GPS Surveying Error Induced by Water Vapor

Delays induced by atmospheric water vapor are significant contributors to high accuracy GPS positioning error (Solheim et al., 1999). These errors can be independently measured and corrected using water vapor radiometers. A basic description of water vapor radiometers and their use in high accuracy GPS positioning follows. Use of ground-based GPS to define moisture fields for atmospheric research and forecasting is described in the following section.

Near one centimeter wavelength (30 GHz) atmospheric emission is generated almost entirely by water vapor and liquid. Water vapor emission is dominated by a molecular resonance near 22 GHz and liquid water emission has a frequency squared dependence in this region. By observing frequencies near 22 and 30 GHz, integrated amounts of water vapor and liquid water can be estimated.

Figure 1. Water vapor radiometer with pointing capability (http://radiometrics.com).

Some water vapor radiometer designs allow pointing in various sky directions to obtain measurements along the line-of-sight to GPS satellites. By pointing a radiometer sequentially to visible GPS satellites, "slant" delays induced by refractive effects of water vapor and liquid can be estimated and corrected. Typically, it takes 5 to 10 minutes to point toward 8 or so GPS satellites. During this time interval the atmosphere has been found to be sufficiently stable to provide effective corrections.

The most repeatable GPS surveying on record was obtained by applying the method described above. All three vector components of a 50 km baseline in Colorado were measured with a repeatability of 1.2 mm rms or better. The radiometer corrections provided a factor of 5 improvement in vertical survey repeatability, as shown in Figure 1. The experiment is described in detail by Alber et al. (1997). The type of pointed radiometer used in the experiment is shown in Figure 2 (Ware et al., 1993).

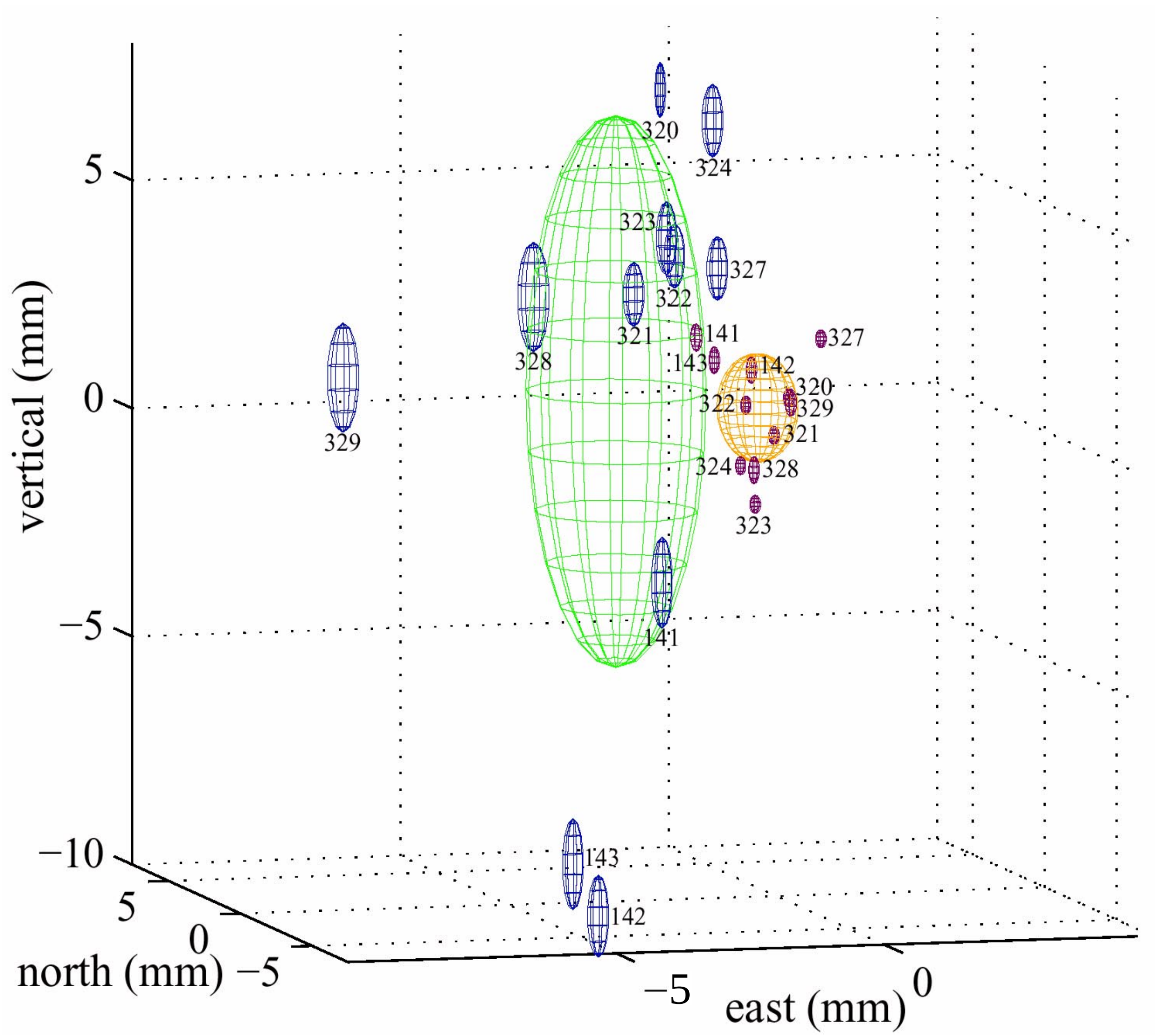

Figure 2. Repeatability for 11 days of GPS surveying on a 50-km baseline in Colorado using pointed (orange) and zenith (green) radiometer corrections. Daily solutions labeled by day of year for pointed (magenta) and zenith (blue) radiometer corrections are included.

Slant GPS for Meteorology

Water vapor is a fundamental driver of atmospheric weather and climate, is highly variable, and is poorly defined over land. Roughly 1,300 radiosonde launches per day are used to define water vapor distribution in global weather and climate models. Satellite microwave radiometers provide accurate water vapor measurements over the oceans where sea surface temperature is well modeled. Over land satellite measurements of water vapor during cloudy conditions are degraded by highly variable surface temperatures.

GPS can provide improved water vapor measurements for meteorology. Slant GPS delays can be obtained as "zero differences" derived from double difference calculations (Alber et al., 2001) or by point positioning (Zumberge et al., 1997). Slant delays calculated by the zero difference method have half the noise of those calculated by point positioning (Braun et al., 2001). Slant water (integrated water vapor along slant paths) measurements by GPS and pointed radiometers above 10 degrees elevation are found to be highly coherent (Braun et al., 2002). Slant delays observed below 1 degree elevation can be measured with better than 1% accuracy (Pany et al., 2001ab; 2002). These delays can provide strong constraints on water vapor distribution for use in weather modeling and forecasting.

There is considerable potential for improvement in atmospheric modeling and forecasting using slant GPS observations. As a result, GPS networks designed for real time atmospheric measurements are being established (Ware et al., 2000; http://www.suominet.ucar.edu). Slant GPS provides strong horizontal constraints on the water vapor field. Combined with water vapor profile measurements by 5 channel radiometers (Ware et al., 2002), slant GPS can provide three dimensional water vapor analysis that promises to improve severe storm forecasting (MacDonald et al., 2002). GPS observations of atmospheric moisture can also be used to monitor climate change (Yuan et al., 1992; Dai et al., 2001; Elgered et al., 2001).

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