Accuracy of Pléiades Photogrammetric Products Under Direct and Controlled Georeferencing

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Abstract

Space-based photogrammetry has benefitted from significant advancements recently, with progress in software, analytical techniques, and a surge in image availability. However, no photogrammetric products can be considered perfect. Estimates of error from photogrammetric modelling are thus important to characterise when faced with the various processing workflows available. This study quantifies and compares errors in photogrammetric products from very high-resolution Pléiades sensors when processed with or without ground control points (GCPs). Furthermore, the availability of an image triplet allowed bi-stereo and tri-stereo restitution scenarios to be compared for each case.

Keywords: Photogrammetry, Pléiades, Digital Surface Model, Error, tri-stereo.

1. Introduction

There have been many recent advancements in photogrammetric science. Progress in hardware and software capabilities allow for rapid processing of the relationship between image and object points. Multiple photogrammetric software have strengths and weaknesses in the various steps involved for photogrammetric modelling. ERDAS Imagine provides a practical interface allowing expert input and refinement of tie points (TP) and Ground Control Points (GCP), as well as a robust Bundle Block Adjustment (BBA) enabling the quality of the triangulation to be critically reviewed and finely adjusted (ERDAS, 2010). However, the software fails to implement modern stereo-matching methods such as semi-global matching (SGM) (Hirschmüller, 2008) for dense surface restitution.

New open-source solutions such as AMES Stereo Pipeline (ASP) provide alternative and complementary options to the photogrammetric workflow (Shean et al., 2016; Beyer et al., 2018). In particular, ASP implements modern dense stereo-matching methods and point cloud filtering options. Like ERDAS, ASP can compute BBA but expert input and refinements to improve the model's robustness are unpractical. A strength is ASP's full automatic processing using direct geo-referencing based on the satellite geometric model supplied in the form of Rational Polynomial Coefficients (RPC), and BBA completed using only automatic TP collection (Beyer et al., 2018).

The main goal of this study is to compare the performances from two main workflows:

1. Fully automatic direct geo-referencing with supplied RPCs (the "BBA" method).

2. Expert driven triangulation in ERDAS Imagine (the "AAT" method)

The area around Franz-Josef Glacier/Kā-Roimata-o-Hine-Hukatere on New Zealand's West Coast provides a desirable, challenging environment for this test, testing each method's functionality in areas of steep topography and low-contrast from shadow and snow. Furthermore, the availability of Pléiades image triplets allows bi- vs. tri-stereo scenarios to be tested under each workflow. This provides insight into how far automatic methods of restitution can be trusted to create accurate DSMs.

2. Data and Methods

A 400 km^2 image triplet captured by the Pléiades-1A sensor on 4th April 2012 includes 0.5-m resolution panchromatic image as well as a two-meter resolution RGB image. The different incidence angles can be leveraged in the photogrammetric package to improve both accuracy from the redundancy of ray intersection and various Base-to-Height ratio (B/H), as well as completeness by unlocking stereo-coverage over steep terrain (Figure 1). 18 GCPs were collected with survey-grade GNSS receivers in and around Franz Josef to support manual triangulation and assessment of the photogrammetric model.

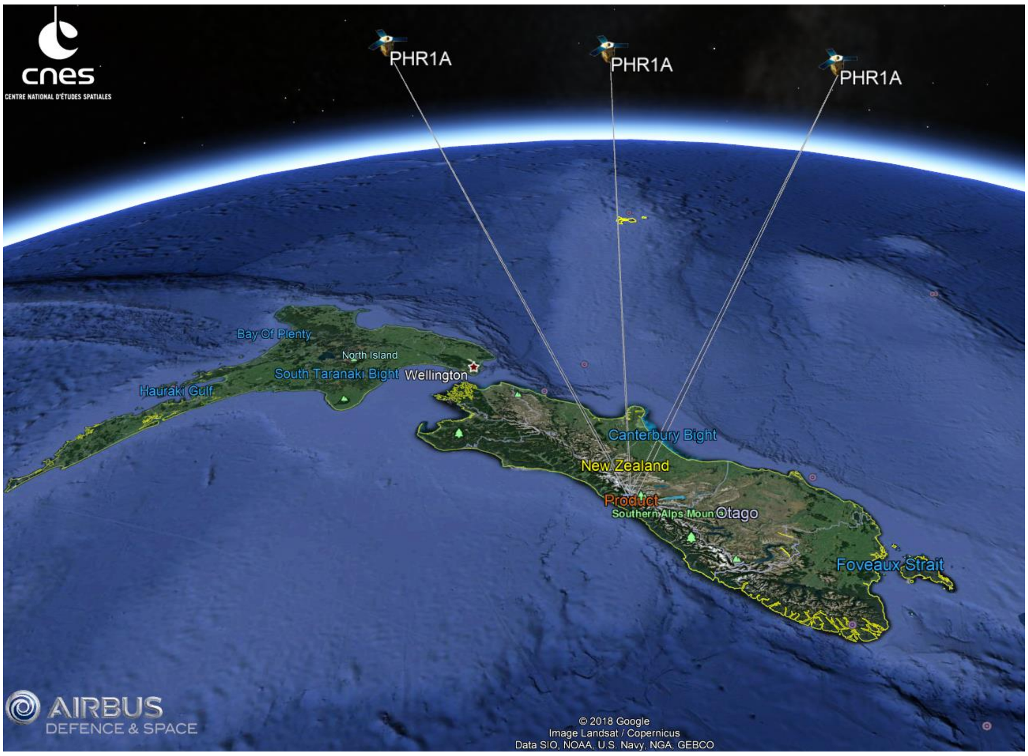

Figure 1: incidence angles of images captured by Pléiades-1A sensor on 4th April 2012 (credit: University of Otago/GNS/© CNES (2012), Distribution Airbus DS).

The imagery was then processed through triangulation and restitution. Three triangulation methods were tested using:

1. *BBA*: automatic TP collection followed by BBA in ASP;
2. *AAT*: triangulation with expert input of GCP/TP and manual refinements of the solution in ERDAS with two variations:

a. AAT 1.0: “soft” GCPs near the Main Divide were transferred from overlap with an existing photogrammetric model extending to the Aoraki/Mt Cook National Park (Sirguey & Cox, 2017)
b. AAT 2.0: the imagery tied to the existing photogrammetric model.

Dense stereo-matching with a hybrid global-matching in ASP (Hirschmüller, 2008; d'Angelo, 2016, Beyer et al., 2018) was used for each method to create DSMs, with which true orthophotmosaics were produced using a combination of GDAL scripts.

Both AAT 1.0 and AAT 2.0 used centimeter-accurate “hard” GCPs collected in the field, a hands-on assessment of TP, and repeated BBA to refine RPCs.

Five DSM restitution scenarios were completed from the image triplet for each triangulation method:

- three bi-stereo DSMs from each pairwise combination of images,
- a blend DSM obtained by averaging the three bi-stereo, weighted by ray intersection error, and
- a tri-stereo DSM from three-ray intersection;

The planimetric accuracy for each method was determined from the displacements of soft and hard GCPs in the resulting orthoimage, as well as selected TP used as reference. Elevation accuracy for each DSM was assessed using residuals from a leave-one-out cross-validation (Sirguey & Cullen, 2014), comparative analysis of histograms over selected flat areas, and differencing each DSM with the AAT 2.0 blend DSM used as a reference.

4. Results

The triangulation error was calculated for AAT 1.0 using leave-one-out cross validation in ERDAS Imagine, setting each point as a check point (both soft and hard GCP) and calculating the residual from the model solution. The results yielded a 0.46 m CE90, and 0.79 m LE90, indicating the expected error due to the triangulation. The BBA has no initial estimation of triangulation error because of the lack of GCPs.

The positions of both soft and hard GCPs, as well as several TP, were imported into ArcMap. Orthophotos from the most nadir image were generated using blended DSMs from each triangulation, from which the locations of these points were digitized. The planimetric residuals between the true and digitized positions were then calculated and plotted in Figure 2.

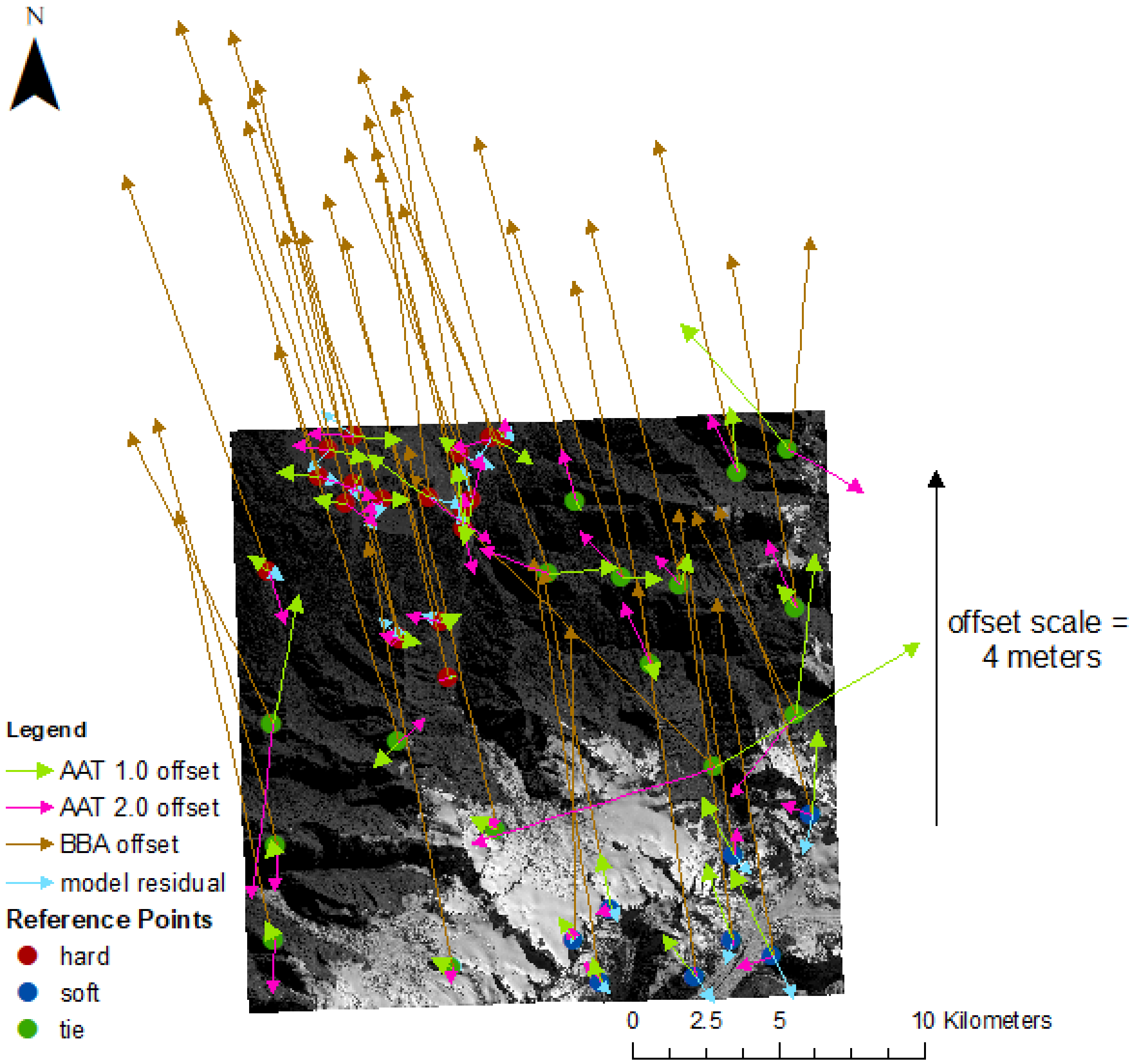

Figure 2: Planimetric residuals determined from reference points including “hard” GCPs measured in the field, “soft” GCPs derived from an existing photogrammetric model spanning across the Main Divide, and selected “tie” points derived from the AAT 1.0 BBA solution.

The vertical accuracy was assessed by sampling three polygons assumed to be representative of flat terrain. The dispersion and potential biases in elevation associated with triangulation methods and restitution scenarios was compared using histograms. Areas were assumed flat by being selected within contours derived from the AAT 1.0 blend DSM, matching the LE90 of 0.79 m. The histograms of all DSM scenarios associated with each triangulation method in one of the three polygons are plotted in Figure 3.

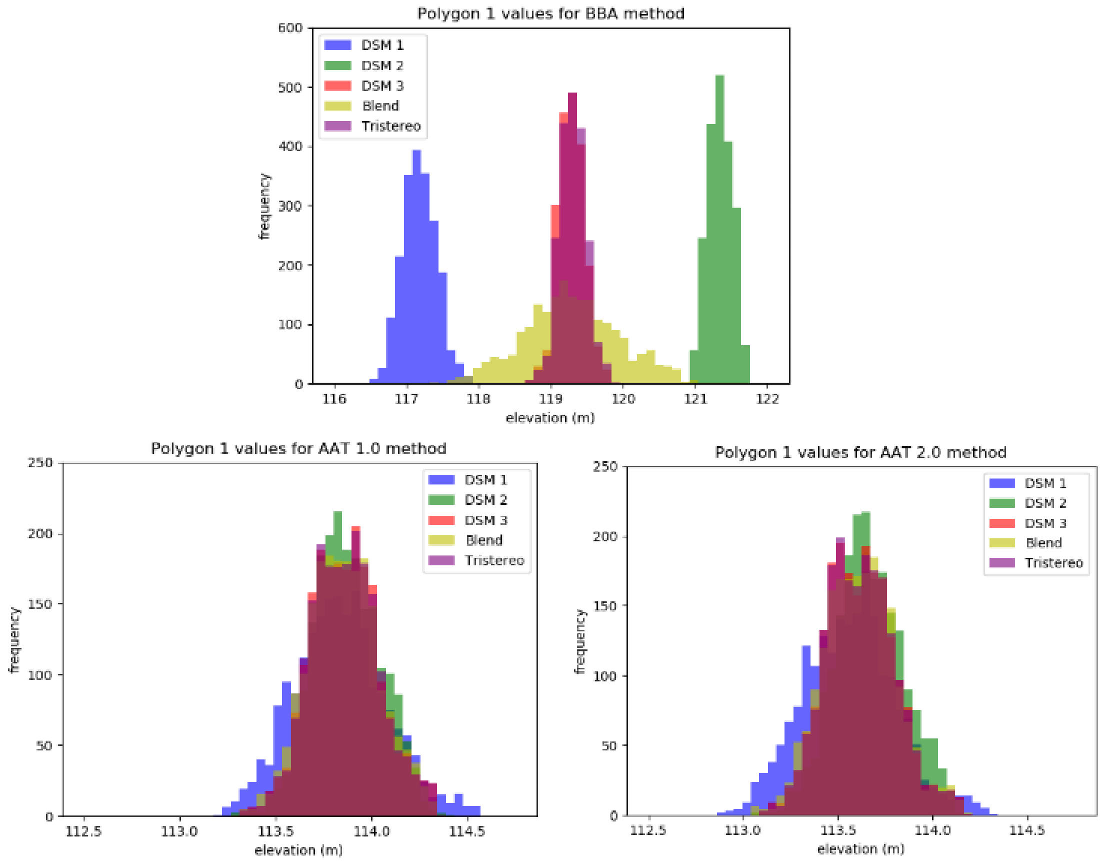

Figure 3: Histograms of DSM elevation values over one test polygon – note that the scales for the AAT methods are held constant, but the BBA values have their own scale as they fall outside the range for the AAT.

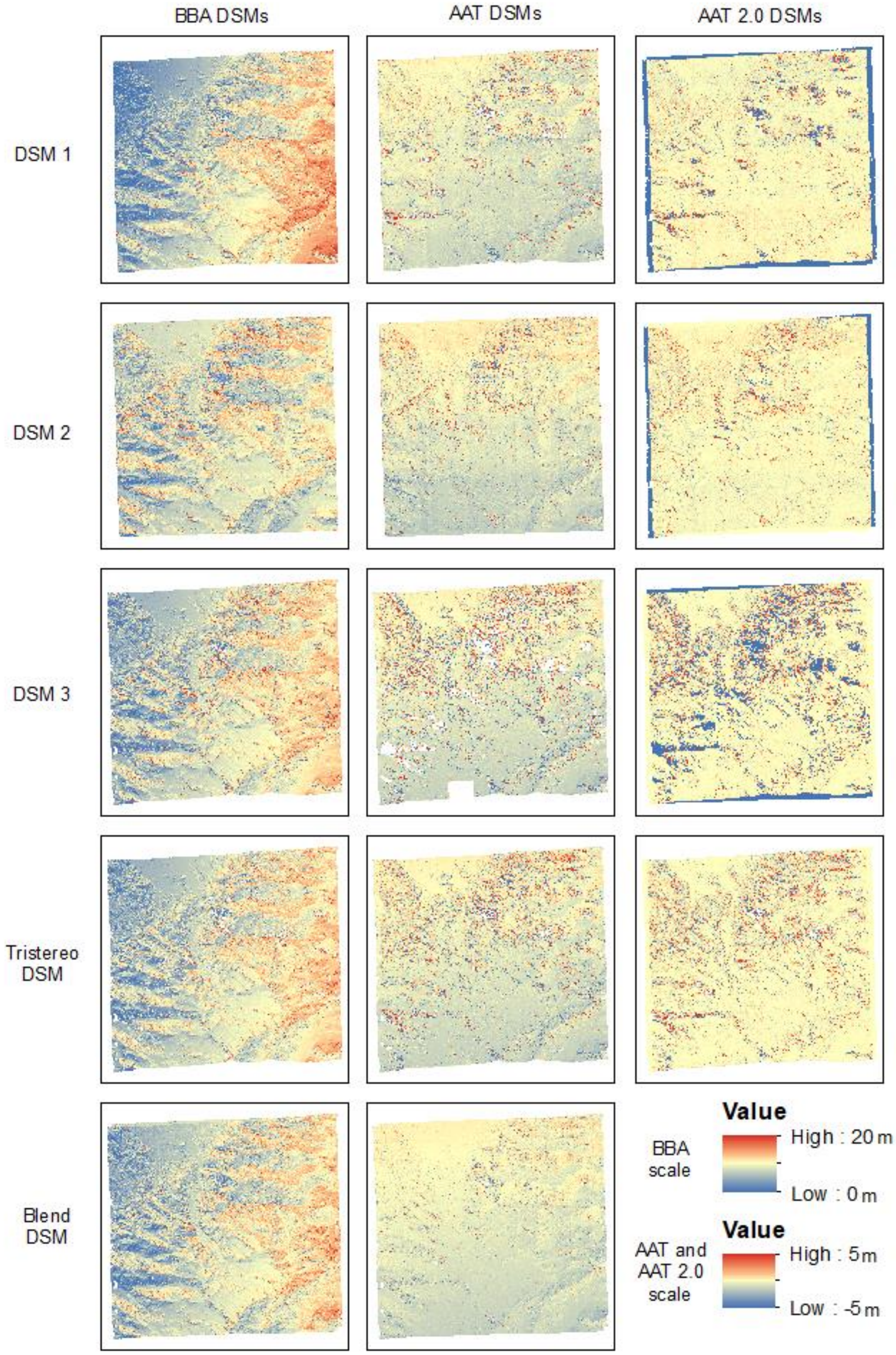

Figure 4: Difference between DSMs and the ASP-AAT 2.0 blend DSM which was used as common reference, in meters.

The BBA exhibits the highest average planimetric offset of 4.38 m towards the northwest. This compounds errors from the triangulation, restitution, and visual digitisation. The main source of this bias originates from limitation of direct geo-referencing and the inherent accuracy of satellite position conveyed by initial RPCs. The AAT 1.0, yielding RPCs refined by triangulation using control from hard and soft GCP, resulted in a significantly lower planimetric offset of 0.58 m. The AAT 2.0 had the lowest overall planimetric error of 0.54 m. Put into perspective with the CE90, this indicates that the additional error due to the restitution and digitisation contributes substantially less the error budget.

Figure 3 illustrates the vertical quality assessment over one selected area assumed flat, by displaying the histograms of DSM from scenarios associated with each triangulation method. The lack of overlap between each pairwise scenario from the BBA method shows that the elevation values between each scenario vary widely by over 2 m, thus demonstrating inconsistent restitutions, likely to be limited by the quality of the BBA. These pairwise biases compromise the blended tri-stereo which exhibits a significantly greater dispersion. However, the three-ray tri-stereo DSM mimics closely the pair with highest B/H ratio.

In contrast, AAT 1.0 and 2.0 exhibit strong internal consistency, as the histograms from the DSMs created with these methods closely overlap. Dispersion associated with each pair-wise DSM is similar to that from BBA because it is mostly indicative of the restitution process alone, regardless of the bias introduced by the method of triangulation. Overall, results from the BBA method show an average vertical bias ranging from 4 to 8 m compared to controlled methods, in consistence with expectations from direct geo-referencing.

Although Figure 3 suggests similar performance between AAT 1.0 and 2.0, Figure 4 reveals a relative tilt in the model creating a variable vertical offset trending negatively towards the south-southeast. AAT 2.0 better leverages the existing photogrammetric model across the Main Divide because it comprehensively ties more images together and relies on GCPs extending further. AAT 1.0 is exposed to more uncertainty associated with soft GCPs. This comparison shows that transferring soft GCPs can yield residual systematic biases in the DSM.

5. Conclusion

The trueness and precision of products of these methods is translated into real-world measurements when they are implemented for change detection, such as for areal measurements like landslide coverage or volumetric measurements such as glacial loss. These geomorphological estimations rely on the products of the triangulation process, which is directly influenced by the methods used for geo-referencing. The results of the assessment speak to the change in quality from the BBA triangulation method implementing direct geo-referencing, to the AAT method of controlled geo-referencing. There is a planimetric offset of over 4 meters from the location of the true measured values to the location of the BBA values, a byproduct of direct geo-referencing using the RPCs. This planimetric offset compounds the vertical offset, resulting in the sampled vertical values over an area of flat terrain to be 4-8 m different from the same area sampled from the AAT. Controlled geo-referencing improves the accuracy of resulting DSMs, decreasing planimetric offset and vertical offset, and is desirable for any user seeking to accurately estimate change using photogrammetry.

6. Acknowledgements

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