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Project location: Great Smokey Mountains, North Carolina

## 1. Survey area

The project area consisted of a square polygon approximately 9 square Km located 18 kilometers northwest of Waynesville, N.C. The project area was flown on Tuesday, November 14, 2006. It required a single flight lasting approximately 3.5 hours of required 0.5 hours of laser-on time.

Figure 1 (next page) is an image showing the shape and location of the project area along with the location of the three GPS reference stations used to support the survey.

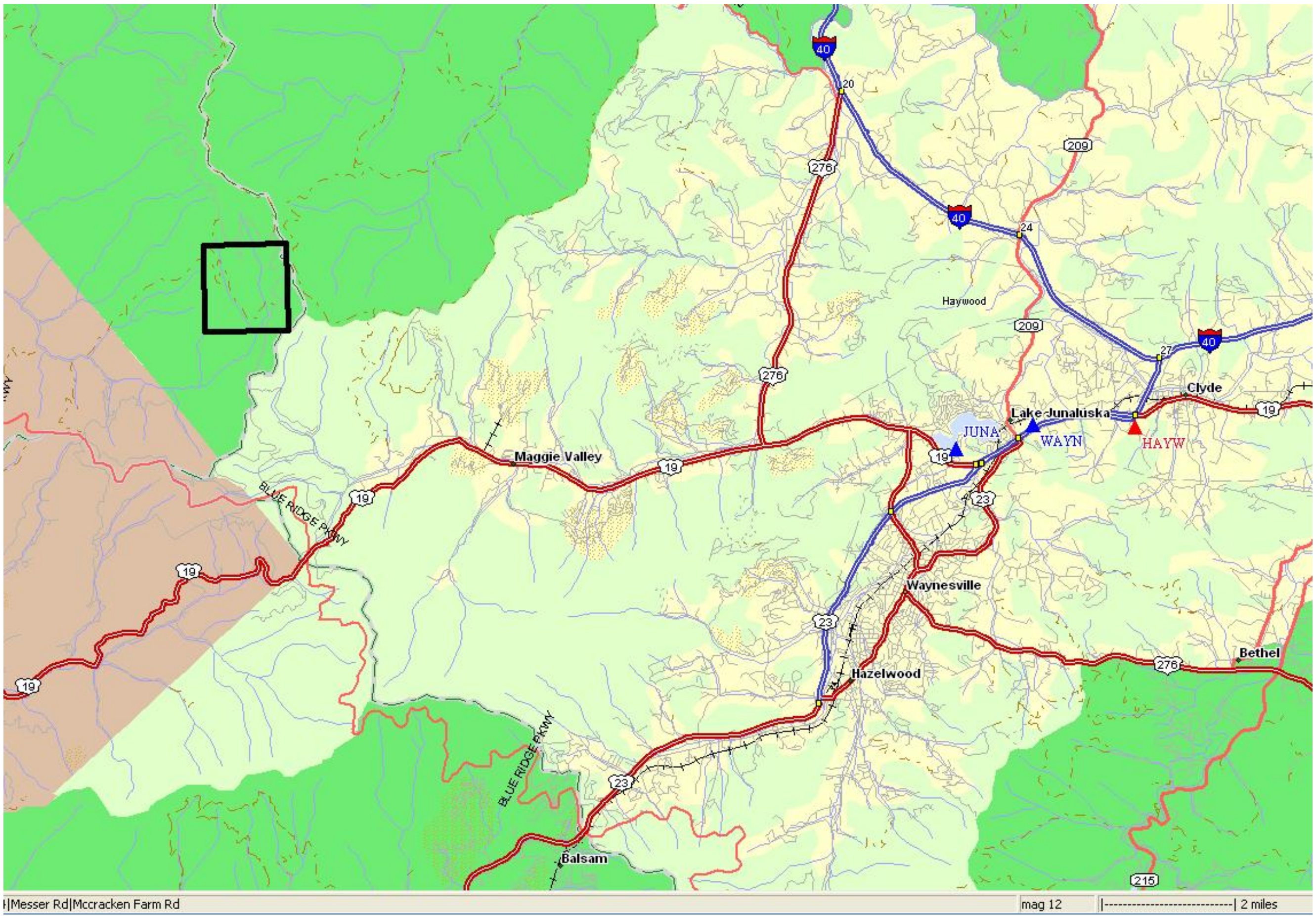


**Figure 1 - Project location map: the project area is the black square; blue triangles show locations and names of NCALM GPS base stations, the red triangle shows the location of HAYW, a NOAA Continuously Operating Reference Station (CORS) at Haywood Community College.**

## 2. Survey Parameters

This project area was flown using 12 flight lines oriented north-south and 11 additional east-west cross lines for canopy penetration and field calibration purposes. The flying height was targeted at 600 meters Above Ground Level (AGL) but varied during the survey from 600 to 1100 meters due to the mountainous terrain. Flying speed was targeted at 60 meters/second (117 knots). The Pulse Rate Frequency of the Optech 2033 ALTM (see http://www.optech.ca/ for more information) used in the survey was 33 KHz. The scan angle was set at +/- 20 degrees, with 0.5 degrees cutoff during processing. The scanning frequency (mirror oscillation rate) was 28 Hz. Point spacing per swath was nominally 1.1 meters along-track at nadir, 2.2 meters along-track at the scan edge and 0.73 meters cross-track. Flight line spacing was set at 215 meters which yielded swath overlap of 100%, (50% sidelap). These survey parameters resulted in approximately 3.5 shots per square meter, before filtering.

## 3. GPS Reference Stations

Three GPS reference station locations were used for post-processing the trajectory of the aircraft. One of these (HAYW) was a Continuously Operating Reference Stations (CORS) managed by NOAA logging at 1 Hz. and two additional stations operated by NCALM. All NCALM GPS observations were also logged at a 1-second rate and were submitted to the NGS on-line processor OPUS with solution files included as Appendix A. NCALM stations logged data for over seven hours on the day of the flight and the position was processed (by OPUS) with respect to three nearby CORS stations, all less than 42 Km distant. Final coordinates for all NCALM reference stations are based on the OPUS solutions. For further information on OPUS see http://www.ngs.noaa.gov/OPUS/ and for more information on the CORS network see http://www.ngs.noaa.gov/CORS/ and http://www.unavco.org/ . NCALM GPS equipment consisted of ASHTECH (Thales Navigation) Z-Extreme receivers, with choke ring antennas (Part# 700936.D) mounted on 1.500-meter fixed-height tripods.

**4. Navigation Processing**

Airplane trajectories for this survey were processed using KARS software (Kinematic and Rapid Static) written by Dr. Gerry Mader of the NGS Research Laboratory. KARS processing requires dual-frequency carrier phase observations and, in contrast to most commercially-used GPS kinematic processing software, yields a fixed integer (double difference) solution for all 1-second epochs.

For quality assurance purposes the project trajectory was processed separately using two of the reference stations and then coordinate differences between the separate solutions were plotted. Figure 2 (below) is a plot of the component differences in Easting, Northing, and Height of the trajectories as processed from the CORS station HAYW and the NCALM station WAYN.

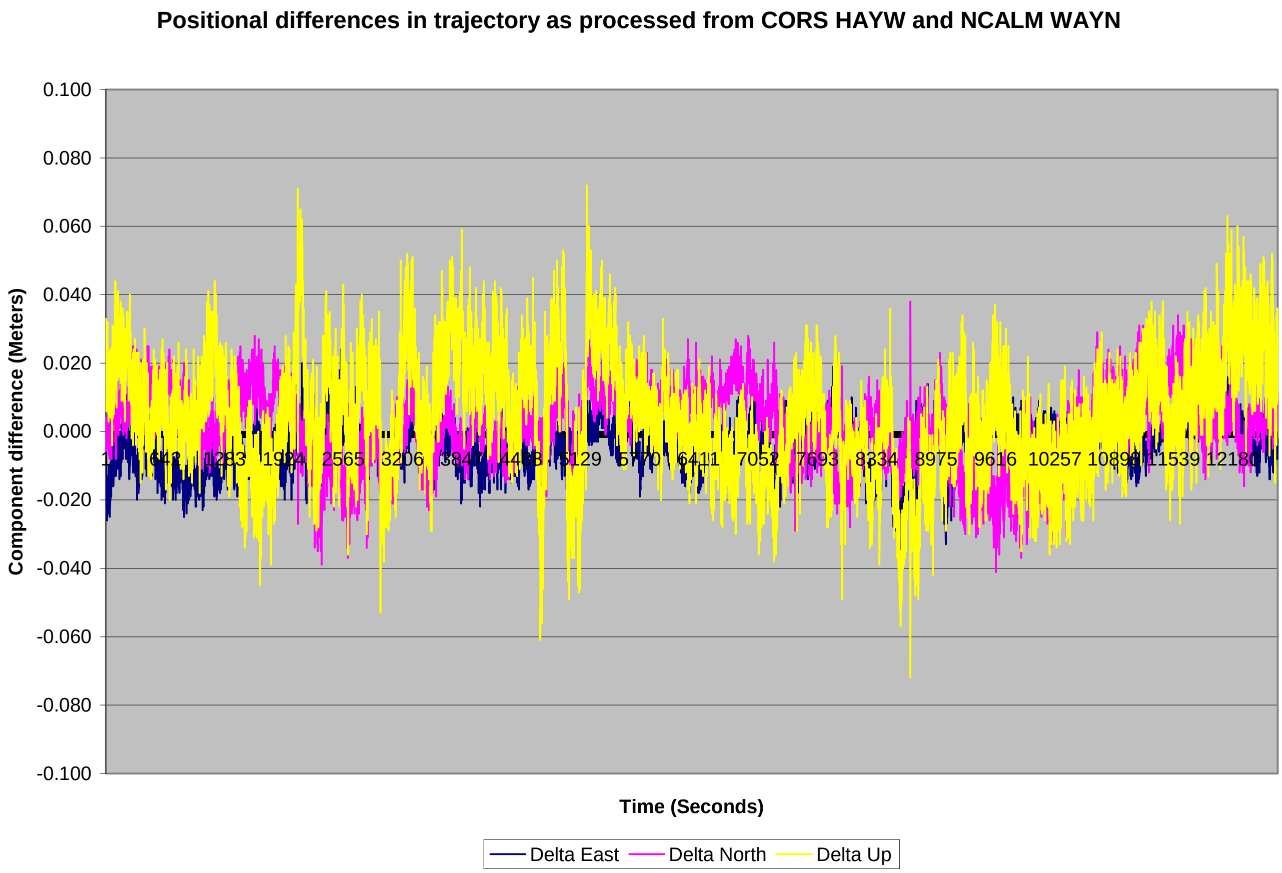


**Figure 2 – Positional differences in trajectory positions of the survey flight; these reference stations are 2.5 Km apart and the distance from reference to airplane ranged out to 25 Km.**

The standard deviation of the trajectory differences is less than 0.011 meters for the horizontal components and less than 0.020 for the vertical component.

## 5. Laser Point Processing

After GPS processing was completed for the flight, the final GPS trajectory and the raw IMU (Inertial Measurement Unit) data collected during the flight were input into APPLANIX software POSPROC. This software employs a Kalman Filter algorithm to combine the 1-Hz final differential GPS solution with the raw 50-Hz IMU orientation measurement data and their respective error models. The final result is a smoothed and blended solution of both aircraft position and orientation at 50 Hz, in SBET format (Smoothed Best Estimated Trajectory). The SBET, laser range, and mirror-angle measurement data were combined using Optech's REALM processing suite to generate point clouds in selected calibration areas, usually locations where cross-lines were flown or ground truth was collected.

System calibration was then performed as a 2-step process: step one (relative calibration) is to adjust the bore sight values of heading, roll, pitch, and scanner mirror scale such that systematic positional errors are minimized; and step two is an absolute calibration such that the laser DEM will match the height values of ground truth collected by vehicle-mounted GPS.

Step 1: Relative calibration was performed in TerraMatch software please see (**http://terrasolid.fi/ENG/Products.htm**) for detailed information.

A general description of the relative calibration procedure follows.

1. Cross-lines are flown for every flight with a heading perpendicular to the project flight line heading.
2. Small polygons containing these cross lines along with project flight lines are processed using approximate calibration values for heading, roll, pitch, and scanner mirror scale. Each line is processed separately.
3. Continuing to process each line separately, all lines are filtered (if necessary) to remove vegetation; then individual flight line surfaces are created.
4. Using TerraMatch, an iterative algorithm is applied to compute the best-fit between the individual flight line surfaces: simultaneously solving for the optimal bore sight values of heading, roll, pitch, and scanner mirror scale.
5. These updated bore sight values are then entered into REALM; new output is produced and checked for all flights.
6. Complete and final output is run using the optimized calibration values for each flight.

The above procedure was run on two areas of the project; calibration values were computed and used to generate final output.

Step 2: Absolute calibration is done by comparing the height of the nearest neighbor laser point to the height of a set of check points that are collected by vehicle-mounted GPS.

Seventy-six check points were collected in a parking lot located on the Haywood community campus near the CORS HAYW for this project. The average difference between the heights of the nearest neighbor laser point to the check point was computed to be 0.154 meters and this bias was subtracted from all project points.

All coordinates were processed with respect to NAD83 Reference Frame (CORS96) (EPOCH: 2002.0000). The projection is UTM Zone 17, with units in meters. Heights are referenced to the GRS80 ellipsoid; they have been converted to NAVD88 elevations using the NOAA GEOID03 geoid model.

The most complete output format is a nine-column ASCII (space delimited), one file per flight strip. The nine columns are as follows:

1. GPS time (seconds of week)
2. Easting last stop
3. Northing last stop
4. Height last stop
5. Intensity last stop
6. Easting first stop
7. Northing first stop
8. Height first stop
9. Intensity first stop

Note that the UTM zone code (17) is appended to the Easting coordinate in this five-column format.

During processing, a scan cutoff angle of 0.5 degrees was used to eliminate points at the edge of the scan lines. This was done to improve the overall DEM accuracy (points farthest from the scan nadir are the most affected by small errors in pitch, roll and scanner mirror angle measurements). Points with very low intensity values were also filtered out (intensity values less than 5), because these points also tend to be the least accurate. This is due to the fact that very weak return pulses yield the noisiest range measurements. These points represent a very small percentage of the total number of points, usually in the neighborhood of a few hundredths of one percent.

All calibration files as well as all raw observation files (both GPS and ALTM) necessary to reprocess this project in its entirety are archived by UC Berkeley.

# APPENDIX A.
# GPS Reference Station Coordinates from OPUS

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                       NGS OPUS SOLUTION REPORT
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      USER: michaels@ufl.edu                        DATE: December 10, 2006
RINEX FILE: wayn318q.06o                            TIME: 21:12:52 UTC


  SOFTWARE: page5  0601.10 master28.pl             START: 2006/11/14  16:16:00
 EPHEMERIS: igs14012.eph [precise]                  STOP: 2006/11/14  23:22:00
  NAV FILE: brdc3180.06n                        OBS USED: 13220 / 13480   :  98%
  ANT NAME: ASH700936D_M    NONE               # FIXED AMB:    47 /    47   : 100%
ARP HEIGHT: 1.500                              OVERALL RMS: 0.011(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2006.8708)

         X:       637581.656(m)   0.005(m)           637580.967(m)   0.005(m)
         Y:     -5158065.923(m)   0.015(m)         -5158064.461(m)   0.015(m)
         Z:      3686063.717(m)   0.009(m)          3686063.568(m)   0.009(m)

       LAT:   35 31 37.00637      0.004(m)       35 31 37.03138      0.004(m)
     E LON:  277  2 47.44285      0.007(m)      277  2 47.42283      0.007(m)
     W LON:   82 57 12.55715      0.007(m)       82 57 12.57717      0.007(m)
    EL HGT:          795.407(m)   0.016(m)              794.071(m)   0.016(m)
 ORTHO HGT:          824.233(m)   0.030(m) [Geoid03 NAVD88]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 17)         SPC (3200 NC  )
Northing (Y) [meters]     3933236.892           204256.164
Easting (X)  [meters]      322880.059           251159.819
Convergence  [degrees]    -1.13543945          -2.28183573
Point Scale                0.99998661           0.99988409
Combined Factor            0.99986178           0.99975927

US NATIONAL GRID DESIGNATOR: 17SLV2288033237(NAD 83)



                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DH3874 NCSY SW COMMUNITY COLL CORS ARP     N352052.407 W0831223.390   30375.1
DE8228 HAYW HAYWOOD CORS ARP               N353135.396 W0825530.127    2581.5
DG7400 NCMA MARSHALL CORS ARP              N354847.313 W0824122.673   39741.7

                 NEAREST NGS PUBLISHED CONTROL POINT
FB3291      BAPTIST                        N353134.466 W0825708.910     120.8
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                              NGS OPUS SOLUTION REPORT
                              ========================

      USER: michaels@ufl.edu                        DATE: December 10, 2006
RINEX FILE: juna318p.06o                            TIME: 21:12:25 UTC


  SOFTWARE: page5  0601.10 master29.pl             START: 2006/11/14  15:38:00
 EPHEMERIS: igs14012.eph [precise]                  STOP: 2006/11/14  23:02:00
  NAV FILE: brdc3180.06n                        OBS USED: 13361 / 13747   :  97%
  ANT NAME: ASH700936D_M    NONE             # FIXED AMB:    48 /    48   : 100%
ARP HEIGHT: 1.500                            OVERALL RMS: 0.012(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2006.8707)

         X:       635671.002(m)   0.005(m)          635670.313(m)   0.005(m)
         Y:     -5158619.902(m)   0.014(m)        -5158618.440(m)   0.014(m)
         Z:      3685548.240(m)   0.010(m)         3685548.091(m)   0.010(m)

       LAT:   35 31 17.44282      0.005(m)       35 31 17.46783      0.005(m)
     E LON:  277  1 29.49558      0.006(m)      277  1 29.47554      0.006(m)
     W LON:   82 58 30.50442      0.006(m)       82 58 30.52446      0.006(m)
    EL HGT:          752.892(m)   0.016(m)             751.556(m)   0.016(m)
 ORTHO HGT:          781.664(m)   0.030(m) [Geoid03 NAVD88]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 17)         SPC (3200 NC  )
Northing (Y) [meters]     3932673.208           203732.173
Easting (X)  [meters]      320904.569           249173.659
Convergence  [degrees]    -1.14787859          -2.29433264
Point Scale                0.99999528           0.99988364
Combined Factor            0.99987712           0.99976549

US NATIONAL GRID DESIGNATOR: 17SLV2090532673(NAD 83)


                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DH3874 NCSY SW COMMUNITY COLL CORS ARP     N352052.407 W0831223.390   28505.8
DE8228 HAYW HAYWOOD CORS ARP               N353135.396 W0825530.127    4579.1
DG7400 NCMA MARSHALL CORS ARP              N354847.313 W0824122.673   41419.9

                 NEAREST NGS PUBLISHED CONTROL POINT
AB2752      SUSIE                          N353104.642 W0825833.098     401.1
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