INITIAL RESULTS OF THE ITALIAN PROJECT ON DIRECT GEOREFERENCING IN AERIAL PHOTOGRAMMETRY

V. Casella[(a)], M. Franzini[(a)], G. Forlani[(b)], R. Galetto[(a)], A. Manzino[(c)], F. Radicioni[(d)], G. Sona[(e)], B. Villa[(f)]

[(a)] DIET – University of Pavia - Italy - (vittorio.casella, marica.franzini, riccardo.galetto) @unipv.it
[(b)] DICATA – University of Parma - Italy - gianfranco.forlani@unipr.it
[(c)] DIGET – Technical University of Torino - Italy - ambrogio.manzino@polito.it
[(d)] DICA – University of Perugia - Italy - topos@unipg.it
[(e)] DIIAR – Technical University of Milano - Italy - giovanna.sona@polimi.it
[(f)] DIRAP – University of Palermo - Italy - bevilla@unipa.it

KEY WORDS: Photogrammetry, GPS/INS, analysis, calibration, triangulation, adjustment, accuracy, reliability.

ABSTRACT:

The paper describes one of the first outcomes of an Italian national research Project on inertial positioning in photogrammetry. The focus of the paper is on the quality which is attainable from direct photogrammetry in an industrial production context.
Even if GPS/IMU-aided photogrammetry is used rather widely, it is still useful to perform rigorous quality assessment of this method, because large and diverse case studies are necessary to prove and quantify the capability of a new methodology. Besides, it is necessary to evaluate such methodology in the ordinary operational conditions, rather than considering data acquired in a dedicated, special context.
To fulfil these requirements several different flights were considered, which were acquired by an Italian photogrammetric company before the beginning of the Project, purely for production aims, and rigorous quantification of residual parallaxes and accuracy was performed. The origin of the considered data, which is not research-oriented, and the vast and heterogeneous case study – different cities, different flights, different calibrations- make the described test very significant and reliable.

1. INTRODUCTION

An Italian national research Project on direct georeferencing in photogrammetry is in progress. Its title is *Integrated Inertial Positioning Systems in Aerial Photogrammetry* and it is chaired by prof. Riccardo Galetto of the University of Pavia. The Project was joined by nine units belonging to as many Italian universities. The Project is greatly articulated and one of its aims is quality assessment of images which have been acquired and directly oriented within an industrial production frame.

Quality assessment of direct georeferencing in photogrammetry is of great interest because this technology is developing rapidly and the case studies already acquired are significant but not exhaustive. Besides, many of the most significant tests, such as the OEEPE test and those performed by the University of Stuttgart, were conducted with dedicated data, which was acquired exclusively for research purposes. Such studies are necessary because they allow estimation of the quality which is attainable using a certain technology in the best possible way; nevertheless it is important to ascertain what the attainable quality in an ordinary daily work-flow is and how high it's reliability.

This is the precise aim of the described step of our Project, which has two main goals: a systematic evaluation of residual parallaxes, which are sometimes critical in directly oriented images, and a systematic assessment of accuracy. The origin of the considered data, which is not research-oriented, and the vast and heterogeneous case study -different cities, different flights, different calibrations- make the described test very significant and reliable.

To perform this phase the nine working groups, belonging to different cities, were given a block above each city, together with EO data measured by an inertial integrated sensor. The data was supplied by the Italian company Compagnia Generale Ripreseaeree - CGR, whose headquarters are in Parma, which joined the Project. The images were acquired before the beginning of our Project, within an industrial project called "TerraItaly-City", devoted to the production of high detail orthophotos for more than 110 Italian cities.

The paper describes the data used for testing, the methodology followed and the main results of the analysis.

2. THE DATASET

Each unit was given a rectangular **block** constituted of 3 strips and 8 images per strip. The blocks were acquired by a plane of the CGR company equipped with a Leica RC30 **camera**, provided with an Applanix POS/AV 510 sensor. The focal length of the lens was 300 mm; the average relative height of the flight was 2900 m; the average image scale, 1:9300. The **digital images** we used were acquired by a Zeiss SCAI scanner with a resolution of 14 microns per pixel.

Two external orientation sets have been delivered: the ones acquired through a direct sensor orientation process (*APP*) and the ones obtained with a light integrated sensor orientation (*AAT*), calculating an airborne triangulation whose observations only consist in the photogram external orientations of the *APP* type and the image coordinates of tie points, automatically measured. The sensor's calibration was performed by the CGR company with the standard Applanix software.

3. MEASUREMENTS PERFORMED BY THE UNITS

The research units performed several measurements on the images and on the ground:

- measurement on the ground of at least 50 GCPs with GPS or topography;
- observation of the landmarks on all the photograms;
- observation of two tie points in each of the nine canonical positions, in each model.

The units measured and recorded the image coordinates of all the observed points, so that it would be possible to manage a wide range of different elaborations.

The units also calculated a manual aerial triangulation for the blocks, in order to know the best possible results attainable with the used data. In order to obtain reliable results, the control points were subdivided into two disjoint sets: the proper GCPs, used for aerial triangulation calculation, and the CKPs, used exclusively for independent validation of results.

To summarize, three EO datasets will be considered; they are indicated with the following acronyms: *APP* - produced with direct sensor orientation; *AAT* - calculated with light integrated sensor orientation; *AT* - derived from traditional, manual aerial triangulation.

4. DATA ANALYSIS

The pilot unit of the University of Pavia prepared a library of objects and procedures for data analysis, working in the Matlab environment. First, all the collimated points are stereoplotted in each model where they are visible; stereoplotting happens on single models, as this is the way map compilation is usually performed. For each stereoplotted point, much data is stored: the point's name, the images constituting the model, the plotted coordinates, the residual parallaxes estimation and many others. For CKPs, the differences between the plotted coordinates and the true ones are calculated and recorded. Residual parallaxes are estimated in the object space, measuring the skewness of the homologous lines; they are also re-projected onto the image space, via the local image scale factor (Casella, Franzini, 2003).

Once the stereoplotting has been performed, it is possible to analyze and plot the data in many ways. There is the possibility of analyzing residual parallaxes for all the tie points and of estimating accuracies for CKPs, for instance. Moreover, it is possible to consider the whole set of the plotted points but also to filter them in a very flexible way, maintaining only those coming from along-track models or those coming from across-track models, for example. Many other combinations are possible.

Within our test, nine datasets were considered, with respect to the nature of the involved models:

- *Whole*: the whole set of the plotted points;
- *Along*: the whole set of the points measured within along-track models;
- *Along 60*: points measured within along-track models whose base corresponds to the ordinary 60% overlap (as in the *Along* dataset models having longer bases are also considered);
- *Across*: the whole set of the points measured within across-track models;
- *Strip 1*, *Strip2*, *Strip3*: single strips;
- *Across 1-2*, *Across 2-3*: points measured within across models belonging to strips 1 and 2 only or 2 and 3 only.

5. SELECTED RESULTS

To summarize, an in-depth analysis was performed for each of the six blocks for which the measurements are finished (Pavia, Perugia, Como, Palermo, Parma, Vercelli), for each of the nine above listed datasets, and for each of the three sets of exterior orientations. Due to space limitations, it is not possible to show all the results: we will only focus on three datasets which are *Whole*, *Along60* and *Across*.

Pavia's block will be considered first (Table 1). Regarding accuracy, RMSEs are around 15 cm for *E* and *N* and around 50 cm for *Z*, for the *Whole* dataset and the *APP* EO; results are similar for the subsets *Along60* and *Across*. Moving to the *AAT* EO, planimetric accuracy gets worse, while the altimetric one doesn't significantly change; the subsets *Along60* and *Across* show the same behaviour as the *Whole* one. If the *AT* EO is considered, planimetric and altimetric accuracies are respectively around 15 and 30 cm for all the datasets. Of great interest is the fact that planimetric accuracy is the same for *APP* (direct sensor orientation) and for *AT* (traditional, manual aerial triangulation). For altimetry *APP* is significantly worse and this is mainly due to the existence of a systematic error which probably could have been eliminated with a proper calibration: this is confirmed by the presence of similar systematic errors in all the blocks. Again it is noticeable that the *Z* standard deviations of *APP* and *AT* are substantially the same: a proper direct sensor calibration could give similar results as *AT*.

If residual parallaxes are taken into consideration (Table 2), RMSE is around 21 microns for the *APP* EO, which is quite a high value: for the *Along60* subset figures are better, while they are rather worse for the *Across* one. For *AAT* EO results are worse for the *Whole* set, but they are better if we focus on the *Along60* set. It must be considered that the *Along60* dataset represents the usual map compilation environment, therefore *AAT* guarantees good stereovision quality. The *AT* EO globally gives results which are comparable to *APP*, and this is astonishing; further analysis shows that results are very good for *Along60*, as the RMSE is around 5 microns, and are worse than *APP* for *Across*: the aerial triangulation adjustment tied along-track much more than across-track. Residual parallaxes and accuracies are surprisingly quite uncorrelated: for the *Along60* dataset, the passage from *APP* to *AAT* halves the parallaxes, but accuracies don't change or get worse.

As there is insufficient space to analyze the other blocks in the same manner, some remarks will be raised, in comparison with Pavia. Aerial triangulation gives substantially the same results for all the blocks: 13-15 cm in planimetry and around 30 cm in altimetry, RMSE, and these represent the attainable quality of the images examined. Focusing on the *Along60* dataset, Figure 2 shows that the application of light integrated sensor orientation, that is the passage from *APP* to *AAT*, always gives a benefit in terms of accuracy. The same happens for parallaxes, as the central diagram of Figure 4 highlights.

For some blocks the *APP* EO itself gives good results, while in other blocks results are not very good for *APP*, even if they become rather better after the application of the smoothing light integrated sensor orientation. The *AAT* EO, which doesn't require any ground measurements, guarantees planimetric RMSEs below 33 cm and results are much better for some blocks; altimetric RMSEs are not greater than 61 cm and are much better for two blocks.

6. CONCLUSIONS

The results of a vast and rigorous test on quality of direct georeferencing on photogrammetry have been shown. They are interesting and encouraging. Some issues have also emerged and in particular the existence of a limited systematic error in height whose cause is probably a residual miscalibration. Further developments will focus strategies for limiting these effects: more frequent calibrations or local calibration on a very small site.

7. BIBLIOGRAPHY

Casella, V., Galetto, R., Surace, L., Ferretti, L., Banchini, G., Cavalli, A., 2001. Esperienze di fotogrammetria supportate da GPS/INS. *Bollettino SIFET*, 4, pp. 35-49, ISSN 0392-4424, Parma.

Casella, V., Franzini M., 2003. *Definition of a methodology for local reduction of parallaxes in directly oriented images*. Proceedings of "*ISPRS* International Workshop*"*, WG I/5, September 2003, Castelldefels, Spain.

Colomina, I., 2002. *Modern sensor orientation technologies and procedures.* Test Report and Workshop Proceedings. Official OEEPE Publication n°43, pp. 59-70.

8. ACKNOWLEDGEMENTS

The research presented in this paper was carried out within the frame of the National Research Project entitled *Integrated inertial positioning systems in aerial Photogrammetry*, co-funded by the Italian Ministry of the University for the year 2002, and chaired by prof. Galetto of the University of Pavia.

APPENDIX A: GRAPHICAL ANALYSIS OF RESULTS

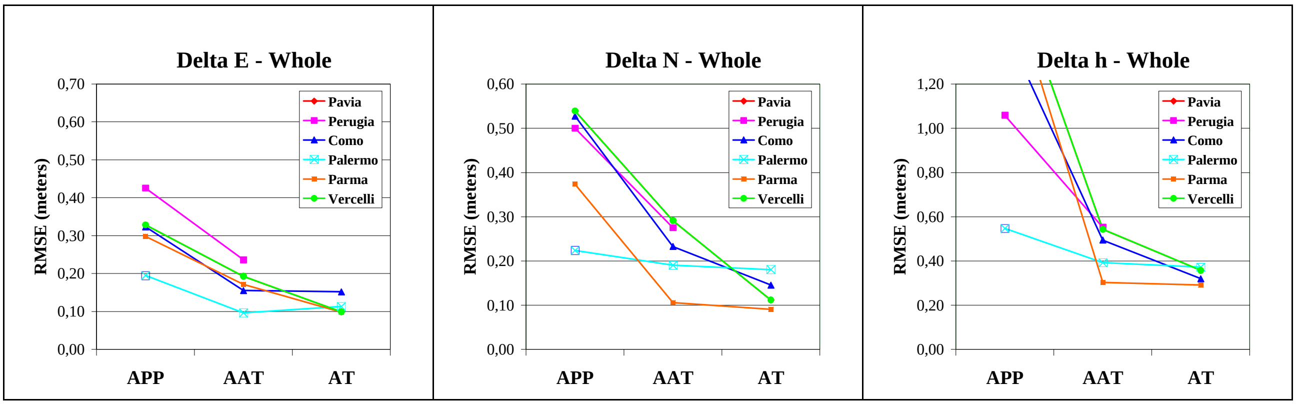

Figure 1. Analysis of accuracy: RMSE of the residuals for the *Whole* dataset, as a function of the EO

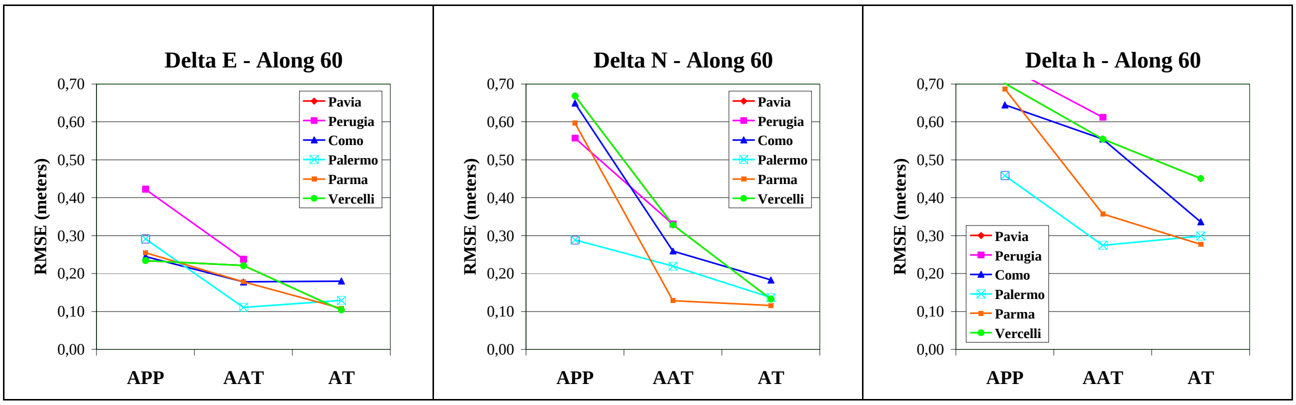

Figure 2. Analysis of accuracy: RMSE of the residuals for the *Along60* dataset, as a function of the EO

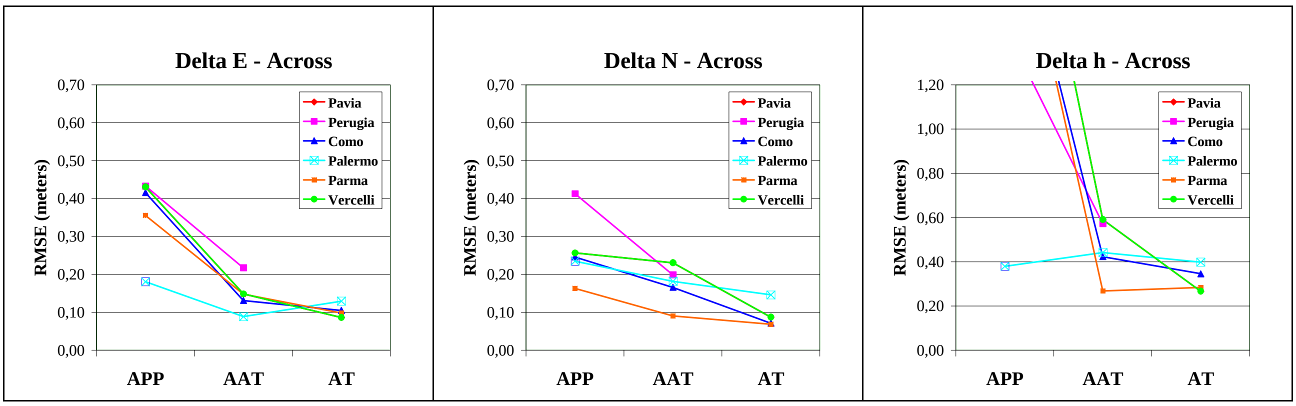

Figure 3. Analysis of accuracy: RMSE of the residuals for the *Across* dataset, as a function of the EO

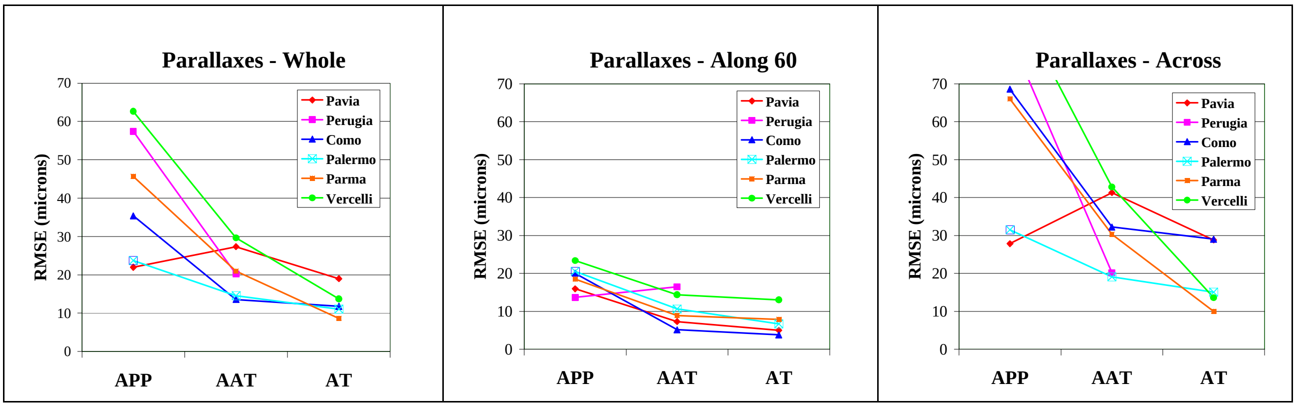

Figure 4. Analysis of residual parallaxes: RMSE of the parallaxes for the *Whole*, *Along60 and Across* dataset, as a function of the EO

APPENDIX B: STATISTICAL ANALYSIS OF RESULTS

				APP					AAT					AT				
		Pts	Obs	Min	Max	Mn	Std	Rmse	Min	Max	Mn	Std	Rmse	Min	Max	Mn	Std	Rmse
Whole	DE	45	224	-0,35	0,46	-0,08	0,15	0,17	-0,38	0,48	0,15	0,15	0,21	-0,39	0,38	0,00	0,15	0,15
	DN			-0,49	0,27	-0,02	0,14	0,14	-0,85	0,48	-0,06	0,23	0,24	-0,61	0,37	0,03	0,14	0,14
	Dh			-0,53	1,34	0,33	0,36	0,49	-1,19	1,49	0,13	0,50	0,52	-0,93	0,63	0,00	0,32	0,32
Along 60	DE	44	88	-0,32	0,45	-0,08	0,16	0,18	-0,14	0,39	0,16	0,14	0,21	-0,39	0,37	-0,01	0,17	0,17
	DN			-0,49	0,27	-0,02	0,15	0,15	-0,85	0,48	-0,05	0,28	0,28	-0,61	0,37	0,02	0,16	0,16
	Dh			-0,53	1,34	0,37	0,42	0,56	-0,54	1,10	0,42	0,35	0,54	-0,89	0,63	-0,01	0,29	0,29
Across	DE	20	104	-0,35	0,46	-0,08	0,13	0,16	-0,38	0,48	0,13	0,16	0,20	-0,33	0,37	0,00	0,12	0,12
	DN			-0,39	0,18	-0,02	0,12	0,13	-0,72	0,22	-0,07	0,18	0,19	-0,31	0,25	0,04	0,12	0,13
	Dh			-0,53	1,10	0,30	0,33	0,45	-1,19	1,49	-0,19	0,48	0,52	-0,93	0,61	0,01	0,37	0,37

Table 1. Accuracy for Pavia (metres)

			APP					AAT					AT				
	Pts	Obs	Min	Max	Mn	Std	Rmse	Min	Max	Mn	Std	Rmse	Min	Max	Mn	Std	Rmse
Whole	254	1211	-76,97	61,76	4,09	21,58	21,97	-98,69	88,33	0,88	27,35	27,36	-63,26	51,75	0,03	18,97	18,97
Along 60	253	516	-58,06	36,59	2,15	15,81	15,96	-36,58	31,05	-1,85	7,07	7,30	-26,87	26,97	0,01	4,98	4,98
Across	80	501	-76,97	61,76	5,95	27,20	27,84	-98,69	88,33	5,91	40,87	41,29	-63,26	51,75	0,21	28,83	28,83

Table 2. Residual parallaxes for Pavia (microns)

				APP					AAT					AT				
		Pts	Obs	Min	Max	Mn	Std	Rmse	Min	Max	Mn	Std	Rmse	Min	Max	Mn	Std	Rmse
Whole	DE	42	214	-0,90	0,80	0,24	0,35	0,43	-0,67	0,55	0,04	0,23	0,24	-	-	-	-	-
	DN			-0,95	0,97	-0,20	0,46	0,50	-1,00	0,89	-0,01	0,27	0,28	-	-	-	-	-
	Dh			-2,14	2,97	0,54	0,91	1,06	-0,67	1,58	0,39	0,39	0,55	-	-	-	-	-
Along 60	DE	36	76	-0,90	0,75	0,19	0,38	0,42	-0,61	0,47	0,02	0,24	0,24	-	-	-	-	-
	DN			-0,95	0,97	-0,15	0,54	0,56	-1,00	0,89	0,00	0,33	0,33	-	-	-	-	-
	Dh			-1,33	2,09	0,43	0,62	0,75	-0,67	1,58	0,41	0,46	0,61	-	-	-	-	-
Across	DE	15	88	-0,44	0,80	0,27	0,33	0,43	-0,64	0,36	0,01	0,22	0,22	-	-	-	-	-
	DN			-0,66	0,45	-0,17	0,37	0,41	-0,32	0,44	0,03	0,20	0,20	-	-	-	-	-
	Dh			-2,14	2,97	0,78	1,24	1,46	-0,67	1,49	0,42	0,39	0,57	-	-	-	-	-

Table 3. Accuracy for Perugia (metres)

			APP					AAT					AT				
	Pts	**Obs**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**
Whole	245	1469	-211,75	214,33	-10,02	56,54	57,42	-87,27	99,40	1,27	20,16	20,20	-	-	-	-	-
Along 60	222	503	-44,50	48,99	3,24	13,26	13,65	-58,66	63,22	-3,93	16,00	16,47	-	-	-	-	-
Across	106	680	-211,75	214,33	-28,32	77,48	82,50	-87,27	99,40	9,68	17,69	20,17	-	-	-	-	-

Table 4. Residual parallaxes for Perugia (microns)

				APP					AAT					AT				
		Pts	**Obs**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**
Whole	DE	22	101	-1,02	0,98	-0,02	0,32	0,32	-0,28	0,40	0,01	0,15	0,15	-0,29	0,41	-0,01	0,15	0,15
	DN			-1,04	0,59	-0,30	0,43	0,53	-0,70	0,12	-0,17	0,16	0,23	-0,41	0,17	-0,07	0,13	0,15
	Dh			-2,98	3,20	0,41	1,40	1,46	-0,55	1,28	0,31	0,39	0,49	-0,37	0,85	0,12	0,30	0,32
Along 60	DE	22	41	-0,39	0,52	0,00	0,24	0,24	-0,28	0,40	0,00	0,18	0,18	-0,29	0,41	-0,02	0,18	0,18
	DN			-1,04	0,59	-0,35	0,55	0,65	-0,70	0,12	-0,18	0,19	0,26	-0,40	0,17	-0,11	0,14	0,18
	Dh			-0,32	1,76	0,48	0,43	0,64	-0,15	1,28	0,49	0,26	0,56	-0,37	0,85	0,16	0,30	0,34
Across	DE	6	41	-1,02	0,98	-0,02	0,42	0,42	-0,28	0,29	0,05	0,12	0,13	-0,16	0,22	0,02	0,10	0,10
	DN			-0,56	0,15	-0,17	0,18	0,25	-0,32	0,04	-0,13	0,11	0,17	-0,19	0,07	-0,04	0,06	0,07
	Dh			-2,98	3,20	0,34	2,16	2,19	-0,55	1,07	0,04	0,42	0,42	-0,33	0,70	0,09	0,33	0,35

Table 5. Accuracy for Como (metres)

			APP					AAT					AT				
	Pts	**Obs**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**
Whole	169	505	-131,21	157,52	18,68	30,05	35,39	-41,07	71,09	0,20	13,57	13,57	-39,45	46,08	0,81	11,77	11,79
Along 60	169	288	-17,15	43,34	13,93	14,44	20,06	-12,02	14,25	-0,53	5,10	5,13	-9,85	13,37	-0,01	3,80	3,80
Across	19	75	-131,21	157,52	22,06	64,96	68,60	-41,07	71,09	5,31	31,78	32,22	-39,45	46,08	5,57	28,51	29,05

Table 6. Residual parallaxes for Como (microns)

				APP					AAT					AT				
		Pts	**Obs**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**
Whole	DE	31	291	-0,57	0,31	-0,11	0,16	0,19	-0,25	0,18	-0,05	0,08	0,10	-0,40	0,25	-0,06	0,09	0,11
	DN			-0,70	0,32	-0,17	0,14	0,22	-0,22	0,44	0,15	0,12	0,19	-0,39	0,52	-0,04	0,18	0,18
	Dh			-0,85	1,70	0,30	0,46	0,55	-0,57	1,00	0,30	0,25	0,39	-0,51	0,94	0,23	0,29	0,37
Along 60	DE	9	9	-0,47	0,14	-0,22	0,19	0,29	-0,20	0,08	-0,06	0,09	0,11	-0,23	0,02	-0,10	0,08	0,13
	DN			-0,41	-0,09	-0,27	0,10	0,29	0,07	0,38	0,19	0,11	0,22	-0,16	0,20	-0,03	0,13	0,14
	Dh			-0,23	0,81	0,29	0,35	0,46	-0,06	0,49	0,22	0,16	0,27	-0,51	0,18	-0,18	0,24	0,30
Across	DE	14	133	-0,44	0,21	-0,12	0,14	0,18	-0,25	0,18	-0,05	0,07	0,09	-0,40	0,25	-0,07	0,11	0,13
	DN			-0,51	0,12	-0,21	0,11	0,23	-0,22	0,35	0,14	0,11	0,18	-0,39	0,30	-0,07	0,13	0,15
	Dh			-0,85	1,08	0,16	0,34	0,38	-0,57	1,00	0,36	0,26	0,44	-0,42	0,87	0,31	0,24	0,40

Table 7. Accuracy for Palermo (metres)

			APP					AAT					AT				
	Pts	**Obs**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**
Whole	95	694	-84,86	87,15	3,81	23,41	23,72	-44,37	55,55	4,32	13,91	14,56	-43,55	40,46	2,68	10,70	11,03
Along 60	27	27	7,82	40,93	19,03	7,81	20,56	-12,08	27,35	1,52	10,53	10,63	-11,74	23,24	-0,30	6,71	6,71
Across	32	288	-84,86	87,15	-0,02	31,52	31,52	-44,37	55,55	12,52	14,46	19,13	-43,55	39,35	6,29	13,70	15,08

Table 8. Residual parallaxes for Palermo (microns)

				APP					AAT					AT				
		Pts	**Obs**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**
Whole	DE	16	160	-0,80	0,71	-0,18	0,24	0,30	-0,44	0,20	-0,09	0,14	0,17	-0,25	0,18	-0,01	0,10	0,10
	DN			-0,75	0,89	0,04	0,37	0,37	-0,25	0,26	0,06	0,09	0,11	-0,37	0,17	-0,03	0,08	0,09
	Dh			-2,83	2,98	0,29	1,71	1,74	-0,83	0,74	0,08	0,29	0,30	-0,57	0,64	0,15	0,25	0,29
Along 60	DE	15	27	-0,45	-0,01	-0,24	0,10	0,26	-0,44	0,18	-0,02	0,18	0,18	-0,20	0,18	-0,01	0,11	0,11
	DN			-0,75	0,89	0,41	0,44	0,60	-0,17	0,24	0,07	0,11	0,13	-0,33	0,15	-0,05	0,10	0,12
	Dh			-0,63	1,06	0,50	0,47	0,69	-0,33	0,74	0,23	0,27	0,36	-0,22	0,64	0,16	0,22	0,28
Across	DE	13	91	-0,80	0,71	-0,18	0,31	0,36	-0,36	0,20	-0,09	0,12	0,15	-0,25	0,15	-0,01	0,10	0,10
	DN			-0,23	0,53	0,06	0,15	0,16	-0,04	0,25	0,06	0,06	0,09	-0,15	0,15	-0,02	0,07	0,07
	Dh			-2,83	2,98	0,25	2,24	2,25	-0,63	0,53	0,01	0,27	0,27	-0,57	0,55	0,12	0,26	0,28

Table 9. Accuracy for Parma (metres)

			APP					AAT					AT				
	Pts	**Obs**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**
Whole	182	939	-153,21	179,29	-1,66	45,65	45,68	-58,31	74,21	2,72	20,80	20,97	-33,91	28,52	1,01	8,60	8,66
Along 60	154	260	-71,55	42,44	-2,05	18,40	18,51	-34,63	32,07	-0,35	8,91	8,92	-25,20	23,42	0,41	7,88	7,89
Across	65	405	-153,21	179,29	1,61	66,04	66,06	-58,31	74,21	7,25	29,44	30,32	-33,91	28,52	2,43	9,73	10,03

Table 10. Residual parallaxes for Parma (microns)

				APP					AAT					AT				
		Pts	**Obs**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**
Whole	DE	35	150	-0,64	1,00	0,11	0,31	0,33	-0,54	0,50	-0,04	0,19	0,19	-0,32	0,29	0,00	0,10	0,10
	DN			-1,10	0,97	0,06	0,54	0,54	-0,10	0,72	0,24	0,16	0,29	-0,60	0,26	0,00	0,11	0,11
	Dh			-3,66	3,78	0,23	1,78	1,79	-1,41	1,31	-0,16	0,52	0,54	-0,89	1,18	0,01	0,36	0,36
Along 60	DE	35	67	-0,54	0,45	0,05	0,23	0,23	-0,54	0,50	-0,04	0,22	0,22	-0,25	0,22	0,00	0,10	0,10
	DN			-1,10	0,97	0,20	0,64	0,67	-0,10	0,72	0,27	0,19	0,33	-0,60	0,26	-0,01	0,13	0,13
	Dh			-1,38	2,16	0,02	0,70	0,70	-1,21	1,31	-0,12	0,54	0,55	-0,89	1,18	0,06	0,45	0,45
Across	DE	11	60	-0,64	1,00	0,18	0,39	0,43	-0,36	0,36	-0,05	0,14	0,15	-0,21	0,19	-0,01	0,09	0,09
	DN			-0,50	0,33	-0,18	0,19	0,26	-0,05	0,48	0,20	0,11	0,23	-0,15	0,26	0,02	0,08	0,09
	Dh			-3,66	3,78	0,54	2,68	2,74	-1,41	0,91	-0,21	0,55	0,59	-0,76	0,48	-0,06	0,26	0,27

Table 11. Accuracy for Vercelli (metres)

			APP					AAT					AT				
	Pts	**Obs**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**	**Min**	**Max**	**Mn**	**Std**	**Rmse**
Whole	36	151	-193,53	199,07	-16,36	60,46	62,63	-99,81	68,50	2,26	29,53	29,62	-39,73	42,35	-0,66	13,69	13,70
Along 60	36	68	-69,91	59,19	-4,06	23,04	23,39	-47,02	43,99	1,21	14,33	14,38	-34,40	27,18	-0,96	12,99	13,03
Across	11	60	-193,53	199,07	-32,93	88,48	94,41	-99,81	68,50	3,11	42,70	42,81	-39,73	27,42	-0,50	13,60	13,61

Table 12. Residual parallaxes for Vercelli (microns)