# APPLICATION OF LARGE SCALE GPS CONTROLLED AERIAL PHOTOS FOR FOREST INVENTORY

**Kevin Megown, Jule Caylor, Jose Callejas, Mark Finco**
USFS Remote Sensing Applications Center (RSAC)
Salt Lake City, Utah

**Gretchen Moisen, Larry DeBlander**
Rocky Mountain Research Station
Ogden, Utah

## ABSTRACT

This paper looks at the ability of large-scale, differentially corrected, real time GPS controlled, aerial photography (LSP), to acquire selected forest inventory and analysis (FIA) data in remote areas. This is the second of a two part report for the acquired photographs. Part one demonstrated that large-scale photos can accurately target known GPS ground points. Part two tests if large-scale aerial photographs can serve as a sufficient sampling and measurement tool to provide accurate estimates of selected individual tree and forest stand variables essential to resource managers. Color aerial photographs at a scale of 1:3,000 were taken over 28 FIA plots on the Beaverhead-Deerlodge and Helena National Forest. Measurements captured by LSP methods include, tree condition, tree height, and species determination. ERDAS Stereo Analyst served as a software platform. Finding plot centers on the LSP was not always possible, and the previously used variable radius plots made the task more difficult. LSP values and estimates were contrasted with field data at an individual tree level. The data collected by the current method of aerial photo interpretation proved to be within tolerable limits. A sample design that incorporates both field and LSP based measurements may be a cost effective approach for acquiring resource data.

## INTRODUCTION

Forest inventories, including those conducted by the Forest Inventory and Analysis (FIA) program, are expensive endeavors. The large amounts of data collected, excessive travel time and increasing frequency with which data must be collected, contribute to the ever increasing expense. With many forest inventories under increased pressure to produce better and more information at reduced costs, economically alternative data collection methods are needed.

Decades prior to the 1950's, aerial photos had been used in forest operations including the direct measurement of individual trees for the estimation of volume and growth (Spurr, 1954). Since the 1950's, the improvement of computing power led to advances in statistical utilization and software concerning the use of aerial photos for forest applications (Pope, 1962; Paine, 1965; Aldred and Kippen, 1967; Aldred and Hall, 1975; Spencer and Hall, 1988; and Patton et. al., 1998). These applications focus on the use of broadcast photo coverage and hard copy interpretation, where the flight path and overlap (both forward and sidelap) captures a relatively large area. A combination of recent technological advances allow for many improvements in the application of aerial photography.

Aerial photos can be captured within a few meters of a target with the combination of real time Geographical Positioning System (GPS) and forward motion compensation (Reutebuch et al., 2000). Combining this method of aerial photo acquisition with improvements in software, an interpreter can easily capture two or three aerial photos within a few meters of most places in the world and *digitally* create a stereo pair. With the advent of hardware allowing one to view aerial photographs in stereo, interpreters can easily "zoom" into a pair of stereo aligned photos by a magnitude of hundreds (ERDAS IMAGINE 2001; Stereo Analyst 2001). This combination of technologies allow sample designs, such as those used by the FIA, to take advantage of photo acquisition and a photo interpreter's ability to capture individual tree measurements.

This study focuses on the methods used and ability of interpreters to capture individual tree measurements from FIA plots using large scale, real time differential GPS, forward motion compensated, aerial photography.

# METHODS

## Study Area and Forest Inventory Data

The study was conducted on the Helena and Beaverhead-Deerlodge National Forests located in Montana. Steep, rugged terrain and remote access areas, including wilderness areas characterize these forests. A total of 28 plots were used, 8 in the Helena National Forest and 20 in the Beaverhead-Deerlodge National Forest. All FIA plots consisted of a 5-subplot bowtie design based on a point sample; where the probability of tallying a tree depends on a tree's diameter at breast height (dbh), its distance from the sample point, and a predetermined basal area factor[1].

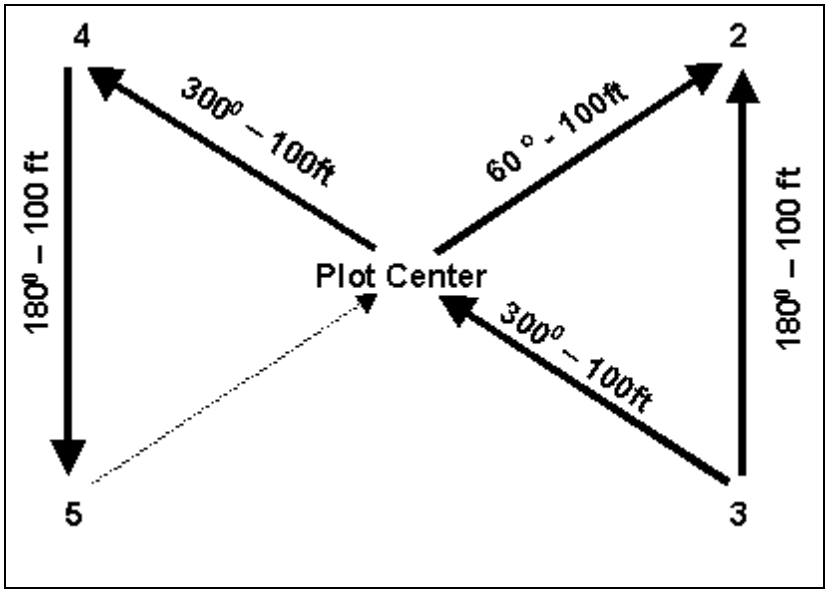


**Figure 1.** The bowtie design showing the location of the five subplots, with subplot 1 being the plot center.

## Acquiring Aerial Photos into a Digital Format

Aerial photos were acquired during fly dates of July 9th 1999 and July 19th 1999, from early to late afternoon. Camera and film information includes: a 305 mm nominal focal length, natural color film, at a photo scale of approximately 1:3000. The negatives were scanned with a high-end photogrammetric scanner at a 12.5*u* scanned resolution. This allowed for a single pixel to represent approximately two square inches on the ground.

## Orthorectification and Stereo Pair Creation

Entering the camera information and orienting the photos by control points, with reference to the digital orthoimages and digital elevation models, accomplished orthorectification. Selecting similar points on each photo, and allowing automatic tie points to be generated created a stereo alignment. For this project, a total MSE of less than 7 was acceptable for control and tie points.

## Locating Field Plots and Tree Measurements

Locating the plot centers involved using all available information provided by the FIA location file. The FIA field crews used a 1: 20,000 scale photo with a pinprick locating the plot center. Diagrams were developed with the field location (distance and azimuth to plot center), species, and tree size for all subplots in the trial. In some cases, the field crew had taken 35mm pictures in the cardinal directions from plot center. All of these 'hints' were used to some degree in helping find the plot centers.

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[1] A predetermined simple prism angle, or angle gauge (Bitterlich stick) are common methods of tallying trees. The field hand simply looks at the breast height of an individual tree using the method of choice, and tree boles which completely fill the sighting angle are tallied (Avery and Burkhart 1994). A basal factor of 40 was used on these plots.

When plot centers were identified, the UTM coordinates were tallied from the stereo pair. It was imperative to visually identify all trees on a plot to confirm location. All trees were measured for species, height, condition (living / dead) and visible crown diameter. When possible, surrounding subplots were identified and individual trees were measured accordingly.

Two separate interpreters were involved with the individual tree measurements including tree height, visible crown diameter and condition, while an expert was included to determine tree species. The process of using two interpreters for tree measurements was to study differences between interpreters as they apply the latest technology. Each interpreter measured tree height five times. A single interpreter was used for determining tree species so as to eliminate bias. The photo interpreters, at times, became very familiar with the plots and species located on them.

Paired-t and Student-Newman-Keuls (SNK) tests were used to determine significant differences between field crew data and aerial photo interpreted data for tree height. Differences in plot coordinates, species and condition were summarized and visible crown diameter was summarized.

## RESULTS

### GPS Plot Coordinates

Of the twenty-eight plots available, eleven were successfully found on the aerial photos. Fourteen of the plots were not discernable for many reasons, including shadow cast by large trees onto the plot, closed canopy, and sample technique (basal / point sampling) not capturing all the trees visible from the aerial photos. Three plots had large differences in the location of the GPS coordinates and the pinpricked aerial photo provided by FIA field notes; these plots were ignored. Within the eleven plots whose centers were located, a total of fourteen subplots were captured (including the plot center subplot).

Differences between the GPS recorded plot centers and the UTM coordinates from the LSP orthorectified stereopair images were recorded. An absolute average of these differences was 23.5m for the X-coordinate and 6.7m for the Y-coordinate.

### Tree Height

Tree height measurements were initially tested using a paired t-test ($\alpha = 0.05$) for contrasting between the average of an individual interpreter, and also an average of both interpreters with the field crew. There are no significant differences between the field values and the aerial photo measured values. It was thought the variation was too high for this test to be accurate as it included all trees with heights from under 10 m to over 20 m (Figure 2).

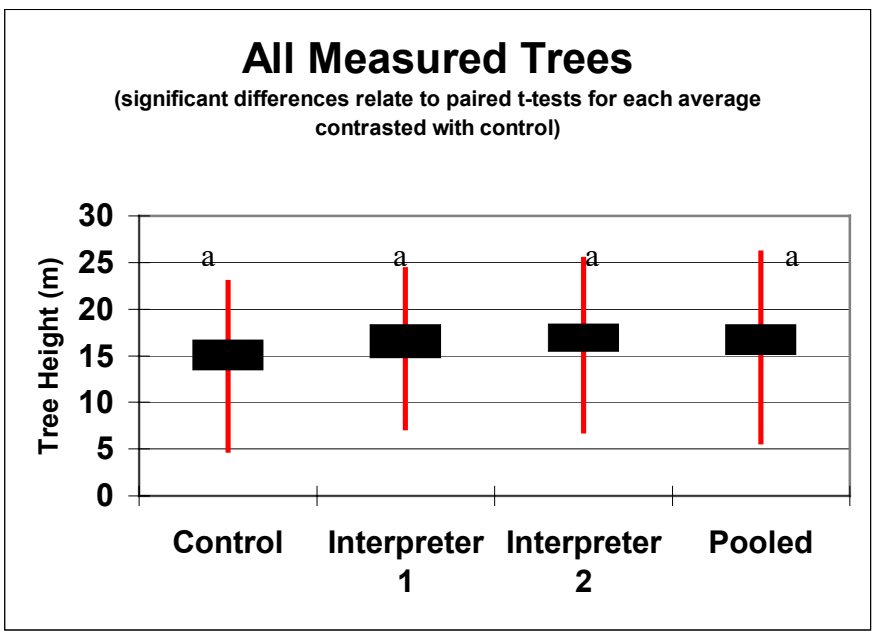


**Figure 2.** Figure 2 includes a 95% confidence interval about the mean with max and min values (seen as box and whisker plots). There are no significant differences between the means as they are individually contrasted with the control for a paired t-test. A SNK test showed no significant differences between all means.

The sampled trees were divided into trees smaller than fifteen meters and larger than fifteen meters to accommodate a threshold between large and small trees. Figure 3 shows significant differences of a Student-Neuman-Kuels (SNK) test (a paired test showed similar results for differences between the individual means contrasted with the field measurements and photo measurement averages). Figure 4 shows significant differences of a SNK test (a paired test showed similar results for differences between the individual means contrasted with the field measurements and photo measurement averages).

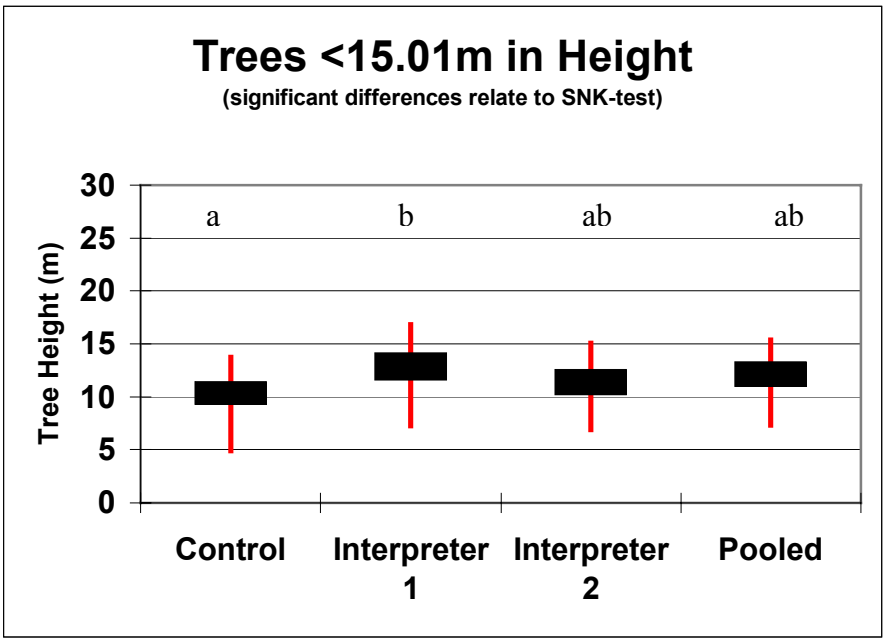


**Figure 3.** Figure 3 includes a 95% confidence interval about the mean with max and min values. A SNK test shows the same significant differences as a paired t-test for individually contrasting the interpreter's work to the ground crew (control).

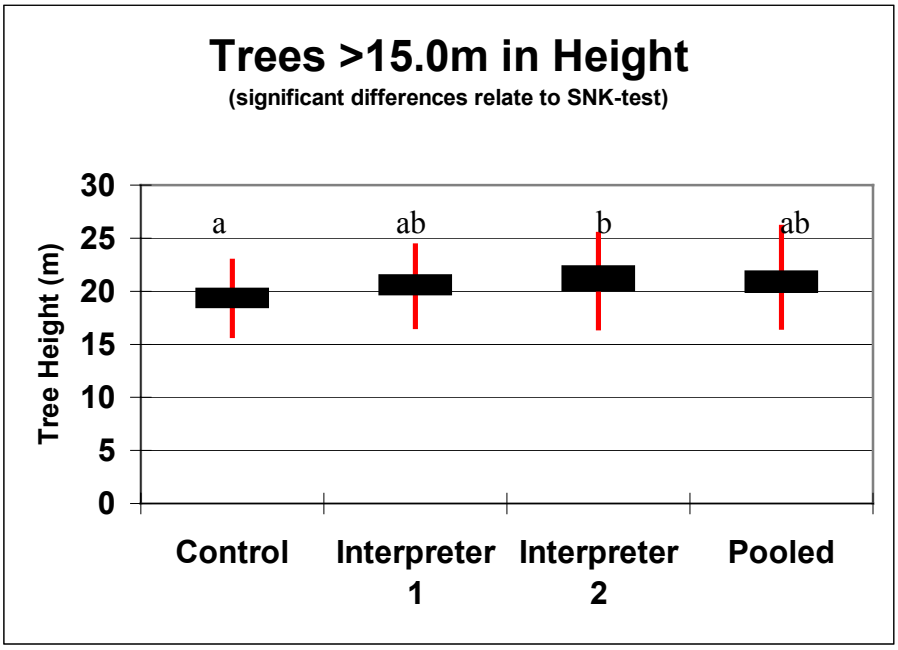


**Figure 4.** Figure 4 includes a 95% confidence interval about the mean with max and min values. A SNK test shows the same significant differences as a pared t-test for individually contrasting the interpreter's work to the ground crew (control).

### Species and Condition

Species found on all the plots include: Douglas fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), ponderosa pine (*Pinus ponderosa*) subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*), and whitebark pine (*Pinus albicaulis*). Of the 40 trees found, three were incorrectly identified. The three were: living, less than 15 m in height, to some degree hidden by shade from taller trees, and are species known to be difficult to determine as younger trees.

All trees were identified correctly as dead or alive. Of the seven dead trees in our sample, all species were identified correctly.

### Visible Crown Diameter

Visible crown diameter was measured for each tree tallied (descriptively summarized for 37 trees in Appendix 1).

## SUMMARY and DISCUSSION

The ability of an interpreter to measure forest variables from scanned aerial photography is determined by the photo quality, the scale of the photo, and scanning resolution. Unlike historical photo interpretation, today's interpreter can "zoom" into the stereo photos and capture very good detail at scales of 1:50. The ability to "zoom" is directly related to the scanned pixel size. A scanned photo from an original scale of 1:4000 can be viewed in stereo, with little distortion at 1:100 with a scanned pixel size of 10u. This would allow an individual to see 0.128 ft per pixel. Allowing individual leaves on a tree to be seen. The downside to this is the file size. A typical 9x9 aerial photo scanned at 10u, will have up to a 1.5 gigabyte file size.

The ability of an interpreter to locate plot centers was confounded by a number of affects. Plots with closed canopies were nearly impossible to locate as it was difficult to specifically locate all the trees as determined by the ground crew. In some plots, we could see most individual trees, but could not discern the plot center as more trees were visible in the photo as represented by the basal plot. Shadows cast by large trees over plot centers was problematic as the smaller trees were not discernable. In a few cases, tree tops of the smaller trees could be seen and some measurements were made. Some of the GPS coordinates given were not near the referenced aerial photo coordinates. These plots were not used.

Locating subplots on photos was confounded by field crews inconsistency in correcting for declination. The crews were not supposed to correct for declination, although some did note a correction, most noted no correction and some did not note either way. The rectification of the aerial photos created a stereo pair visible 'towards' true north. Most field plot alignments were towards magnetic north. Hence our ability to locate most subplots was not possible.

The photo quality, scanning capability and software and hardware utilized in this study allowed us to measure tree height and determine tree condition within tolerable errors (10% of tree height is acceptable for a tree height measurement and condition is 0% error). Species determination was successful due to the employment of an expert (the use of the "zoom" capability helped). Tree height measurements could have been more precise if the dates of photo acquisition and field measurements were closer. A difference of 4 years was most common, although a few of the field measurement dates were 9 years prior to aerial photo acquisition. This may account for the general increase in height when contrasting the ground crew data with the aerial photo interpreter's data.

A quick look at the two different interpreters ability to measure tree height indicate that there are different bias's associated with each individual. Interpreter 1 captures the taller trees better, while interpreter 2 captures shorter trees better. It is not uncommon for interpreters to have a bias, while it is also not uncommon for different photo interpreters to have different bias (Bonner 1968; Paine 1981). Methods of reducing bias are common, while not employed here, it is imperative a comprehension of an interpreters bias's be adjusted for during production.

The learning curve associated by this method (using Stereo Analyst) can be difficult, although manageable.

## CONCLUSIONS

The application and incorporation of technology allowed specific GPS ground coordinate locations to be secured by aerial photography, and individual tree measurements captured within tolerance from a digital stereo pair. Future work is needed in the location of field plots on stereo aligned large-scale photos. Quality assessment

of aerial photo interpreters, statistical design implications for application of measurements from aerial photography (development of inferred and modeled variables), and acceptance of aerial photography to provide value, is important for LSP to become operational.

The suggestion of replacing ground crews is not the intent of this work, rather, it is to raise awareness of the opportunity to optimizing data collection strategies by incorporating low altitude photography into the sample design.

This current study focused on photo interpreter' ability to capture individual tree data, and determine the effectiveness of the methods; both of which are a success. It is thought that the ability to capture data from a scanned digital method coupled with other remote sensing capabilities and some ground crew assessments can further add value to a more spatial comprehension of forest resources at many scales.

## ACKNOWLEDGMENTS

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# APPENDIX 1

| | Mean (m) | St. Error | Median | Kurtosis | Skewness | Range | Min | Max | Height (m) | DBH (in) | Species Code |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Avg. | 8.32 | 0.252 | 8.33 | 0.7647 | 0.0980 | 1.4 | 7.6 | 9.0 | 14.8 | 10.7 | - |
| 1 | 5.32 | 0.201 | 5.41 | 1.6480 | -0.9856 | 1.2 | 4.6 | 5.8 | 12.19 | 20.6 | 93 |
| 2 | 5.81 | 0.264 | 5.87 | 2.7329 | -1.4605 | 1.6 | 4.8 | 6.4 | 16.46 | 13.2 | 93 |
| 3 | 4.67 | 0.138 | 4.55 | -2.6632 | 0.2786 | 0.7 | 4.3 | 5.0 | 20.73 | 10.0 | 93 |
| 4 | 6.02 | 0.209 | 5.90 | 3.3936 | 1.7831 | 1.2 | 5.7 | 6.8 | 10.06 | 9.0 | 108 |
| 5 | 5.23 | 0.119 | 5.20 | -1.1820 | 0.0846 | 0.7 | 4.9 | 5.6 | 1.67 | 10.7 | 108 |
| 6 | 5.18 | 0.163 | 5.14 | 2.7464 | 1.3494 | 1.0 | 4.8 | 5.8 | 9.75 | 8.9 | 202 |
| 7 | 2.06 | 0.041 | 2.05 | 1.1232 | -0.1081 | 0.3 | 1.9 | 2.2 | 10.97 | 13.8 | 108 |
| 8 | 1.88 | 0.065 | 1.87 | 1.0205 | -0.663 | 0.4 | 1.7 | 2.1 | 9.45 | 7.2 | 108 |
| 9 | 5.76 | 0.189 | 5.69 | -1.3886 | 0.5692 | 1.0 | 5.4 | 6.3 | 10.67 | 8.1 | 108 |
| 10 | 12.40 | 0.681 | 12.54 | -1.9191 | -0.3142 | 3.6 | 10.4 | 14.0 | 9.14 | 5.8 | 108 |
| 11 | 6.46 | 0.326 | 6.42 | 0.4429 | -0.3495 | 2.0 | 5.4 | 7.4 | 13.72 | 12.7 | 108 |
| 12 | 7.97 | 0.235 | 7.76 | 4.0967 | 1.9888 | 1.3 | 7.6 | 8.9 | 6.71 | 5.1 | 108 |
| 13 | 8.06 | 0.253 | 8.09 | 0.5626 | 0.9204 | 1.4 | 7.5 | 8.9 | 10.97 | 7.1 | 108 |
| 14 | 15.83 | 0.474 | 15.39 | 2.1943 | 1.5135 | 2.7 | 14.9 | 17.6 | 12.19 | 7.1 | 108 |
| 15 | 16.46 | 0.835 | 17.16 | -1.3834 | -0.1678 | 4.7 | 14.1 | 18.8 | 10.06 | 5.7 | 108 |
| 16 | 10.22 | 0.218 | 10.11 | -1.8347 | -0.1039 | 1.1 | 9.6 | 10.7 | 21.03 | 8.6 | 108 |
| 17 | 3.93 | 0.175 | 3.86 | -2.2090 | 0.1452 | 0.9 | 3.5 | 4.4 | 20.42 | 7.4 | 108 |
| 18 | 2.41 | 0.054 | 2.43 | 2.7114 | -1.1814 | 0.3 | 2.2 | 2.5 | 19.51 | 7.9 | 108 |
| 19 | 6.78 | 0.161 | 6.77 | 1.2292 | 1.0124 | 0.9 | 6.4 | 7.3 | 17.68 | 7.8 | 108 |
| 20 | 3.10 | 0.096 | 3.11 | -0.6513 | 0.5221 | 0.5 | 2.9 | 3.4 | 21.03 | 7.8 | 108 |
| 21 | 3.37 | 0.057 | 3.39 | 2.9028 | -1.3647 | 0.3 | 3.2 | 3.5 | 20.42 | 9.3 | 108 |
| 22 | 4.77 | 0.197 | 4.88 | -1.8477 | -0.5258 | 1.0 | 4.2 | 5.2 | 21.64 | 10.4 | 108 |
| 23 | 2.97 | 0.125 | 2.95 | 1.2984 | 1.0720 | 0.7 | 2.7 | 3.4 | 17.68 | 11.0 | 108 |
| 24 | 22.01 | 0.209 | 21.87 | 1.3906 | 1.3209 | 1.1 | 21.6 | 22.8 | 16.76 | 12.3 | 202 |
| 25 | 16.82 | 0.240 | 16.99 | 4.4146 | -2.0721 | 1.3 | 15.9 | 17.2 | 16.76 | 10.7 | 202 |
| 26 | 10.03 | 0.440 | 10.28 | -0.4095 | -0.2839 | 2.6 | 8.7 | 11.3 | 91.20 | 11.7 | 108 |
| 27 | 16.67 | 0.648 | 15.81 | -2.3762 | 0.6470 | 3.3 | 15.3 | 18.6 | 19.81 | 13.5 | 108 |
| 28 | 12.43 | 0.576 | 13.20 | -0.1380 | -1.1629 | 2.9 | 10.5 | 13.4 | 17.07 | 10.7 | 108 |
| 29 | 13.44 | 0.171 | 13.36 | 2.7728 | 1.6045 | 1..0 | 13.1 | 14.1 | 10.97 | 15.4 | 108 |
| 30 | 7.84 | 0.166 | 7.66 | -2.2789 | 0.6901 | 0.8 | 7.5 | 8.3 | 6.71 | 4.1 | 93 |
| 31 | 12.90 | 0.342 | 12.94 | 0.8751 | 0.4810 | 2.1 | 11.9 | 14.0 | 4.88 | 1.2 | 108 |
| 32 | 6.55 | 0.072 | 6.52 | -0.0097 | 0.5311 | 0.4 | 6.4 | 6.8 | 11.58 | 7.4 | 108 |
| 33 | 4.69 | 0.159 | 4.62 | 3.3195 | 1.6091 | 0.9 | 4.32 | 5.3 | 13.72 | 8.9 | 101 |
| 34 | 5.20 | 0.146 | 5.18 | 1.5246 | 0.0028 | 0.9 | 4.7 | 5.7 | 22.86 | 24.5 | 101 |
| 35 | 12.07 | 0.577 | 12.31 | 1.0584 | -1.1682 | 3.2 | 10.0 | 13.2 | 20.42 | 211.6 | 101 |
| 36 | 10.93 | 0.254 | 11.15 | 1.8752 | -1.4031 | 1.4 | 10.0 | 11.4 | 12.19 | 19.6 | 101 |
| 37 | 9.71 | 0.054 | 9.75 | 3.2524 | -1.7816 | 0.3 | 9.5 | 9.8 | 21.64 | 19.5 | 101 |