VGOS Operations and Geodetic Results

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Abstract Over the past two years the first VGOS geodetic results were obtained using the GGAO12M and Westford broadband systems that have been developed under NASA sponsorship and funding. These observations demonstrated full broadband operation, from data acquisition through correlation, delay extraction, and baseline estimation. The May 2013 24-hour session proceeded almost without human intervention in anticipation of the goal of unattended operation. A recent test observation successfully demonstrated the use of what is expected to be the operational version of the RDBE digital back end and the Mark 6 system on which the outputs of four RDBEs, each processing one RF band, were recorded on a single module at eight gigabits per second. The complex-sample VDIF data from GGAO12M and Westford were cross-correlated on the Haystack DiFX software correlator, and the instrumental delay was calculated from all of the phase calibration tones in each channel. A minimum redundancy frequency sequence (1, 2, 4, 6, 9, 13, 14, 15) was utilized to minimize the first sidelobes of the multiband delay resolution function.

Keywords Geodesy, VGOS

1 Introduction

The next generation geodetic VLBI instrument is being developed with a goal of 1 mm position uncertainty in

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twenty-four hours. The broadband signal chain, which is essential for obtaining the required delay accuracy from a network of relatively small antennas, has been implemented on the 12-meter antenna at Goddard Space Flight Center, Maryland, USA, and on the 18-meter Westford antenna at Haystack Observatory, Massachusetts, USA, in several phases over the past two years. Observing sessions to evaluate the status of the VGOS systems were conducted in October 2012 and in May 2013. Some results from these sessions are presented here.

Over the same period, improvements to the signal chains at both antennas continued. Desirable features were added to some of the components, and the entire recording system was replaced. These changes, which included installation of the Monitor and Control Instrumentation at Westford and implementation of complex samples in the RDBE, were evaluated in a successful fringe test in April 2014. The primary missing component is the cable delay measurement system, which is ready for proof-of-concept testing.

2 Geodetic Results

2.1 October 2012

In October 2012, two six-hour sessions were carried out on successive days. The instrumentation configuration, observing procedures, correlation and observable extraction, and analysis are described in [1]. During early testing of the broadband system at GGAO it became apparent that the aircraft avoidance radar associated with the nearby (co-located) Satellite Laser Ranging systems is powerful enough to damage the VLBI

front ends if the radar is pointed in the direction of the VLBI antenna. Thus, when the antenna is operating, either it must avoid pointing within a cone of approximately 40 degrees of the radar, or the SLR systems must not be operating. One scenario was exercised in each of the two sessions. The effect on the scheduled observations is seen in Figure 1 in which the azimuth and elevation for every scan is viewed as a projection on a horizontal plane. The loss of sky coverage reduces the positional accuracy along the direction of the missing data, but more importantly, reduces common visibility with other antennas in the network in that direction.
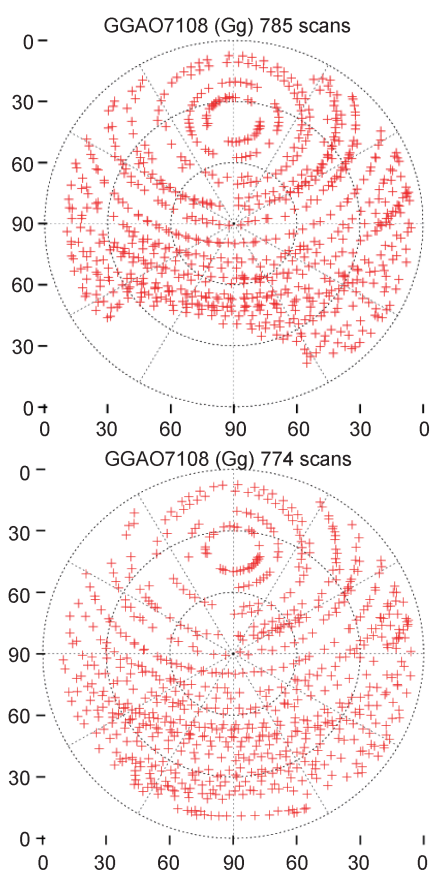

Fig. 1 Azimuth-elevation plots of the directions of all observations for 2012 October 4 (top) for which the direction to the SLR system was masked out, and October 5 (bottom) for which no mask was imposed (plots courtesy of GGAO).

The broadband signal chain provides the signal from two polarizations, vertical and horizontal, at the antenna. The two polarizations will be combined coherently in post-correlation for most sessions (and could be for these), but for these initial geodetic observations, they were processed separately in order to provide a measure of precision, because the two should agree to much less than the uncertainty for each. This is because the uncertainties are based on the scatter of the post-fit delay residuals, and these are probably dominated by errors in the atmosphere modeling and by other effects that are common-mode to the two polarizations. The components of the position of GGAO relative to Westford, and the baseline lengths, each relative to the mean of the values, are shown in Figure 2.

A new feature of the broadband technique is the need to estimate the 1/frequency term of the phase variation with frequency simultaneously with the other observables (single-band delay, group delay, delay rate, and phase). This is ascribed to the difference in total electron content (dTEC) along the lines of sight through the ionosphere to the radio source at each site. As a check on the consistency of the estimates of dTEC from the 2012 October 5 data, the values were compared with the same quantity derived from GPS TEC measurements. The results are shown in Figure 3.

2.2 May 2013

One goal of the 2013 May 22 session was the demonstration of unattended operation. This was the first full twenty-four hour VGOS session, and it required only the re-start of one RDBE when it timed out during the session. The antennas were controlled by the Field System, while the RDBEs and Mark 5Cs were run by a script generated from the same *sked* output file that provided the input to the Field System.

Another goal was to evaluate the fringe amplitude calibration of the interferometer. The frequencies of the four bands were chosen to span 3.3 GHz to 8.8 GHz so that the highest band (8.3 GHz – 8.8 GHz) overlaps the X-band from geodetic sessions [3]. The schedule took advantage of the high speed of both antennas to achieve an observing rate of approximately 45 scans/hour, limited by a minimum scan length chosen to be 30 seconds and by an excess latency in the startup motion of the Westford antenna, which has since been fixed. For this session, the SLR mask was on. Outside of this range, the minimum elevation was $5°$.
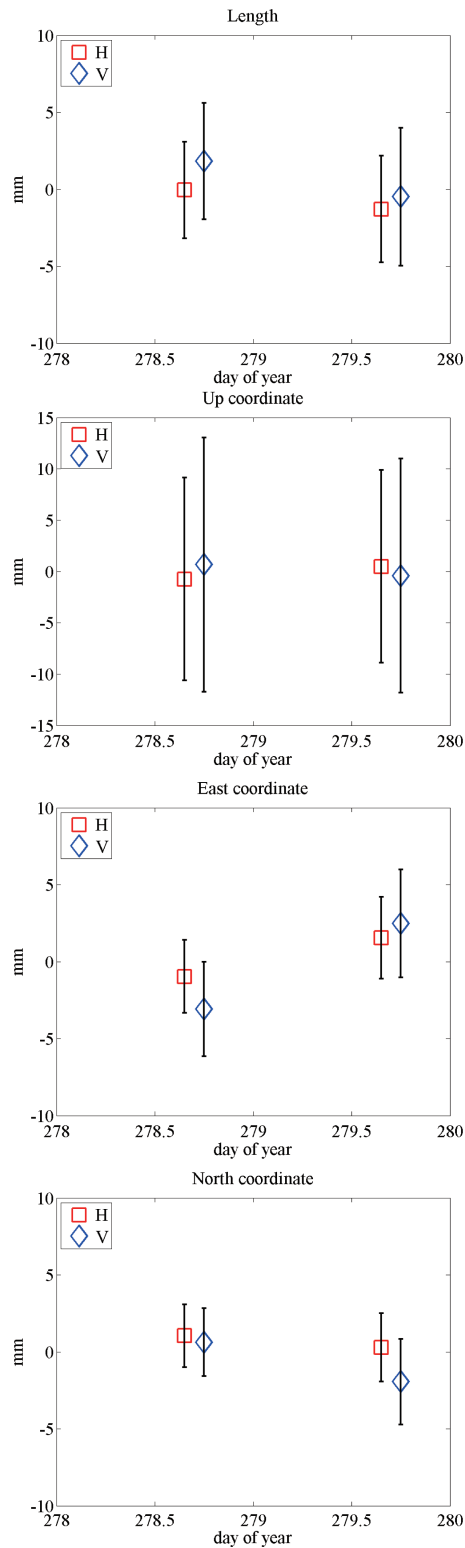
Fig. 2 Residual to the mean of the components of the position of GGAO relative to Westford.
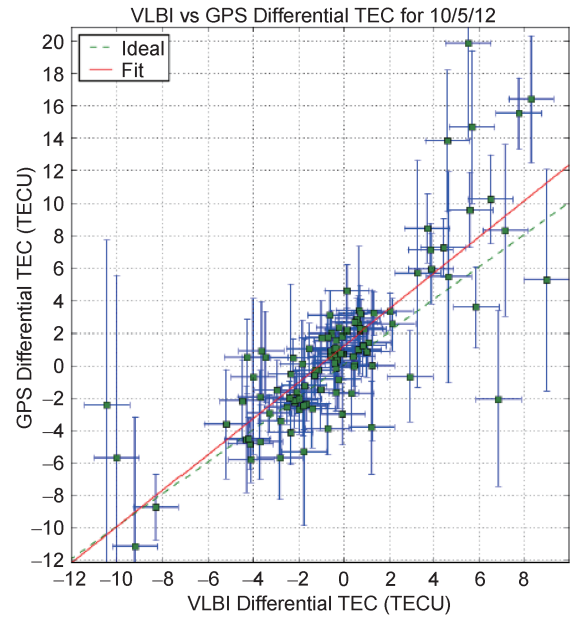

Fig. 3 Comparison of difference of TEC along line of sight from each antenna as estimated from the VLBI data of 2012 Oct 5 and from GPS TEC values.

Following correlation of the four bands in separate passes, the correlator outputs were merged into one file. The delay and dTEC were estimated for all 1,140 scans, and the position of GGAO was estimated relative to Westford using nuSolve with the clock and atmosphere parameters modeled as stochastic processes.

As a measure of the precision of the VGOS system, the position was estimated for separate, approximately six-hour segments for comparison with the full session. The results are shown in Figure 4.

2.3 Testing the Operational Configuration (April 2014)

Since the 2013 observations, several improvements have been made to various components of the system to bring both sites close to the operational configuration. At Westford the hardware for the Monitor and Control Instrumentation was installed. For both sites the RDBEs were upgraded by significant changes to the FPGA code and server software. At Westford two of the RDBEs were upgraded with a new synthesizer board and simpler attenuator components. Perhaps the
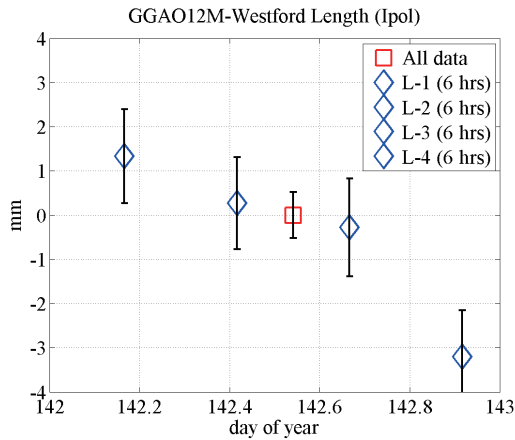
Fig. 4 Baseline length between Westford and GGAO12M on 2013 May 22. Red square: solution for all 24 hours of data; blue diamonds: independent six hour segments analyzed with the same parameterization as the full 24-hour solution.

Fig. 5 Diagram of the Broadband Delay System. The dashed box indicates the components that are mounted on the antenna and cooled to approximately 20K. Phase and noise calibration signals are injected between the feed and each LNA. X-pol and Y-pol represent the two linear polarization signals produced by the QRFH feed.

most significant change was to make use of the Mark 6 recorder, which replaced four Mark 5C recorders.

The signal chain as currently implemented is illustrated in Figure 5. Previously, the output from each RDBE was recorded on a separate Mark 5C [2].

The RDBE upgrade provides many new features. The data samples are now complex representations and are output in VDIF (VLBI Data Interchange Format). This brings the RDBE into compliance with the VLBI standards, as well as reducing resource requirements in the FPGA fabric. Equally important, two capabilities were added: a) measurement of differences in the 1 pps epochs among the maser pulse, the external GPS time, and the internally re-generated 1 pps pulse; and b) extraction of the phase cal phases and amplitudes. The former allows continuous monitoring of the RDBE clock throughout a session, and the latter allows more thorough station checking both outside of an observing session and during the observations.

A short VLBI observation was made on 2014 April 17 to verify the operation of the new configurations. The new instrumentation performed as expected for the features that could be tested, and the correlator modifications required to process the data were validated as well. However, the two new capabilities were not able to be demonstrated, nor was the control and utilization of the noise diode switching for improved system temperature calibration.

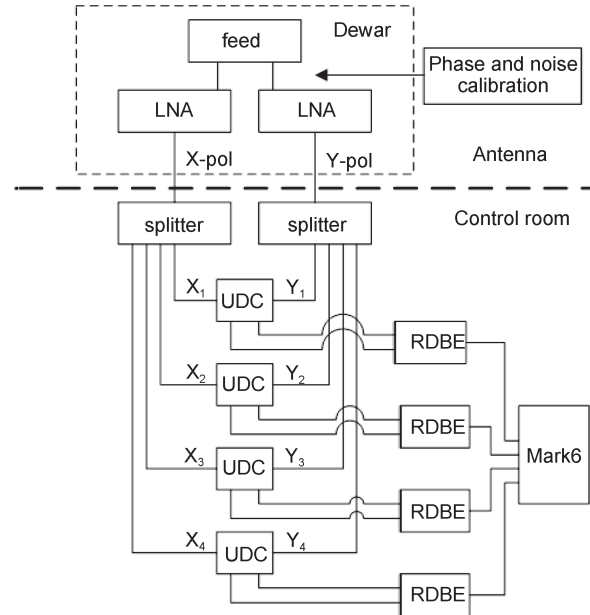The final development needed to complete the VGOS system is the cable delay measurement system.

A proof-of-concept unit has been thoroughly tested on the bench, and components are being constructed for installation of prototype units on both antennas. Testing of these units and the other features will be initiated on the GGAO antenna.

3 Summary

Operations on a regular basis using scripts as described above can begin as soon as the new features are verified and the delay calibrator is completed and checked out. However, full IVS usage also requires incorporation of the VGOS capabilities into the session preparation software (e.g., *sked*) and modification of the Field System to control the RDBE and Mark 6.

Finally, it is extremely important to develop a coordinated observing scheme with the SLR systems in order to avoid losing the geometric strength and common visibility that arises from loss of observations in the direction of the SLR.

Acknowledgements

References

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