Installation and Operation of a GPS System Around the ARM Southern Great Plains Central Facility to Observe Water Vapor Fields

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Abstract

A network of fourteen single-frequency Global Positioning System (GPS) stations has been installed around the Atmospheric Radiation Measurement (ARM) Program's Southern Great Planes (SGP) Central Facility. This network is designed to measure the integrated water vapor along ray paths between individual GPS satellites and each of the fourteen GPS stations. The installation of the network was completed in late September 1999. Since then, daily slant water (SW) observations have been computed for each site. Periods of significant variability have been observed, and these occurrences should increase through the spring and summer. We present an overview of the GPS network, discuss errors caused by the ionosphere and ground reflected multipath, and show preliminary examples of the observed water vapor structure. In the next year, nine additional stations will be installed. We will implement and test a tomographic solution of the three-dimensional (3-D) structure of water vapor above the network. For particularly interesting and significant events, we have begun collaboration with the Mesoscale and Microscale Meteorology (MMM) group at National Center for Atmospheric Research (NCAR) for the assimilation and comparison to their mesoscale model (MM5) numerical model.

GPS Network

Fourteen single GPS stations were installed in a dense array around the U.S. Department of Energy's (DOE) ARM SGP central facility near Lamont, Oklahoma. The primary purpose of this GPS array is to measure small-scale variations in the 3-D water vapor field around the facility. This network is centrally located within a larger dual-frequency GPS network operated by the National Oceanic and Atmospheric Administration's (NOAA) Forecast Systems Laboratory (FSL). Both networks are displayed in Figure 1.

GPS Stations and Data Communications

Each GPS station consists of a twelve-channel Canadian Marconi Allstar GPS receiver, a MicroPulse GPS antenna, and a Freewave radio modem. The system is powered using a solar panel with battery backup. Concrete monuments were installed for stability. The monuments are 4-ft tall pillars, and extend at least 3 ft into the ground. Two of the monuments are shown in Figure 2.

Figure 1. The NOAA-FSL and CORS sites are shown in the large view of the central United States. The single-frequency GPS systems are deployed around the ARM Central Facility. Each station in the single-frequency network is placed within an 8 km x 8 km rectangular grid. The spacing between each station is approximately 2 km.

Figure 2. Two L1 GPS systems are shown. Each system consists of a GPS receiver, a radio modem, and has solar power with battery backup.

All data are continuously streamed to a central collection computer using TDMA technology. The master radio modem is mounted on top of the 60-meter weather tower at the central facility, then relayed to a computer in the optical trailer. Each night the previous day's worth of GPS observations are transferred back to Boulder for processing. In the future, we plan to modify the system so that the data analysis takes place within 30 minutes of its collection.

Data Analysis and Processing

The GPS observations are processed using the Bernese version 4.2 software. The International GPS Service (IGS) rapid satellite orbits are used. Ionospheric scale errors are removed using the daily ionosphere model from the Center for Orbit Determination in Europe (CODE). Satellite and receiver clock errors and most ionospheric errors are removed through double differencing. Once the data have been analyzed, the double difference residuals are inverted back into single station, single satellite, zero difference residuals to compute SW. To accurately measure SW, antenna multipath and phase center variations must be minimized. We are "stacking" the carrier phase residuals on a daily basis to compute a specific multipath and phase center map for each station. These station maps are then subtracted from the daily residuals leaving the un-modeled atmospheric variability. SW observations are combined with data from the NOAA-FSL network to determine the absolute SW values. We have started to work on ingesting these measurements into the LOTTOS tomography software (developed at IEEC, Barcelona) for the determination of the three dimensional water vapor field above the L1 network.

Ionosphere Models

The daily global ionosphere model produced by the CODE IGS analysis center is used to remove scale errors within the network. This model works well during night conditions, but does not contain sufficient detail to remove all the small scale ionospheric disturbances which occur during the day. To remove these small-scale disturbances, we have developed a technique to estimate high-resolution ionosphere models for individual satellites at each epoch using dual-frequency receivers. We have used data from the NOAA-FSL network to compute these corrections, but it appears as if the spacing of these receivers (150 km to 200 km) is not dense enough to accurately model all disturbances. We have tested this technique using data from Japan's Geographical Survey Institute's (GSI) GPS network, which has a spacing of approximately 30 km. For this network, the corrections work well. We expect that the installation of the SoumiNet network will improve our modeling of the ionosphere.

Observations and Results

Periods of significant variability in water vapor across the 8 km x 8 km network have been observed in the five mostly winter months of operation. In general, the highest variability occurs during precipitation events, and when the total precipitable water (PW) is high. See Figures 3 and 4. Because of this, we expect to see an increase in small-scale variability throughout the spring and summer months when the total column water vapor content will increase. An analysis of the observations indicates that the network is sensitive to variations in SW as small as 0.2 mm, during quite ionospheric conditions (night

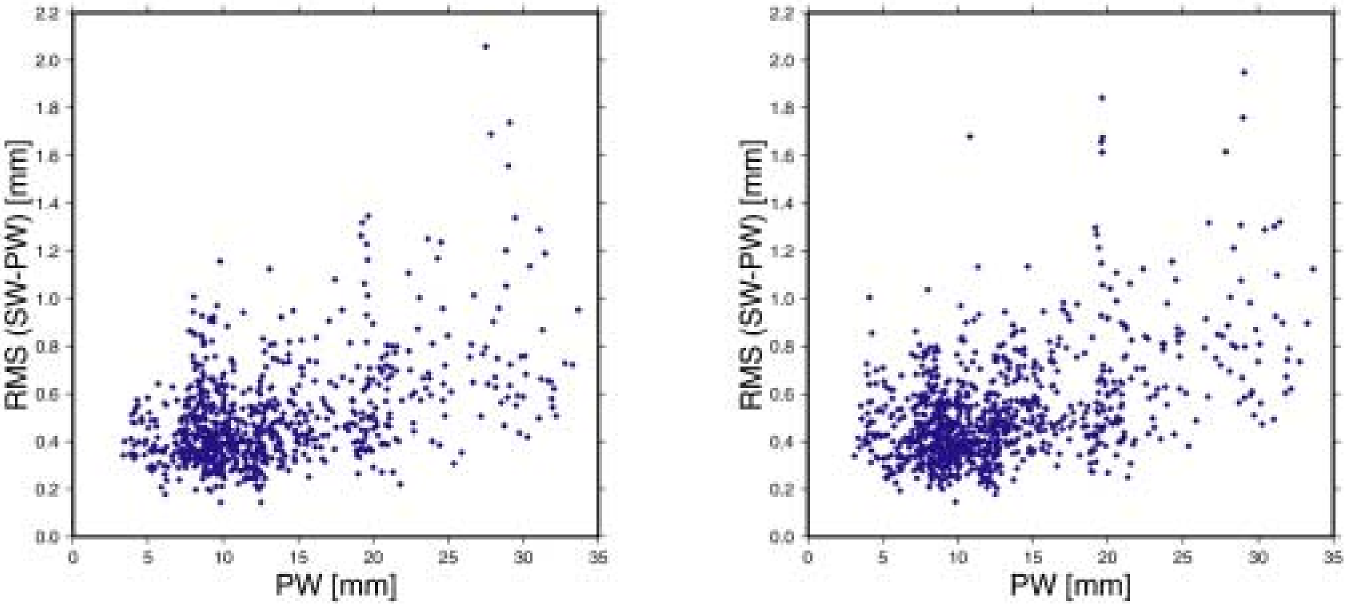

Figure 3. In the two figures above, each diamond represents the root-mean-square (rms) variation of the SW observations relative to the average PW value during a 30-minute time window. The two panels are for different stations. Twenty-one days of observations from February and March of 2000 were used to prepare these two panels.

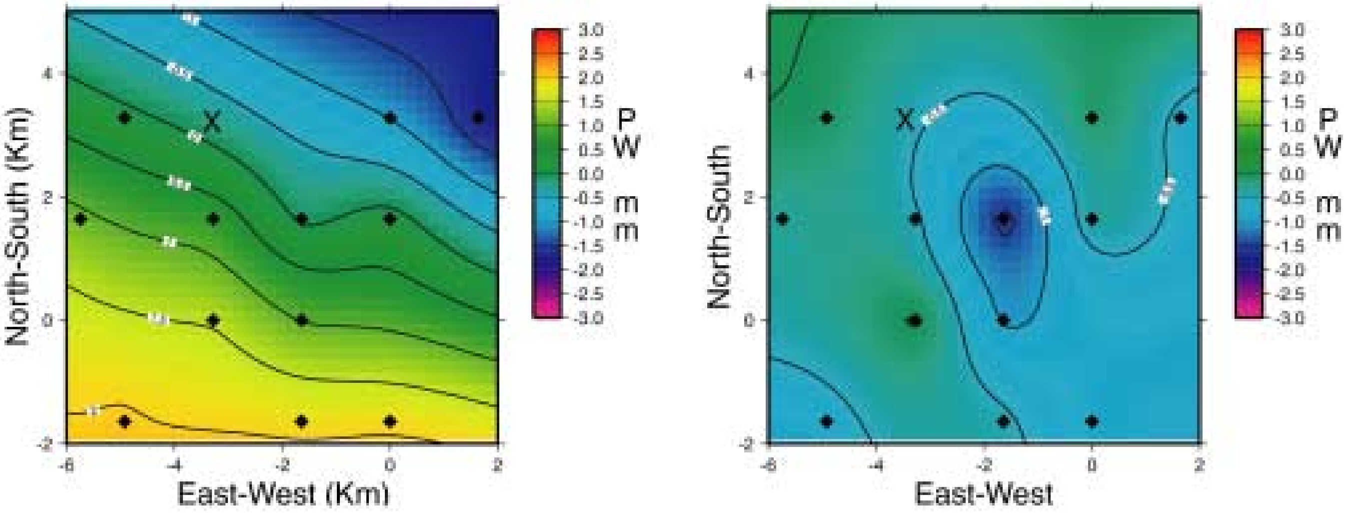

Figure 4. Examples of horizontal variations in PW (relative to station "x") over the network. Each illustration represents a 30-minute time interval. In the left panel, a north-south gradient of 3 mm is observed. The panel on the right shows a small portion of dry air in the center of the network relative to the rest of the air (1 mm = 1 kg/m^2).

time). To realize this sensitivity during the day, additional ionospheric corrections will be required. To compute these corrections, at least three additional dual frequency sites will need to be located within 50 km to 100 km of the CF.

Conclusions

A 14-station, single-frequency, GPS network has been installed to monitor small-scale variations in the water vapor field above and around the ARM SGP central facility. During the networks operation, there have been periods of significant variability in the water vapor structure around the SGP central facility. We expect these periods to increase in frequency and magnitude over the spring and summer. This network has been continuously and reliably operating since October 1999. These data are being transferred back to Boulder for the analysis of SW. Our automated processing includes a recently developed GPS multipath correction technique that is station dependent, and significantly reduces the errors due to antenna phase center variation and ground reflected multipath. We do experience some degradation of the analysis of SW when the ionosphere is highly active. We expect to minimize these errors by computing high-resolution models of the ionosphere with data collected from the SoumiNet network, which is scheduled to be installed later this year.

Next Steps

In the next year, we plan on installing nine additional GPS stations around the central facility to increase the total number of stations to 23. We also plan on utilizing data from the SoumiNet network to remove errors associated with ionospheric disturbances during the day. Participation in the Intensive H_2O Observation Period (IHOP) experiment scheduled for spring 2001 should allow for additional validation and testing of our network with other instruments.

In addition to the tomographic work, we have initiated a joint study with the NCAR MMM program. For this project, we will provide SW observations for assimilation into their MM5 model to investigate their effect on the recovery of the water vapor field, and precipitation forecasting.

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