 parallel tests of GPS-IPW impact will be continued for multiweek periods in both summer and winter.

7. ACKNOWLEDGMENTS

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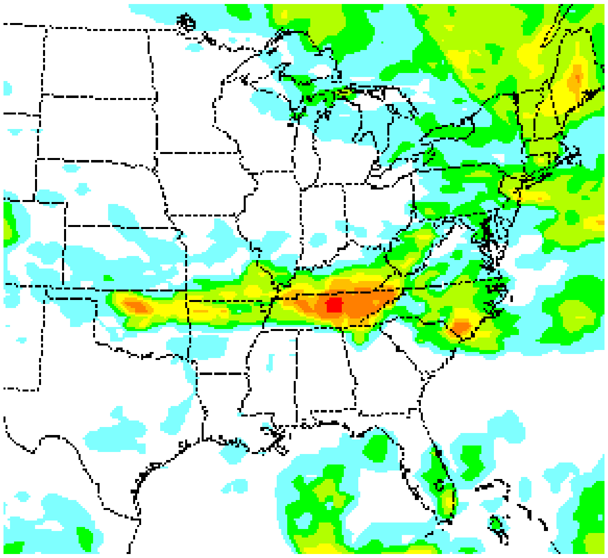

Figure 7. RUC20 precipitation (sum of two 12-h forecasts) from the NOGPS run for 24 May 2000.

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