AGH University of Science and Technology
Faculty of Mining Surveying and Environmental Engineering
Department of Photogrammetry and Remote Sensing
Al. Mickiewicza 30, 30-059 Cracow, POLAND

Validation of methods for measurement of land parcel areas – near-VHR imagery

supplementary study to the service contract

No 22581-2004-12F1SC ISP PL

FINAL REPORT

Author:	**Beata Hejmanowska** AGH University of Science and Technology, Cracow, Poland
Co-author:	**Rodolphe Palm** Unité de Statistique et Informatique, USI Gembloux, Belgium
Date:	2005-12-22

fax. ++48 12 633 17 91, phone. ++4812 617 22 88
E-mail: galia@uci.agh.edu.pl, URL: www.fotogrametria.agh.edu.pl

Content

1. Assumption of supplementary study

Remote sensing experiments in project: “Validation of methods for measurement of land parcel areas” was performed on the basis of 3 kind of orthoimageries:

- aerial from photos: 1: 13 000 (panchromatic), 2004 pixel size 0.2m, (OP_0_2)
- aerial from photos: 1: 26 000 (color), 1999 (or earlier), pixel size 0.75m, (OP_0_5)
- IKONOS (pansharpening), 2004, pixel size 1m, (OP_1_0)

From the project can be state as following:

- area error is only slightly increasing with increasing pixel size (Fig. 1)
- area measurements are not influenced by operator (skilled and unskilled provide similar results)

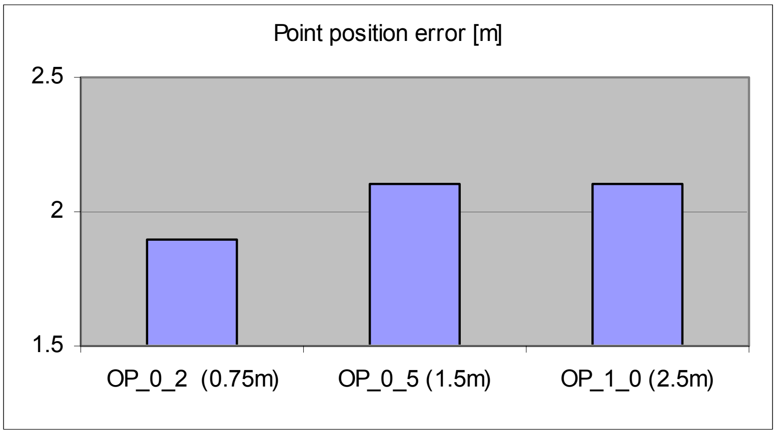


Fig. 1. Point position error as parcel area accuracy estimation for RS data

The main aim of the supplementary study: ”Validation of methods for the measurement of land parcel area – near VHR imagery” was to test the area accuracy measurement basing on 2 additional orthoimagery (Kraków site):

- SPOT 5, pixel size of 3m
- EROS 1A, pixel size of 2m

We tried in the new project to find the limit of pixel size for area measurements, i.e. to find the resolution when the area error increases significant.

The supplementary study was performed according Technical Specification to the main study (JRC IPSC/G03/P/SKA/ska D(2004) (3419)).

Parcels were the same in the supplementary study as in the main study. 36 the same parcels were measured, except when it couldn’t be possible. In this case other parcel was chosen.

During the main project there were no significant differences between skilled and unskilled operators. Therefore amount of the operators in supplementary study was limited to 6.

Experiment design and data collection methodology was the same as in main experiment. Sequences of parcels were statistically randomized similar to the main study.

Parcels were digitized on the screen and data were collected using GIS software: GeoMedia Professional.

Statistical analyses wereperformed according the methodology presented in the final report to the main project (Chpt 3 and Chpt 6).

Validation method proposed in the main project (Chpt 8) was tested in the supplementary study. Variants of measurement sets (number of parcels, operations, and repetitions) were also tested. The observations were split into smaller datasets. Each of these datasets was analyzed separately to examine the variability between parcels. Then the results for each dataset were compared.

2. The statistical analysis – testing of different data sets from main study

2.1 Introduction

In order to examine the influence of the decrease of the number of observations on a given parcel, several simulations have been carried out. Three orthophotos, OP_0_2, OP_0_5 and OP_0_1, have been considered. For each photo, the measurements have been split into groups in three different ways:

- two groups of six operators,
- three groups of four operators,
- four groups of three operators.

The different groups of operators can be considered as replications. The operators are allocated at random to these replications, regardless of their skill, but the same allocations are used for each of the three photos. Each replication is considered as a precision experiment. For a given parcel, critical examination of the data is performed and the observations considered as outlying observations by the statistical tests are discarded. The variance components are estimated. Repeatability and reproducibility are then obtained and the buffer is computed. This whole sequence of data processing is repeated for each parcel, each photo and each replication. So, the sequence has been repeated 972 times (36 parcels × 3 photos × 9 groups of operators).

2.2 Results for photo OP_0_2

The values of buffer for each parcel are given in Tab 1 (replications with 6 operators), Tab 2 (replications with 4 operators) and Tab 3 (replications with 3 operators). The standard deviations between the replications, as well as the buffers computed with all twelve operators (36 measurements) considered as reference values, are also given in each table.

The plots of the values obtained for the replications as a function of the reference values are given in figures: Fig. 2-Fig. 4. These figures show that the standard deviations between replications depend on the value of the buffer, the variability being larger for large values of reference buffer.

For this reason, we consider the coefficient of variation (standard deviation of buffer divided by the value of reference buffer), which is not related to buffer. A boxplot of these ratios is given in figure: Fig. 5 for two, three and four operators.

Tab 1. OP_0_2: Values of buffer for 12 operators and for the two replications of 6 operators and standard deviation of the two replications.

PARCEL	BUF_all	BUF_R1	BUF_R2	STD_BUF
1	0.324	0.292	0.353	0.043
2	0.214	0.206	0.227	0.015
3	0.172	0.204	0.143	0.043
4	0.207	0.209	0.216	0.005
5	0.171	0.263	0.319	0.039
6	0.231	0.236	0.221	0.011
7	0.295	0.290	0.311	0.015
8	0.357	0.315	0.413	0.070
9	0.313	0.401	0.322	0.056
10	0.311	0.276	0.362	0.061
11	0.187	0.203	0.178	0.017
12	0.153	0.147	0.183	0.026
13	0.477	0.418	0.529	0.078
14	1.267	1.131	1.346	0.152
15	0.247	0.275	0.235	0.028
16	0.526	0.308	0.673	0.258
17	0.252	0.164	0.325	0.114
18	0.197	0.157	0.238	0.057
19	0.301	0.318	0.286	0.023
20	0.138	0.120	0.148	0.020
21	0.193	0.161	0.139	0.016
22	0.230	0.277	0.182	0.067
23	0.351	0.411	0.285	0.089
24	0.205	0.219	0.377	0.112
25	0.388	0.348	0.394	0.033
26	0.469	0.900	0.442	0.323
27	0.168	0.175	0.092	0.059
28	0.609	0.662	0.624	0.027
29	0.427	0.322	0.427	0.074
30	0.345	0.351	0.346	0.004
31	0.572	0.706	0.435	0.192
32	0.761	0.737	0.820	0.059
33	0.182	0.155	0.206	0.036
34	0.238	0.254	0.212	0.029
35	0.643	0.816	0.457	0.254
36	1.214	0.958	0.629	0.233

Tab 2. OP_0_2 : Values of buffer for 12 operators and for the three replications of 4 operators and standard deviation of the three replications.

PARCEL	BUF_all	BUF_R1	BUF_R2	BUF_R3	STD_BUF
1	0.324	0.227	0.386	0.336	0.082
2	0.214	0.173	0.244	0.160	0.045
3	0.172	0.112	0.192	0.115	0.046
4	0.207	0.177	0.234	0.235	0.033
5	0.171	0.186	0.319	0.343	0.085
6	0.231	0.148	0.278	0.184	0.067
7	0.295	0.315	0.210	0.373	0.083
8	0.357	0.274	0.401	0.351	0.064
9	0.313	0.246	0.437	0.365	0.096
10	0.311	0.297	0.355	0.316	0.030
11	0.187	0.234	0.140	0.210	0.049
12	0.153	0.142	0.146	0.205	0.035
13	0.477	0.341	0.507	0.554	0.112
14	1.267	1.316	0.931	1.883	0.479
15	0.247	0.292	0.244	0.221	0.036
16	0.526	0.312	0.409	0.798	0.257
17	0.252	0.189	0.276	1.024	0.459
18	0.197	0.160	0.138	0.291	0.083
19	0.301	0.263	0.381	0.275	0.065
20	0.138	0.095	0.177	0.126	0.042
21	0.193	0.244	0.167	0.148	0.051
22	0.230	0.103	0.380	0.153	0.148
23	0.351	0.430	0.272	0.369	0.080
24	0.205	0.225	0.219	0.439	0.125
25	0.388	0.261	0.328	0.453	0.098
26	0.469	1.019	0.473	0.493	0.310
27	0.168	0.184	0.139	0.189	0.027
28	0.609	0.633	0.730	0.619	0.061
29	0.427	0.357	0.487	0.452	0.067
30	0.345	0.320	0.392	0.399	0.044
31	0.572	0.623	0.475	0.513	0.077
32	0.761	0.676	0.821	0.928	0.127
33	0.182	0.050	0.172	0.227	0.091
34	0.238	0.303	0.206	0.247	0.049
35	0.643	0.387	0.577	0.697	0.156
36	1.214	0.787	1.173	0.677	0.260

Tab 3. OP_0_2 : Values of buffer for 12 operators and for the four replications of 3 operators, and standard deviation of the four replications.

PARCEL	BUF_all	BUF_R1	BUF_R2	BUF_R3	BUF_R4	STD_BUF
1	0.324	0.295	0.516	0.375	0.205	0.132
2	0.214	0.204	0.255	0.210	0.215	0.023
3	0.172	0.106	0.256	0.052	0.163	0.087
4	0.207	0.192	0.242	0.282	0.146	0.059
5	0.171	0.177	0.411	0.104	0.151	0.137
6	0.231	0.191	0.313	0.119	0.254	0.083
7	0.295	0.284	0.336	0.296	0.223	0.047
8	0.357	0.494	0.422	0.291	0.242	0.117
9	0.313	0.315	0.576	0.232	0.245	0.160
10	0.311	0.422	0.515	0.171	0.233	0.160
11	0.187	0.131	0.184	0.256	0.212	0.052
12	0.153	0.053	0.129	0.184	0.143	0.055
13	0.477	0.457	0.451	0.670	0.318	0.146
14	1.267	0.825	1.885	1.160	1.090	0.454
15	0.247	0.135	0.166	0.335	0.248	0.090
16	0.526	0.270	0.727	0.546	0.412	0.195
17	0.252	0.199	0.101	0.291	0.339	0.105
18	0.197	0.255	0.164	0.178	0.222	0.042
19	0.301	0.195	0.500	0.208	0.258	0.142
20	0.138	0.092	0.227	0.093	0.155	0.064
21	0.193	0.109	0.193	0.156	0.295	0.079
22	0.230	0.259	0.244	0.175	0.179	0.044
23	0.351	0.297	0.136	0.432	0.284	0.121
24	0.205	0.233	0.234	0.210	0.187	0.022
25	0.388	0.188	0.508	0.324	0.384	0.133
26	0.469	0.300	0.259	1.089	0.557	0.382
27	0.168	0.122	0.113	0.157	0.256	0.066
28	0.609	0.358	0.586	0.735	0.619	0.158
29	0.427	0.597	0.182	0.406	0.455	0.172
30	0.345	0.251	0.544	0.179	0.364	0.159
31	0.572	0.661	0.405	0.563	0.269	0.173
32	0.761	0.847	0.889	0.808	0.593	0.132
33	0.182	0.150	0.235	0.157	0.220	0.043
34	0.238	0.175	0.287	0.329	0.233	0.067
35	0.643	0.501	1.098	0.300	0.715	0.341
36	1.214	0.617	1.244	1.749	1.284	0.465

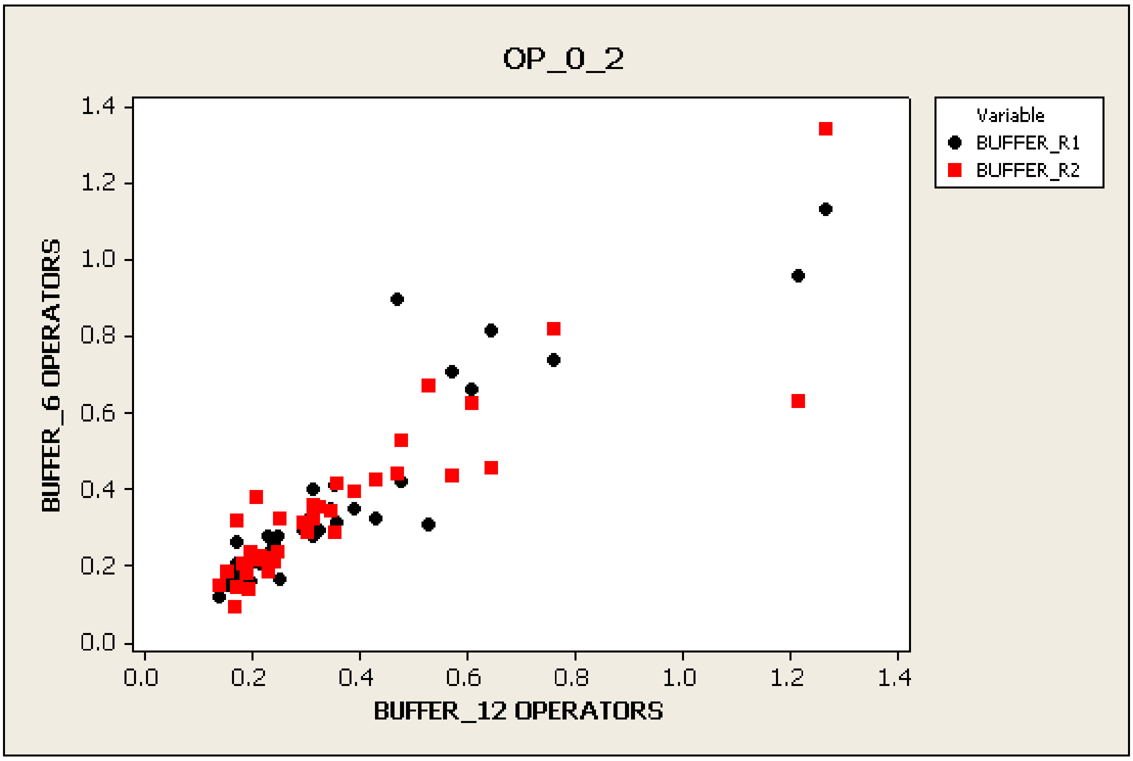


Fig. 2. OP_0_2 : Buffer for each replication of six operators, as a function of the reference buffer (12 operators).

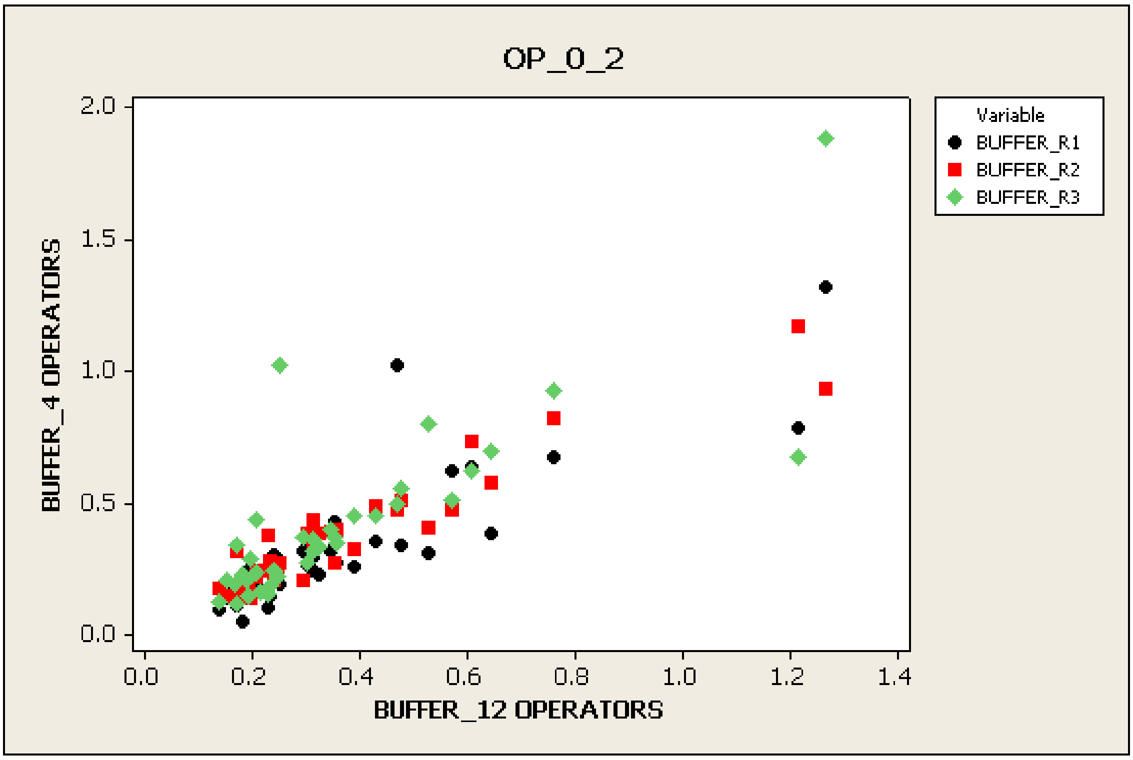


Fig. 3. OP_0_2 : Buffer for each replication of four operators, as a function of the reference buffer (12 operators).

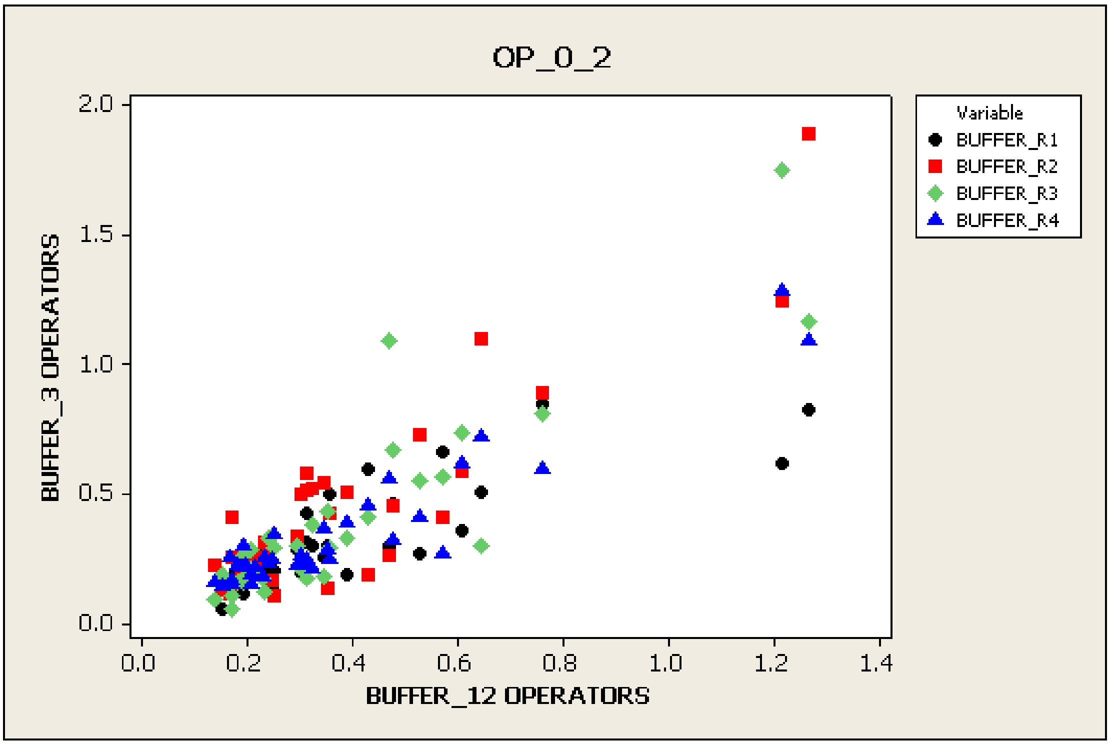


Fig. 4. OP_0_2 : Buffer for each replication of three operators, as a function of the reference buffer (12 operators).

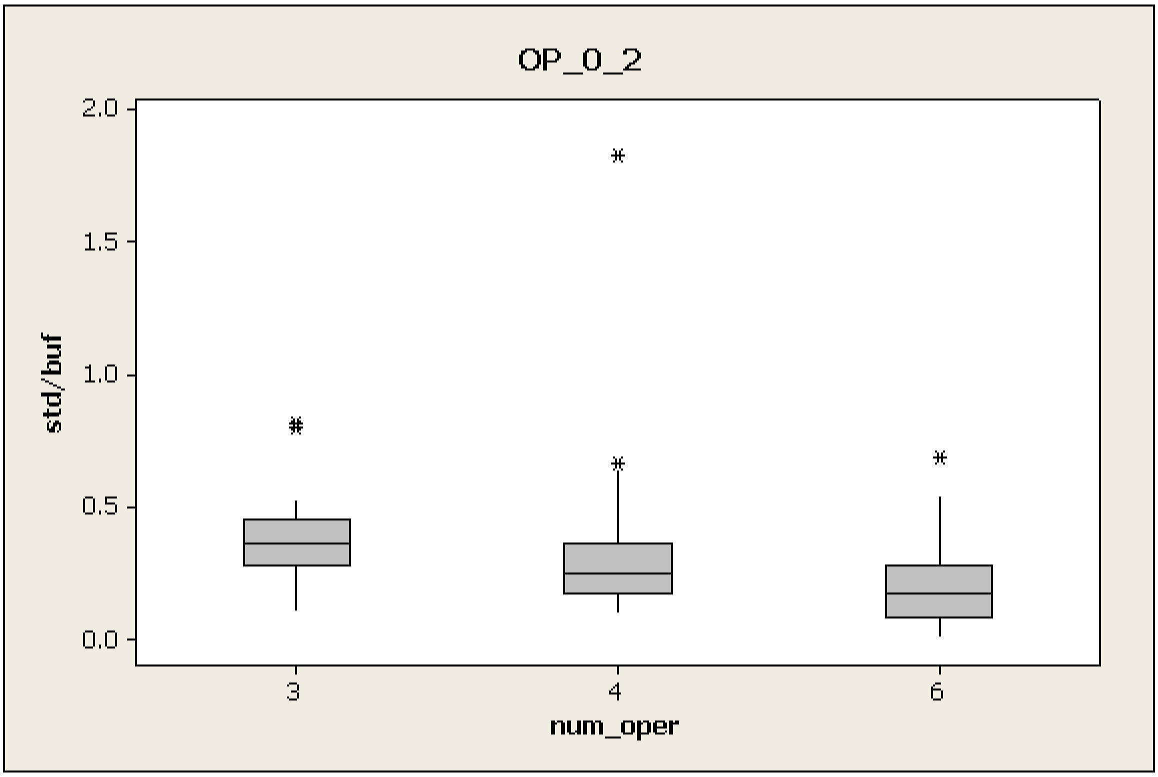


Fig. 5.:OP_0_2 : Boxplot of the ratios (standard deviation /reference buffer) for three, four and six operators.

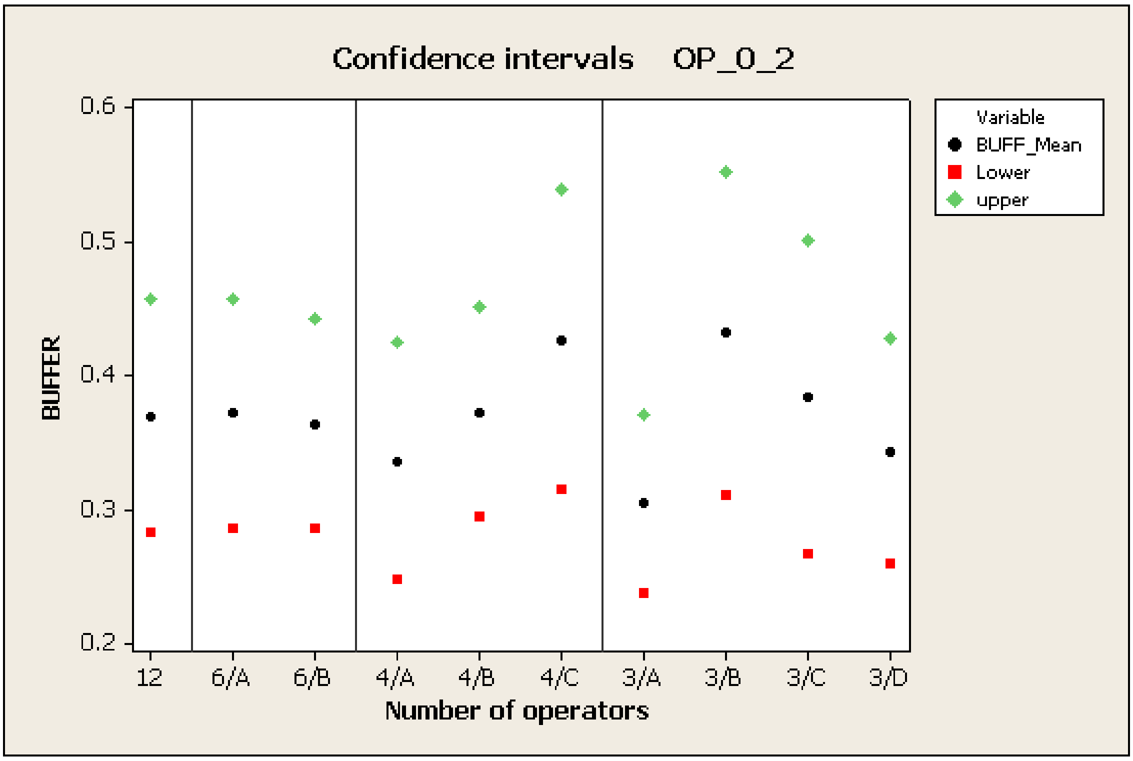


Fig. 6. OP_0_2 : 95 % confidence intervals of the mean value of buffer for the replications of 6, 4 and 3 operators and for the reference buffer (12 operators).

If we are interested in the estimation of the mean value of buffer for all the 36 parcels, the influence of the number of operators can be seen in figure: Fig. 6, which shows the 95 % confidence intervals of the mean value of buffer for the replications of 6, 4 and 3 operators and for the complete set of observations (12 operators).

2.3 Results for photo OP_0_5

The results are given in tables: Tab 4 - Tab 6 and in figures: Fig. 7 - Fig. 11.

Tab 4. OP_0_5 : Values of buffer for 12 operators and for the two replications of 6 operators and standard deviation of the two replications.

PARCEL	BUF_all	BUF_R1	BUF_R2	STD_BUF
1	0.235	0.232	0.245	0.009
2	0.212	0.204	0.237	0.023
3	0.193	0.176	0.182	0.004
4	0.219	0.209	0.214	0.004
5	0.323	0.333	0.318	0.010
6	0.239	0.279	0.215	0.045
7	0.283	0.190	0.267	0.054
8	0.287	0.290	0.262	0.020
9	0.411	0.426	0.416	0.007
10	0.260	0.238	0.306	0.048
11	0.471	0.457	0.505	0.034
12	0.266	0.286	0.274	0.009
13	0.588	0.586	0.601	0.010
14	1.037	1.011	1.042	0.022
15	0.701	0.803	0.592	0.149
16	0.408	0.424	0.389	0.025
17	0.221	0.193	0.249	0.040
18	0.378	0.427	0.206	0.157
19	1.323	1.403	1.150	0.179
20	0.297	0.240	0.335	0.067
21	0.393	0.419	0.380	0.027
22	0.417	0.436	0.418	0.013
23	0.397	0.423	0.400	0.016
24	0.316	0.385	0.248	0.097
25	0.389	0.413	0.375	0.027
26	0.439	0.475	0.410	0.046
27	0.336	0.329	0.323	0.005
28	0.435	0.535	0.318	0.154
29	0.439	0.420	0.470	0.035
30	0.371	0.371	0.400	0.021
31	0.466	0.365	0.538	0.122
32	0.740	0.704	0.794	0.064
33	0.583	0.552	0.642	0.064
34	0.223	0.144	0.285	0.099
35	0.886	0.867	0.957	0.064
36	0.690	0.712	0.686	0.019

Tab 5. OP_0_5 : Values of buffer for 12 operators and for the three replications of 4 operators and standard deviation of the three replications.

PARCEL	BUF_all	BUF_R1	BUF_R2	BUF_R3	STD_BUF
1	0.235	0.241	0.194	0.300	0.053
2	0.212	0.213	0.159	0.242	0.042
3	0.193	0.173	0.166	0.208	0.022
4	0.219	0.254	0.162	0.248	0.052
5	0.323	0.345	0.315	0.768	0.253
6	0.239	0.264	0.201	0.235	0.032
7	0.283	0.583	0.267	0.252	0.187
8	0.287	0.252	0.328	0.300	0.038
9	0.411	0.397	0.414	0.416	0.010
10	0.260	0.268	0.381	0.252	0.070
11	0.471	0.502	0.373	0.578	0.103
12	0.266	0.240	0.296	0.275	0.029
13	0.588	0.587	0.582	0.660	0.044
14	1.037	1.192	0.693	1.270	0.313
15	0.701	0.927	0.603	0.580	0.194
16	0.408	0.439	0.360	0.444	0.047
17	0.221	0.366	0.200	0.230	0.089
18	0.378	0.341	0.137	0.272	0.104
19	1.323	1.564	1.503	0.315	0.704
20	0.297	0.271	0.179	0.402	0.112
21	0.393	0.487	0.261	0.448	0.121
22	0.417	0.452	0.307	0.462	0.087
23	0.397	0.489	0.351	0.433	0.070
24	0.316	0.236	0.402	0.224	0.099
25	0.389	0.383	0.275	0.414	0.073
26	0.439	0.424	0.499	0.445	0.038
27	0.336	0.380	0.368	0.238	0.079
28	0.435	0.459	0.558	0.311	0.125
29	0.439	0.448	0.387	0.467	0.042
30	0.371	0.405	0.314	0.468	0.078
31	0.466	0.345	0.428	0.614	0.137
32	0.740	0.713	0.663	0.924	0.138
33	0.583	0.671	0.555	0.627	0.059
34	0.223	0.155	0.198	0.357	0.106
35	0.886	0.849	0.852	0.907	0.032
36	0.690	0.583	0.911	0.646	0.174

Tab 6. OP_0_5 : Values of buffer for 12 operators and for the four replications of 3 operators, and standard deviation of the four replications.

PARCEL	BUF_all	BUF_R1	BUF_R2	BUF_R3	BUF_R4	STD_BUF
1	0.235	0.253	0.264	0.650	0.271	0.194
2	0.212	0.212	0.255	0.194	0.224	0.025
3	0.193	0.152	0.096	0.264	0.272	.087
4	0.219	0.082	0.148	0.260	0.355	0.121
5	0.323	0.383	0.384	0.295	0.331	0.043
6	0.239	0.173	0.152	0.298	0.177	0.066
7	0.283	0.224	0.276	0.677	0.281	0.210
8	0.287	0.194	0.400	0.216	0.331	0.097
9	0.411	0.455	0.537	0.312	0.332	0.106
10	0.260	0.186	0.381	0.203	0.383	0.109
11	0.471	0.349	0.500	0.538	0.399	0.088
12	0.266	0.237	0.352	0.168	0.313	0.082
13	0.588	0.359	0.566	0.831	0.463	0.203
14	1.037	0.859	1.436	0.395	1.243	0.460
15	0.701	0.357	0.730	0.918	0.927	0.267
16	0.408	0.403	0.329	0.591	0.243	0.148
17	0.221	0.148	1.328	0.194	0.330	0.557
18	0.378	0.610	0.257	0.212	0.392	0.179
19	1.323	1.466	0.265	1.629	1.916	0.727
20	0.297	0.159	0.313	0.453	0.212	0.129
21	0.393	0.363	0.499	0.376	0.223	0.113
22	0.417	0.279	0.453	0.492	0.370	0.094
23	0.397	0.230	0.372	0.488	0.464	0.117
24	0.316	0.178	0.130	0.266	0.324	0.087
25	0.389	0.178	0.448	0.401	0.070	0.180
26	0.439	0.489	0.519	0.312	0.465	0.092
27	0.336	0.417	0.353	0.265	0.212	0.091
28	0.435	0.398	0.576	0.360	0.408	0.096
29	0.439	0.347	0.567	0.531	0.282	0.139
30	0.371	0.306	0.277	0.569	0.313	0.136
31	0.466	0.463	0.389	0.648	0.362	0.129
32	0.740	0.563	0.681	0.849	0.851	0.140
33	0.583	0.558	0.658	0.556	0.431	0.093
34	0.223	0.233	0.176	0.214	0.316	0.059
35	0.886	1.141	0.986	0.824	0.934	0.132
36	0.690	0.864	0.916	0.439	0.744	0.214

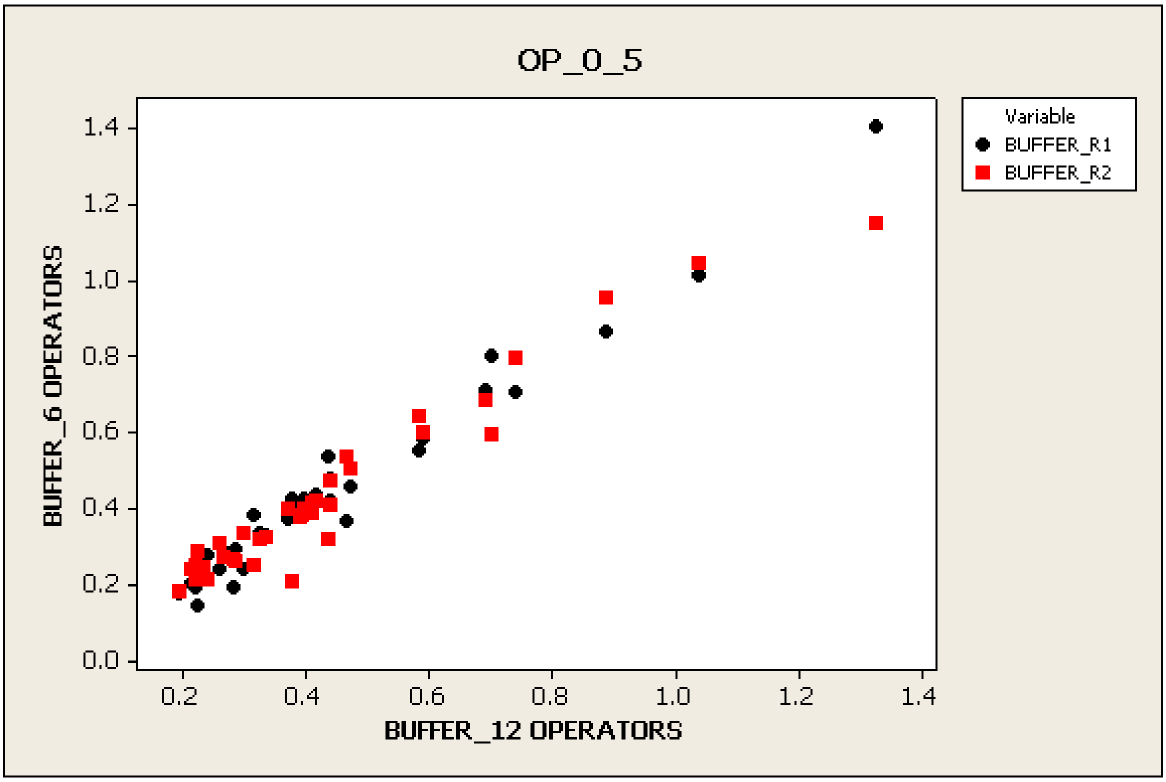


Fig. 7. OP_0_5 : Buffer for each replication of six operators, as a function of the reference buffer (12 operators).

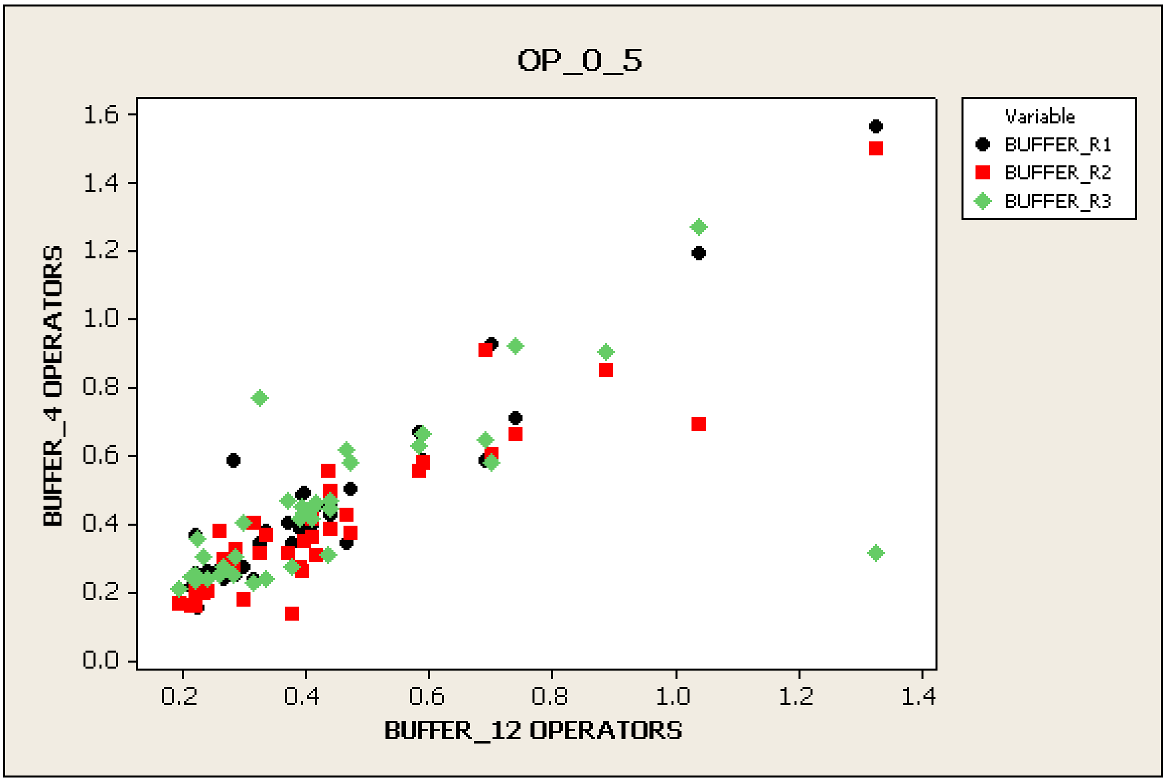


Fig. 8. OP_0_5 : Buffer for each replication of four operators, as a function of the reference buffer (12 operators).

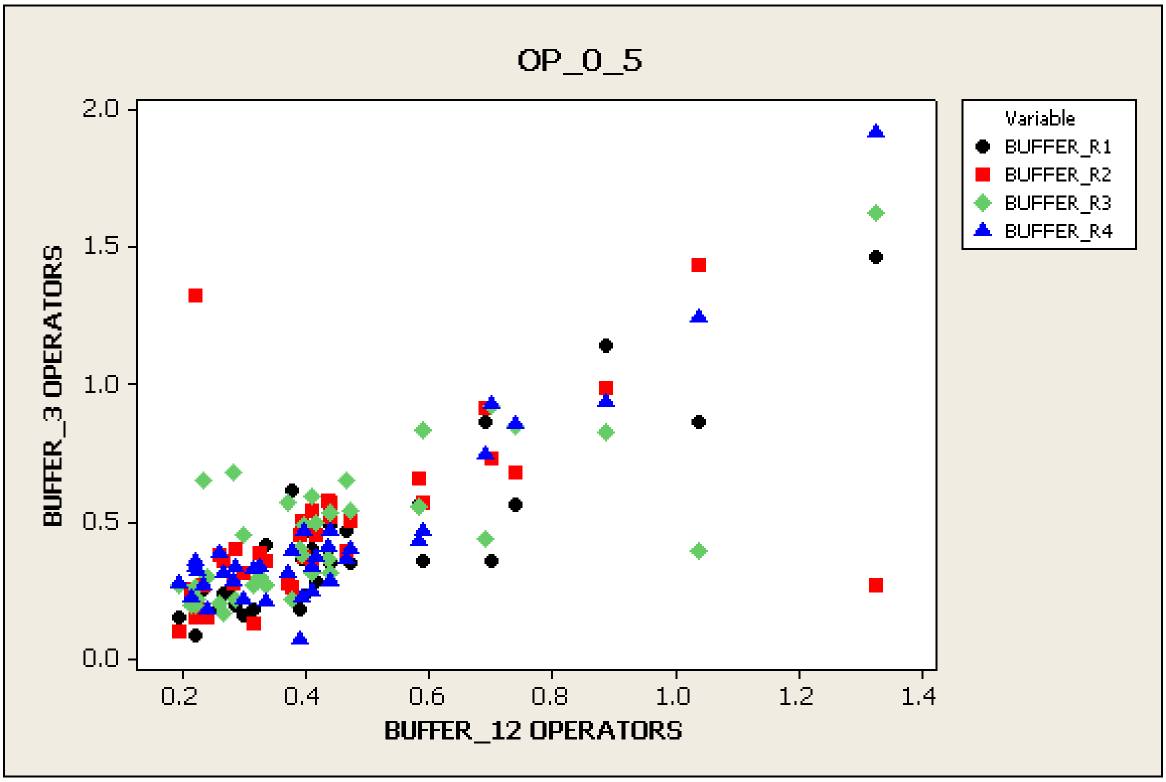


Fig. 9. OP_0_5 : Buffer for each replication of three operators, as a function of the reference buffer (12 operators).

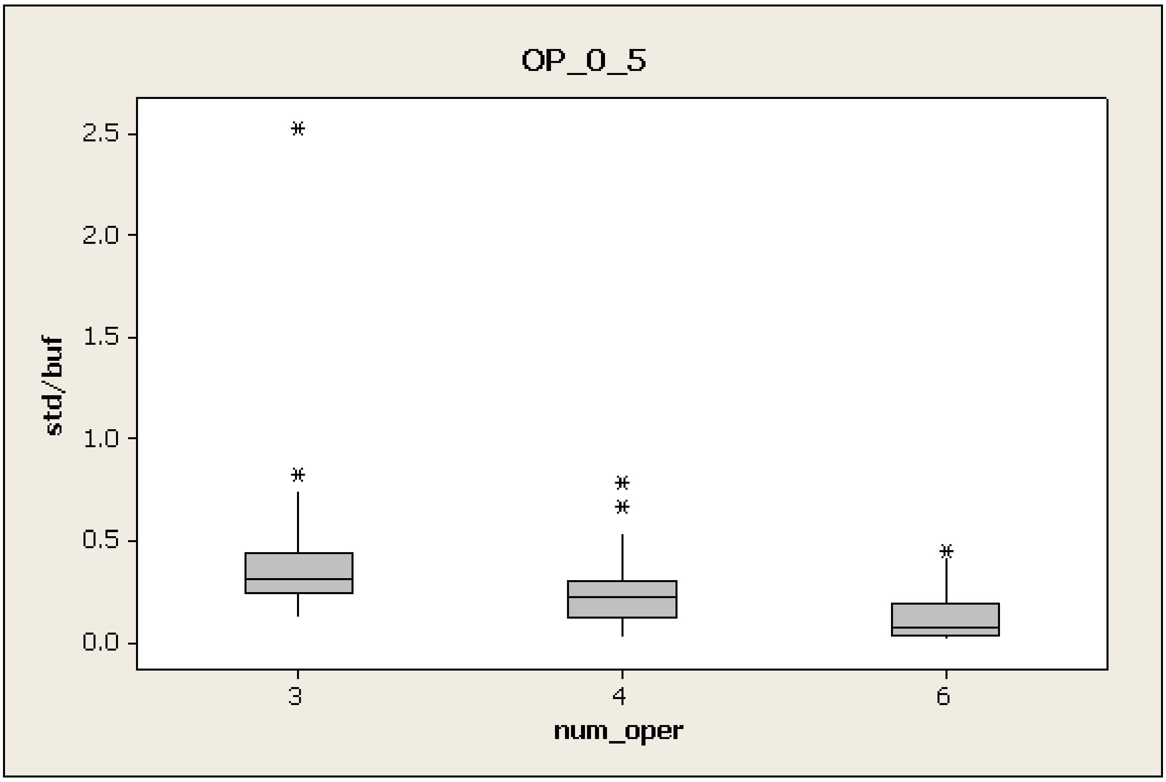


Fig. 10. OP_0_5 : Boxplot of the ratios (standard deviation /reference buffer) for three, four and six operators.

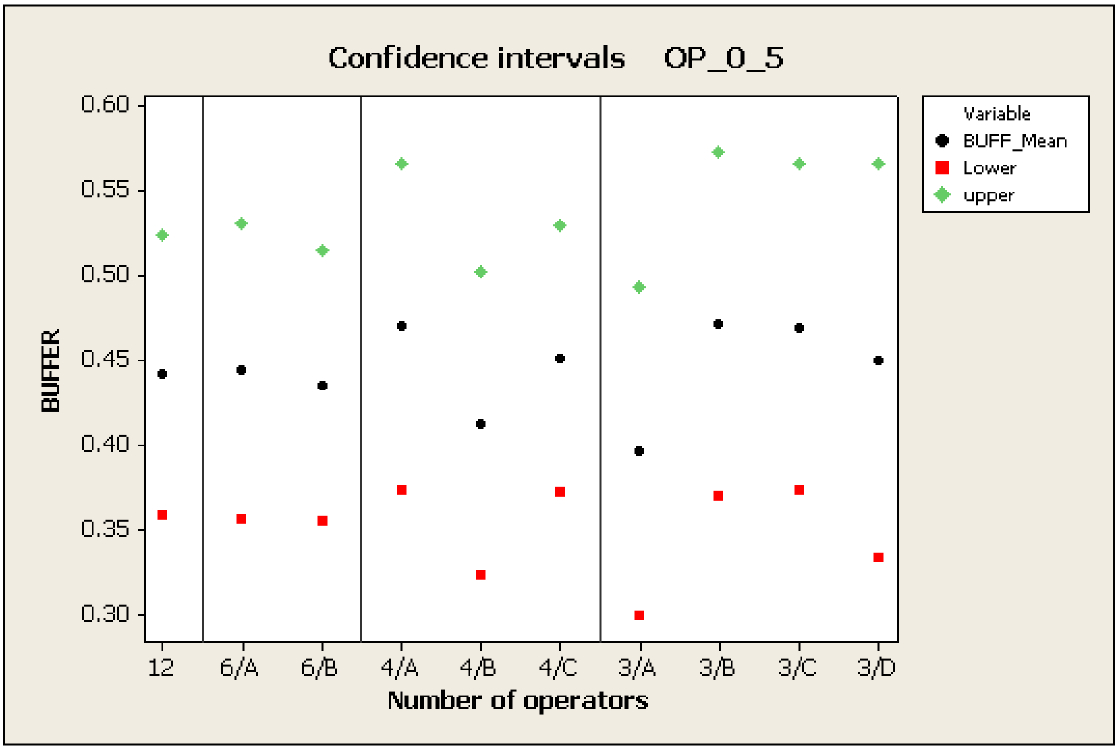


Fig. 11. OP_0_5 : 95 % confidence intervals of the mean value of buffer for the replications of 6, 4 and 3 operators and for the reference buffer (12 operators).

2.4 Results for photo OP_1_0

The results are given in tables: Tab 7 - Tab 9 and in figures: Fig. 12 - Fig. 16.

Tab 7. OP_1_0 : Values of buffer for 12 operators and for the two replications of 6 operators and standard deviation of the two replications.

PARCEL	BUF_all	BUF_R1	BUF_R2	STD_BUF
1	0.515	0.529	0.528	0.001
2	0.362	0.389	0.316	0.051
3	0.139	0.147	0.136	0.008
4	0.241	0.228	0.255	0.020
5	0.313	0.364	0.297	0.048
6	0.267	0.293	0.160	0.094
7	0.254	0.264	0.246	0.013
8	0.279	0.209	0.340	0.093
9	0.412	0.314	0.518	0.144
10	0.394	0.327	0.482	0.110
11	0.307	0.219	0.389	0.121
12	0.199	0.205	0.201	0.003
13	0.734	0.653	0.800	0.104
14	2.009	1.883	2.134	0.177
15	0.270	0.295	0.240	0.039
16	0.362	0.522	0.317	0.145
17	0.218	0.213	0.240	0.019
18	0.183	0.181	0.192	0.008
19	0.265	0.224	0.398	0.123
20	0.276	0.262	0.289	0.019
21	0.338	0.303	0.405	0.072
22	0.473	0.503	0.409	0.066
23	0.431	0.429	0.424	0.004
24	0.257	0.203	0.466	0.186
25	0.675	0.786	0.522	0.187
26	0.204	0.201	0.220	0.013
27	0.235	0.225	0.254	0.021
28	0.626	0.661	0.603	0.041
29	0.650	0.802	0.477	0.230
30	0.670	0.533	0.806	0.193
31	0.487	0.465	0.524	0.042
32	0.855	0.683	1.017	0.236
33	0.267	0.246	0.299	0.037
34	0.406	0.424	0.427	0.003
35	0.836	1.051	0.625	0.301
36	0.692	0.760	0.684	0.053

Tab 8. OP_1_0 : Values of buffer for 12 operators and for the three replications of 4 operators and standard deviation of the three replications.

PARCEL	BUF_all	BUF_R1	BUF_R2	BUF_R3	STD_BUF
1	0.515	0.551	0.533	0.553	0.011
2	0.362	0.398	0.365	0.231	0.089
3	0.139	0.163	0.106	0.162	0.033
4	0.241	0.259	0.213	0.296	0.041
5	0.313	0.434	0.264	0.311	0.088
6	0.267	0.244	0.385	0.164	0.112
7	0.254	0.224	0.302	0.215	0.048
8	0.279	0.534	0.295	0.289	0.140
9	0.412	0.231	0.440	0.506	0.144
10	0.394	0.323	0.342	0.567	0.136
11	0.307	0.228	0.374	0.324	0.074
12	0.199	0.215	0.156	0.239	0.043
13	0.734	0.684	0.828	0.769	0.073
14	2.009	2.009	1.472	2.382	0.458
15	0.270	0.245	0.331	0.260	0.046
16	0.362	0.417	0.571	0.359	0.110
17	0.218	0.225	0.213	0.202	0.012
18	0.183	0.191	0.184	0.132	0.032
19	0.265	0.183	0.329	0.474	0.145
20	0.276	0.302	0.242	0.281	0.030
21	0.338	0.291	0.344	0.459	0.086
22	0.473	0.504	0.460	0.477	0.022
23	0.431	0.471	0.562	0.355	0.104
24	0.257	0.617	0.216	0.484	0.204
25	0.675	0.703	0.939	0.466	0.236
26	0.204	0.236	0.157	0.390	0.118
27	0.235	0.236	0.223	0.252	0.015
28	0.626	0.720	0.598	0.634	0.062
29	0.650	0.883	0.487	0.565	0.210
30	0.670	0.644	0.692	0.717	0.037
31	0.487	0.463	0.435	0.582	0.078
32	0.855	0.667	0.828	1.158	0.251
33	0.267	0.131	0.266	0.338	0.105
34	0.406	0.399	0.374	0.381	0.013
35	0.836	1.012	1.076	0.644	0.233
36	0.692	0.756	1.173	0.664	0.272

Tab 9. OP_1_0 : Values of buffer for 12 operators and for the four replications of 3 operators, and standard deviation of the four replications.

PARCEL	BUF_all	BUF_R1	BUF_R2	BUF_R3	BUF_R4	STD_BUF
1	0.515	0.542	0.478	0.590	0.588	0.053
2	0.362	0.337	0.441	0.354	0.339	0.050
3	0.139	0.113	0.111	0.190	0.181	0.043
4	0.241	0.265	0.233	0.333	0.203	0.056
5	0.313	0.274	0.163	0.501	0.294	0.141
6	0.267	0.230	0.319	0.168	0.247	0.062
7	0.254	0.186	0.278	0.133	0.279	0.072
8	0.279	0.338	0.677	0.162	0.572	0.232
9	0.412	0.611	0.353	0.318	0.378	0.133
10	0.394	0.440	0.445	0.403	0.284	0.075
11	0.307	0.236	0.319	0.241	0.220	0.044
12	0.199	0.178	0.248	0.150	0.269	0.056
13	0.734	0.420	0.855	0.702	0.838	0.201
14	2.009	1.207	2.120	2.392	2.070	0.513
15	0.270	0.249	0.356	0.175	0.654	0.210
16	0.362	0.309	0.699	0.376	0.527	0.173
17	0.218	0.256	0.037	0.199	0.302	0.116
18	0.183	0.251	0.154	0.193	0.139	0.050
19	0.265	0.398	0.297	0.180	0.304	0.089
20	0.276	0.192	0.295	0.229	0.365	0.076
21	0.338	0.333	0.295	0.196	0.498	0.126
22	0.473	0.367	0.525	0.650	0.463	0.119
23	0.431	0.814	0.390	0.498	0.356	0.209
24	0.257	0.448	0.228	0.693	0.349	0.197
25	0.675	0.762	0.525	0.448	0.543	0.135
26	0.204	0.122	0.224	0.179	0.213	0.046
27	0.235	0.221	0.174	0.252	0.257	0.038
28	0.626	0.621	0.702	0.748	0.523	0.099
29	0.650	0.303	0.667	0.826	0.329	0.257
30	0.670	0.522	0.598	0.685	0.996	0.208
31	0.487	0.519	0.456	0.603	0.492	0.062
32	0.855	0.853	0.928	0.533	1.206	0.277
33	0.267	0.424	0.317	0.126	0.155	0.140
34	0.406	0.436	0.529	0.339	0.448	0.078
35	0.836	1.157	0.813	0.371	1.084	0.356
36	0.692	1.295	0.845	0.318	0.754	0.401

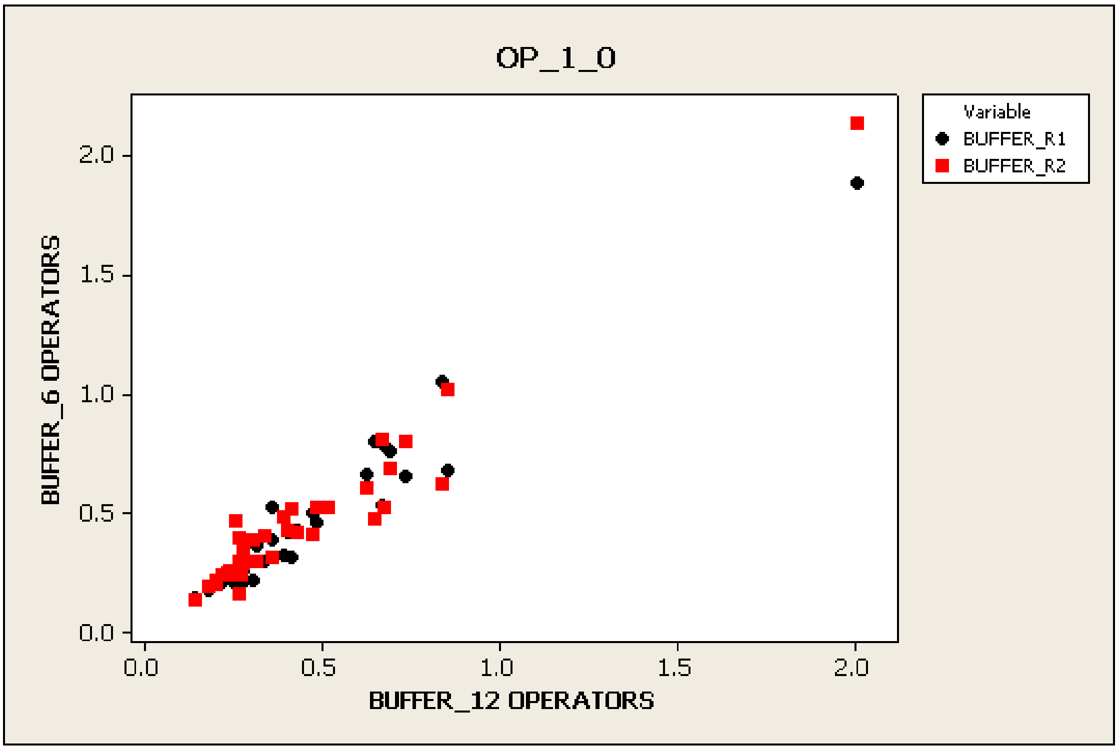


Fig. 12. OP_1_0 : Buffer for each replication of six operators, as a function of the reference buffer (12 operators).

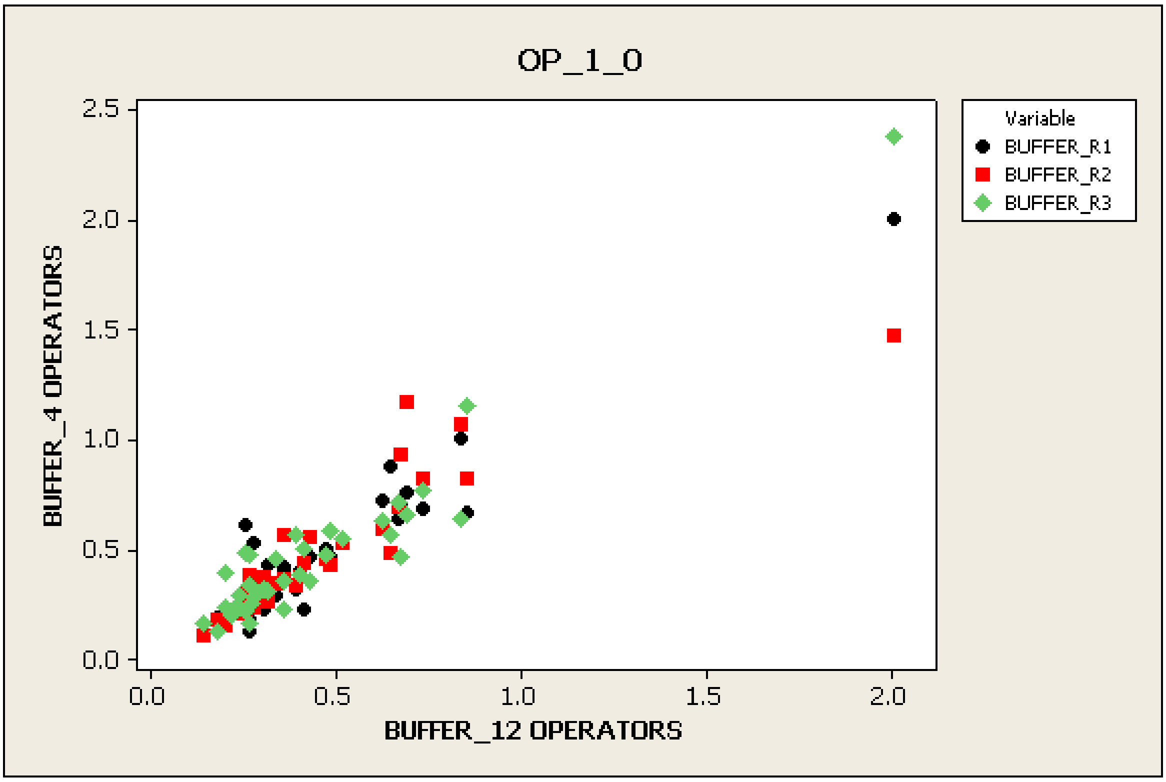


Fig. 13. OP_1_0 : Buffer for each replication of four operators, as a function of the reference buffer (12 operators).

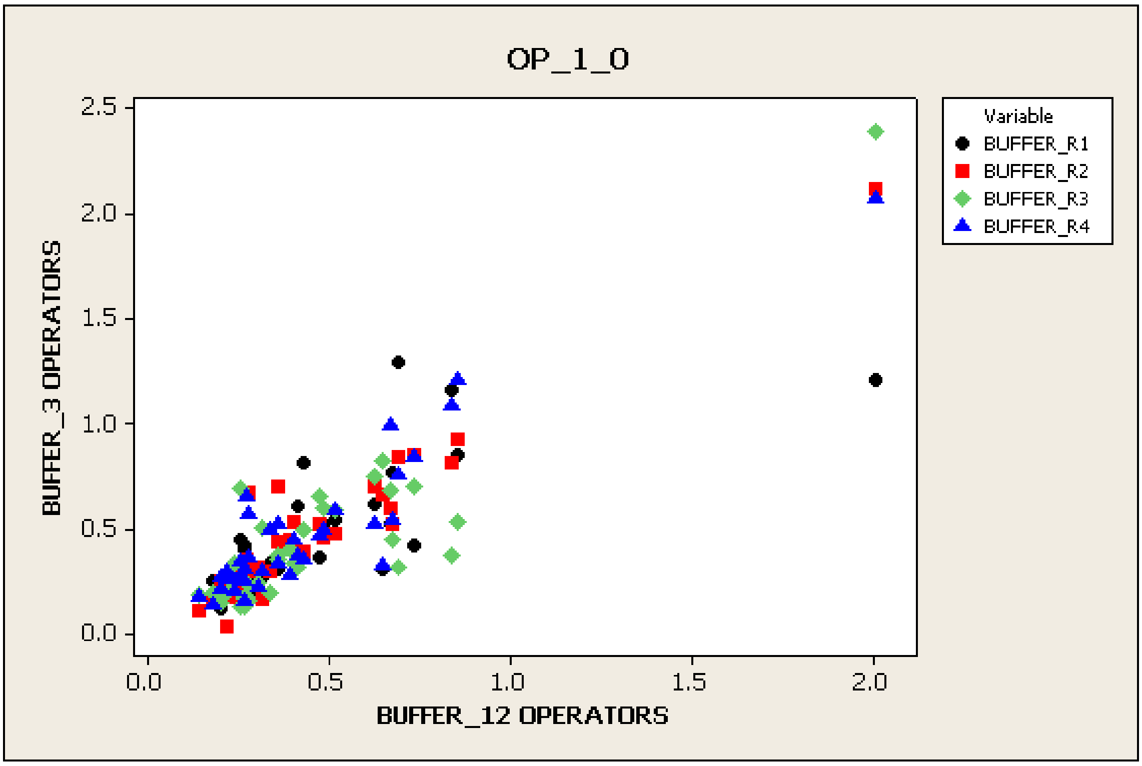


Fig. 14. OP_1_0 : Buffer for each replication of three operators, as a function of the reference buffer (12 operators).

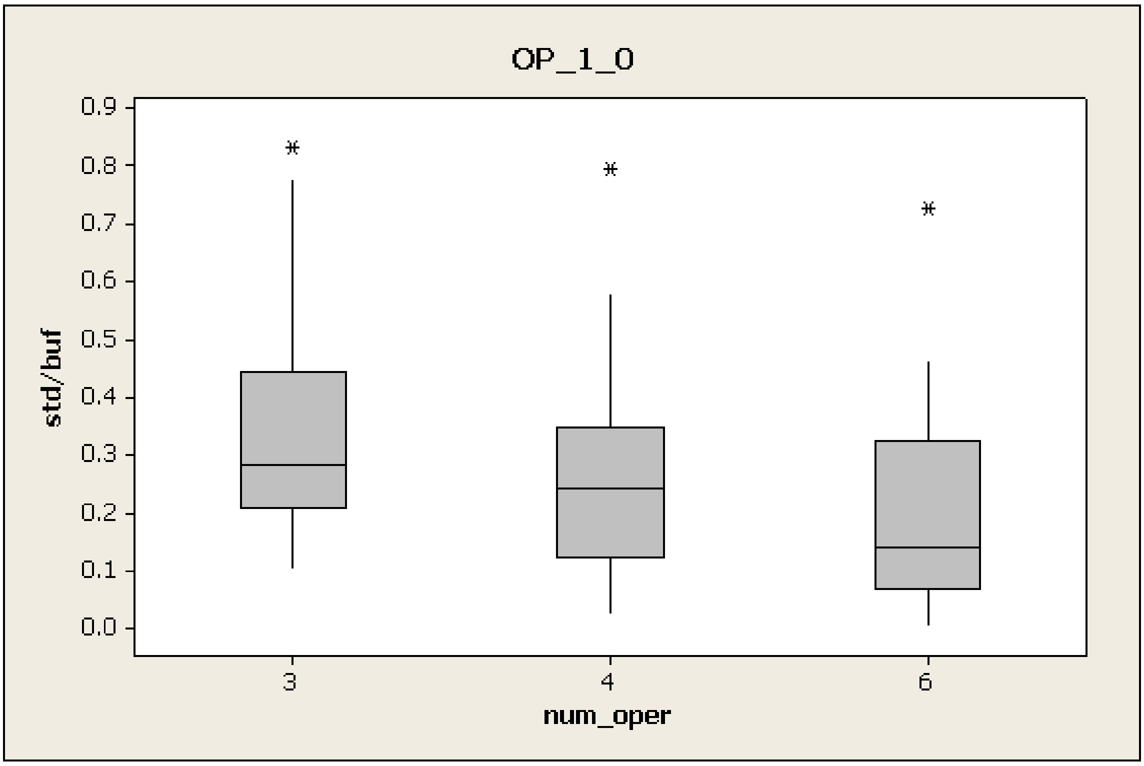


Fig. 15. OP_1_0 : Boxplot of the ratios (standard deviation /reference buffer) for three, four and six operators.

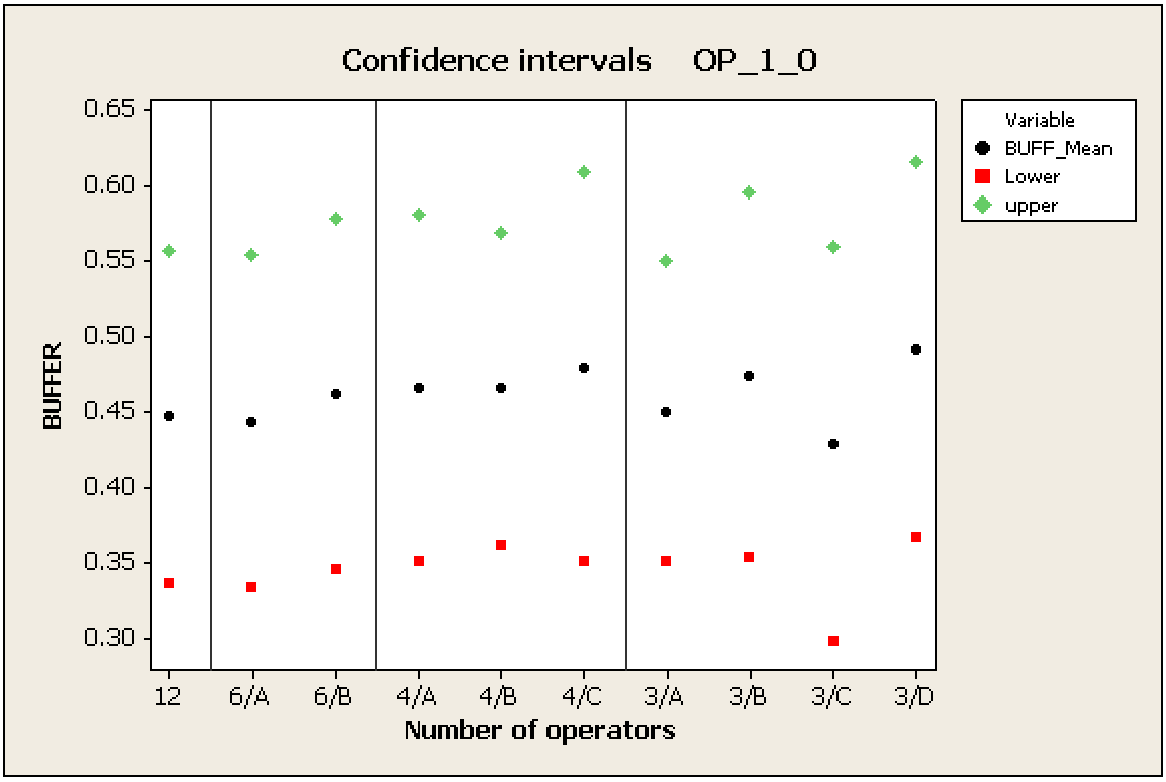


Fig. 16. OP_1_0 : 95 % confidence intervals of the mean value of buffer for the replications of 6, 4 and 3 operators and for the reference buffer (12 operators).

2.5 Discussion

The simulation study shows that the replications of the measurements on a given parcel can provide values of buffer which are sometimes very variable. This variability in buffer depends on the value of the reference buffer (buffer estimated with 12 operators) and on the number of operators. To discard the influence of reference buffer, we consider the ratio:

(1) standard deviation of buffer/reference buffer.

The mean values of these ratios are given in table: Tab 10. As expected, they increase when the number of operators decreases.

This increase in the variability of the estimated buffer of a given parcel does, however, not dramatically increase the 95 % confidence interval of the general mean of a set of parcels, due to the important between parcels variability.

Tab 10. Mean values of the ratios (standard deviation/reference buffer).

Number of operators	OP_0_2	OP_0_5	OP_1_0
6	0.20	0.12	0.19
4	0.33	0.25	0.26
3	0.37	0.40	0.34

3. Measurements experiment

3.1 Parcel sets

In supplementary study parcel set was composed of 36 parcels. 35 parcels were the same as in main project, one (parcel number 28) had to be changed because of clouds. Size, shape and measurement's conditions of the parcels were precisely defined in main project. The parcels in the supplementary study are characterized by the same size and shape for not changed parcels. Measurements conditions for RS were defined as: GOOD and BAD parcel edge recognitions. Planning in main experiment was performed basing on accessible images and therefore GOOD and BAD edge recognitions could be traced on all images. In the supplementary study parameter of the parcel: "edge quality" couldn't reflect real conditions on EROS and SPOT.

From the main project can be state that the area measurements are not influenced by operator (skilled and unskilled provide similar results). Therefore amount of the operators in supplementary study was limited to 6. Each parcel was measured by each operator 3 times on one ortho.

Finally in supplementary study were:

- 36 parcels
- 6 operators
- 2 ortho
- 3 repetitions

An experiments set was composed of 1296 measurements.

Parcels will be digitized on the screen and data will be collected using GIS software: GeoMedia Professional.

3.2 Applied remote sensing imagery

RS data were obtained from JRC and orthofotomap were generated at: AGH UST Kraków, Poland:

- Panchromatic ortofotomaps generated from SPOT image:
    - Registered: 29.08.2005
    - With pixel size: 2.5 m

- Panchromatic ortofotomaps generated from EROS image
  - Registered: 3.07.2005
  - With pixel size: 2.0 m

Fig. 17. Panchromatic ortofotomaps generated from SPOT image

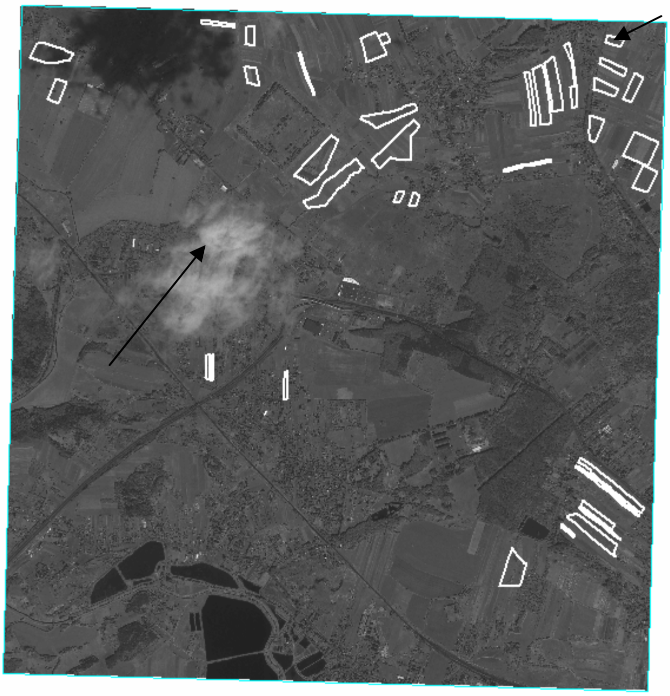


Fig. 18. Panchromatic ortofotomaps generated from EROS image (see clouds and new parcel 28)

3.3 Ortho generation

EROS and SPOT images have been orthorectified in PCI Geomatics software applying DTM generated on the base of aerial photos in scale: 1:13 000. Control (GCP) and check points (CP) for triangulation were obtained from ortophoto: OP_0_2. Triangulation was performed basing on rational function model using RPC data.

On Eros -17 points were measured (10 GCPs, 7 CPs). RMS for GCP is 0.82 [pixel] and for Check is 1.22 [pixel]. On SPOT - 23 points were measured (13 GCPs, 10 CPs). RMS for GCP is 0.82 [pixel] and for Check is 1.1 [pixel]. In table (Tab 11 and Tab 13) residuals errors at all points are presented. In table (Tab 12, Tab 14) RMS for EROS and SPOT is shown.

Tab 11. EROS - residual errors in pixels

	ID	Res X	Res Y	Res	Type
1	G0013	2.05	2.05	0.03	CP
2	G0006	1.4	0.1	-1.4	GCP
3	G0003	1.31	-1.28	-0.3	CP
4	G0008	1.24	-0.6	1.08	GCP
5	G0004	1.14	0.45	1.05	CP
6	G0009	1.11	0.71	-0.85	CP
7	G0011	1.05	-0.77	-0.72	GCP
8	G0001	0.77	-0.1	0.76	GCP
9	G0005	0.64	0.39	-0.5	GCP
10	G0002	0.54	-0.53	-0.06	CP
11	G0010	0.49	0.42	0.26	GCP
12	G0016	0.43	-0.41	-0.11	CP
13	G0017	0.39	-0.3	-0.24	GCP
14	G0015	0.31	0.14	-0.28	CP
15	G0012	0.3	0.21	0.21	GCP
16	G0007	0.2	0.2	0.02	GCP
17	G0014	0.18	-0.06	0.17	GCP

Tab 12. EROS – RMS - summary

Type of point	No of points	RMS (X)	RMS (Y)
GCPs:	10	0.41	0.72
CPs:	7	1.08	0.58

Tab 13. SPOT - residual errors in pixels

	ID	**Res X**	**Res Y**	**Res**	**Type**
1	**G0017**	**1.5**	**1.14**	**0.98**	**CP**
2	**G0005**	**1.44**	**-1.2**	**0.8**	**GCP**
3	**G0009**	**1.39**	**-1.38**	**-0.11**	**CP**
4	**G0007**	**1.37**	**0.99**	**-0.95**	**CP**
5	**G0003**	**1.28**	**1.09**	**-0.68**	**GCP**

6	**G0020**	**1.16**	**0.89**	**-0.74**	**CP**
7	**G0002**	**1.04**	**-0.87**	**-0.57**	**CP**
8	**G0016**	**1.03**	**0.15**	**-1.02**	**CP**
9	**G0019**	**0.91**	**0.55**	**0.72**	**GCP**
10	**G0021**	**0.89**	**-0.59**	**-0.66**	**GCP**
11	**G0014**	**0.88**	**-0.61**	**0.64**	**GCP**
12	**G0023**	**0.83**	**0.74**	**0.37**	**CP**
13	**G0018**	**0.73**	**-0.55**	**-0.48**	**GCP**
14	**G0001**	**0.57**	**0.56**	**0.11**	**GCP**
15	**G0015**	**0.57**	**0.3**	**-0.48**	**GCP**
16	**G0006**	**0.55**	**0.19**	**-0.52**	**CP**
17	**G0013**	**0.5**	**0.49**	**0.09**	**GCP**
18	**G0022**	**0.48**	**-0.26**	**-0.41**	**CP**
19	**G0012**	**0.47**	**-0.23**	**-0.41**	**CP**
20	**G0011**	**0.46**	**0.45**	**-0.12**	**GCP**
21	**G0004**	**0.42**	**-0.21**	**0.37**	**GCP**
22	**G0008**	**0.4**	**0.26**	**-0.3**	**GCP**
23	**G0010**	**0.2**	**-0.17**	**-0.1**	**GCP**

Tab 14. EROS – RMS - summary

Typ of point	No of points	RMS (X)	RMS (Y)
GCPs:	13	0.64	0.52
CPs:	10	0.85	0.71

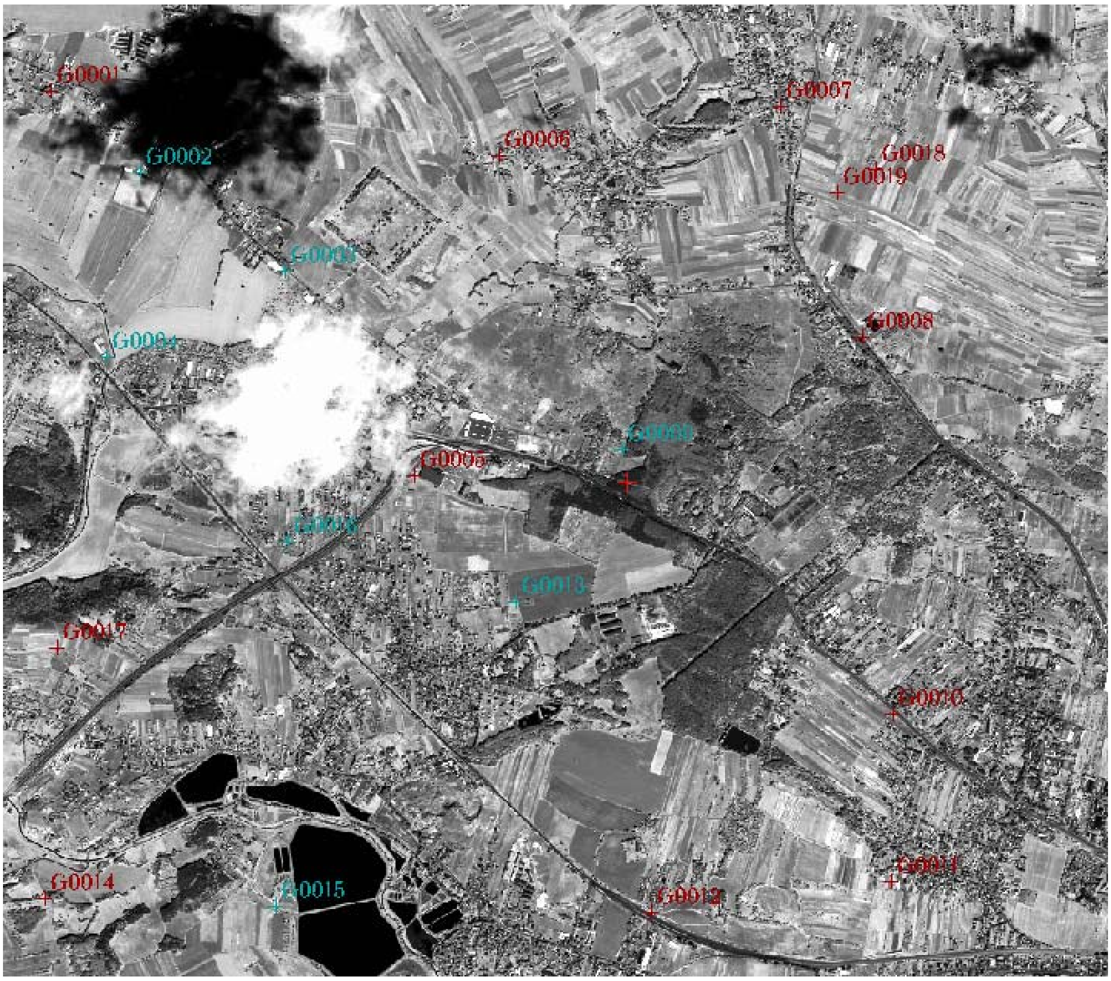


Fig. 19. EROS – GCP, CP distribution

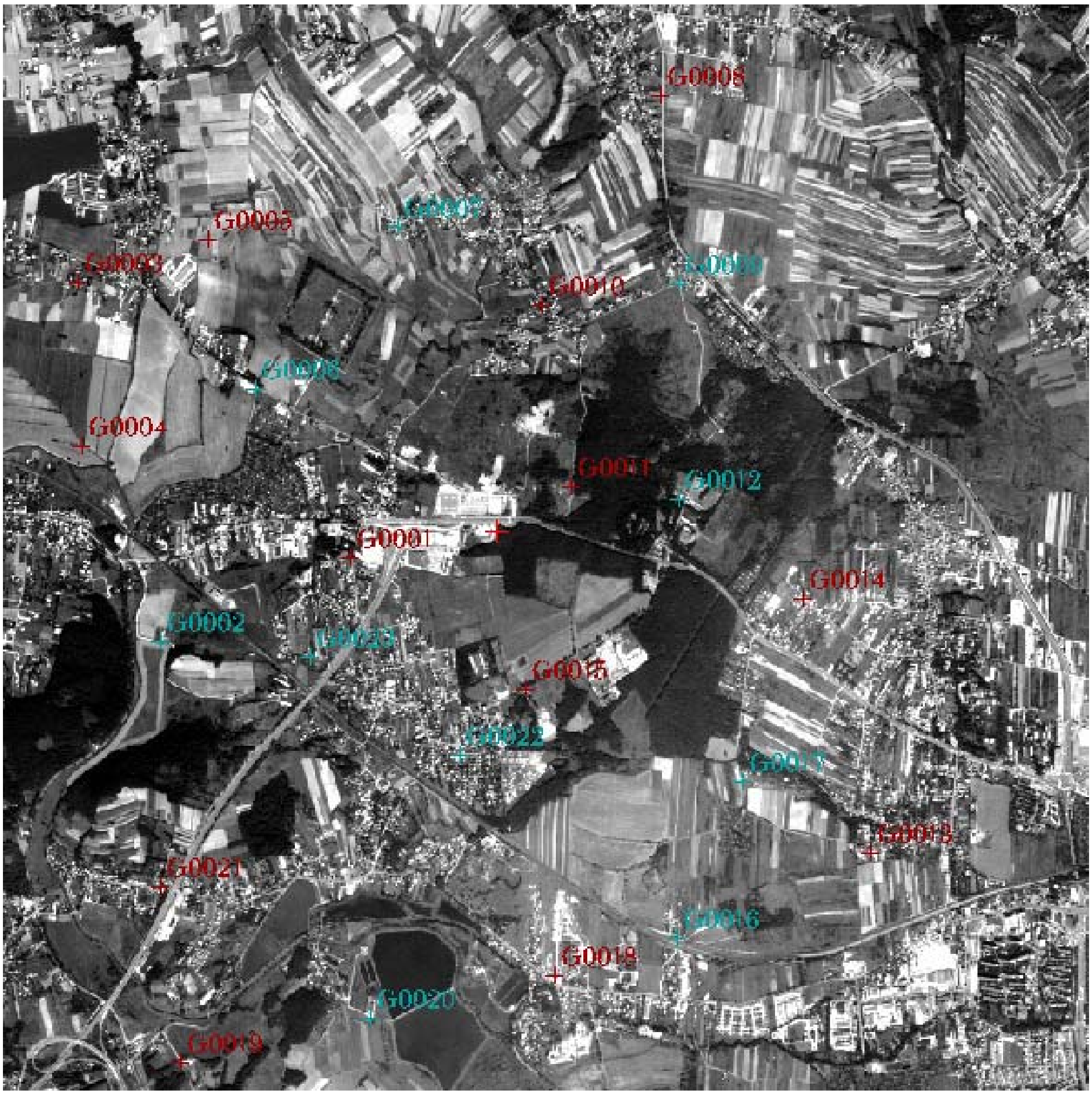


Fig. 20. SPOT – GCP, CP distribution

3.4 Measurement workflow

Measurements are prepared like in main project according ISO 5725: "basic method for determination of repeatability and reproducibility a standard measurement method" (ISO 5725-1), regarding very carefully predefined measurement conditions, especially the parcel sequences measured by each operator in all experiment period.

3.4.1 Control procedure

Before measurements operators (especially 2 new operators) were shortly trained and precisely instructions were them provided.

Measurements in main project were controlled and gross errors (mainly mistakes of chosen parcel to measuring) are currently corrected. In supplementary study any changes were not made. In this case parcels were marked by letter like in main study but also by letters: “x” for marking the surrounding parcels NOT to be measured. Parcel edges on EROS and SPOT were sometimes very poor to recognize (see Fig. 21, Fig. 22, Fig. 23, Fig. 24).

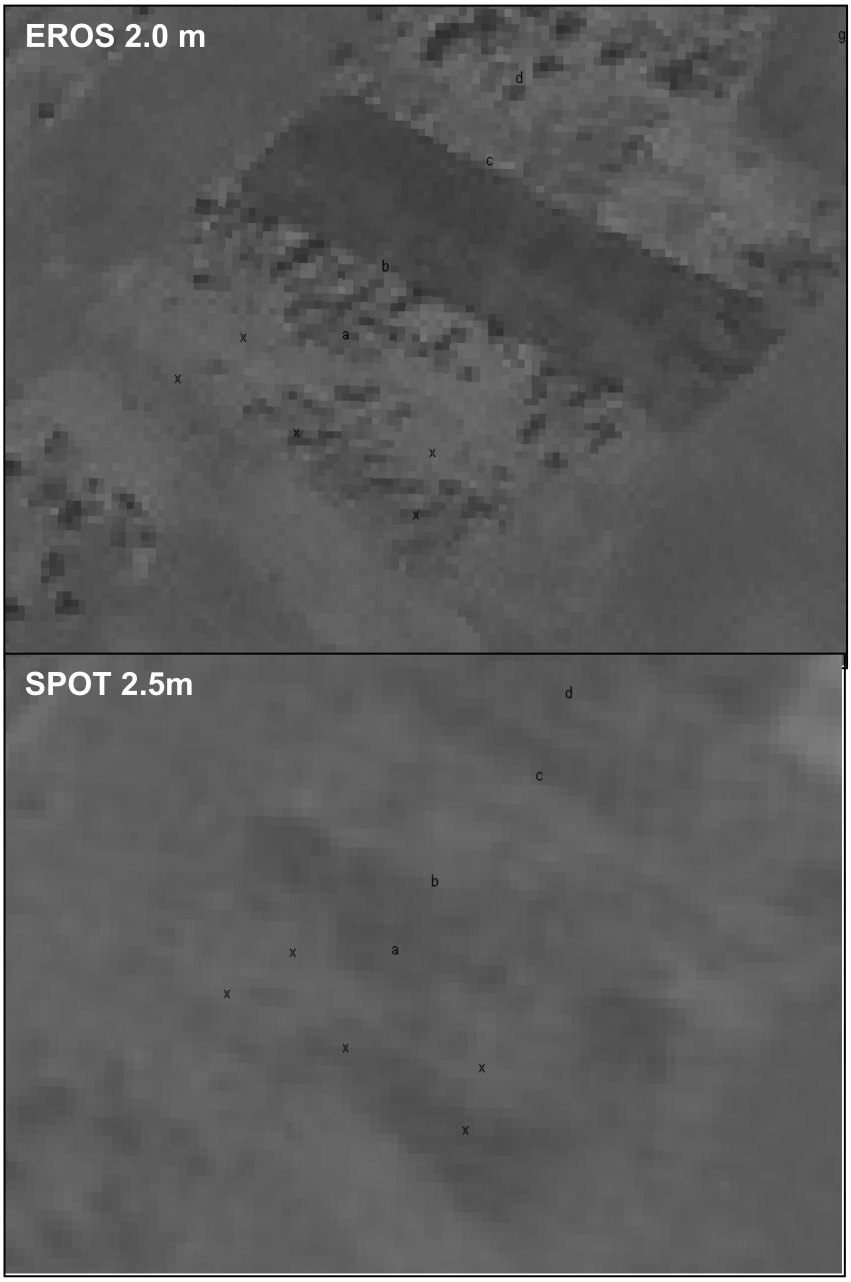


Fig. 21. Comparison of border condition on 2 ortophotos

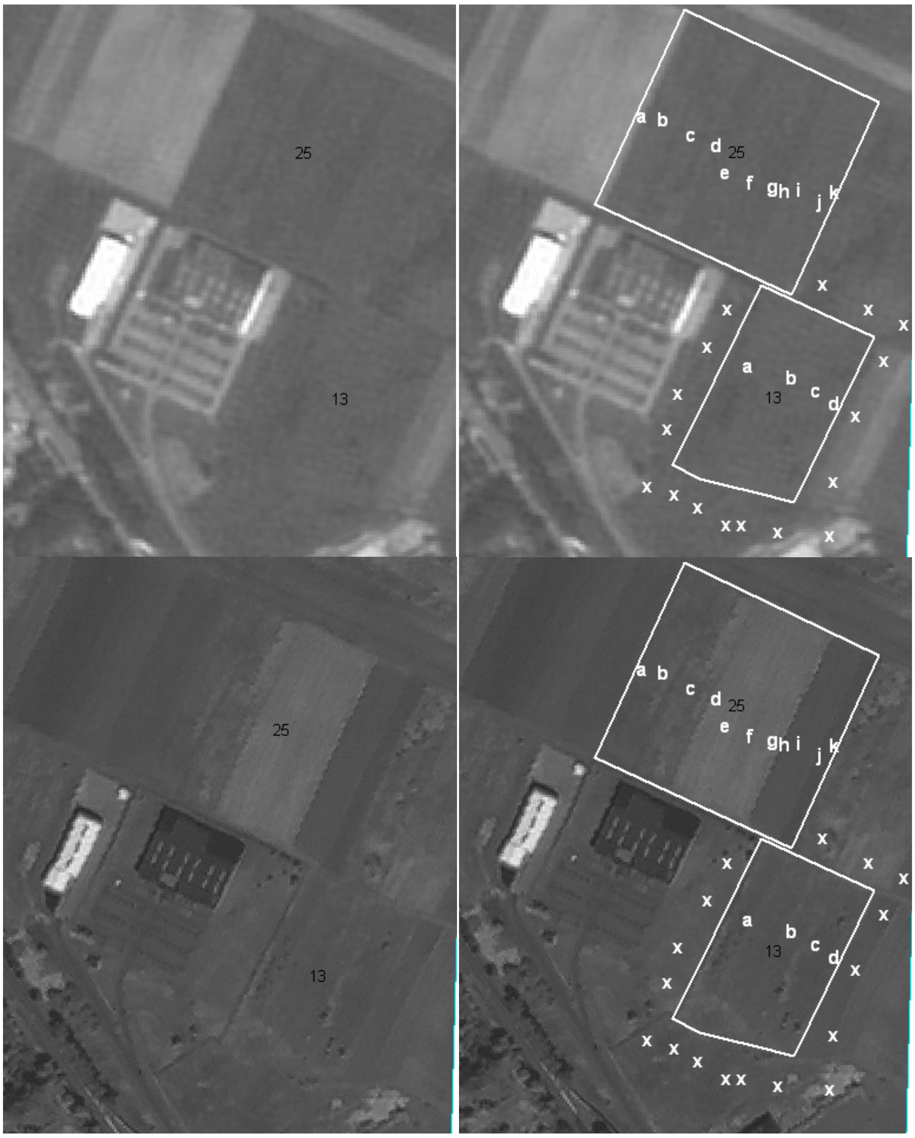


Fig. 22. Difficulties of edge recognition (letter “x” showing parcels not belonging to reference one)

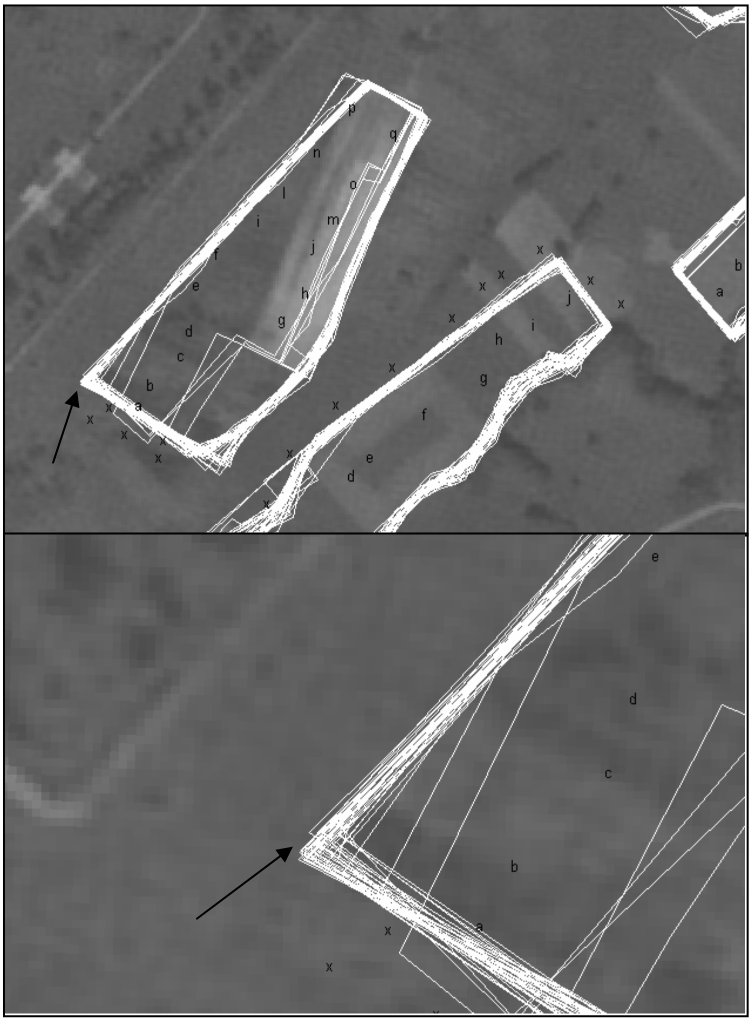


Fig. 23. Panchromatic ortofotomap from SPOT (pixel size of 2.5m)

Fig. 24. Panchromatic ortofotomap from EROS (pixel size of 2.0m)

3.5 Cadastre parcels as reference parcels

In supplementary study like in main one cadastre parcels were reference parcels. Notice only changed parcel nr 28.

Tab 15. List of reference parcels

IDENT	REPLIC	BORDER	SIZE	SHAPE	AREA_REF	PERIM
1	A	GOOD	S	S1	3,431.80	248.7
2	A	GOOD	S	S2	3,179.50	394
3	A	GOOD	S	S3	4,081.80	650.9
4	A	GOOD	M	S1	8,450.70	388.6
5	A	GOOD	M	S2	12,387.30	519.5
6	A	GOOD	M	S3	8,567.10	1,150.40
7	A	GOOD	L	S1	23,511.30	623.3
8	A	GOOD	L	S2	27,960.70	711.4
9	A	GOOD	L	S3	24,503.30	897.9
10	A	BAD	S	S1	4,145.90	276
11	A	BAD	S	S2	3,856.80	375.6

12	A	BAD	S	S3	4,785.90	712.6
13	A	BAD	M	S1	17,747.00	546
14	A	BAD	M	S2	12,768.20	490.3
15	A	BAD	M	S3	10,955.00	635.3
16	A	BAD	L	S1	41,745.40	951
17	A	BAD	L	S2	30,883.10	965.7
18	A	BAD	L	S3	24,143.00	1,229.70
19	B	GOOD	S	S1	3,795.70	247.2
20	B	GOOD	S	S2	3,446.30	433.2
21	B	GOOD	S	S3	3,722.30	750.5
22	B	GOOD	M	S1	8,807.90	396.8
23	B	GOOD	M	S2	8,832.40	483.7
24	B	GOOD	M	S3	11,658.10	815.4
25	B	GOOD	L	S1	33,676.90	734.1
26	B	GOOD	L	S2	27,455.10	876.3
27	B	GOOD	L	S3	26,106.50	959.9
28	B	BAD	S	S1	6,381.90	343.6
29	B	BAD	S	S2	2,338.70	277.7
30	B	BAD	S	S3	4,312.30	501.5
31	B	BAD	M	S1	12,334.10	471.2
32	B	BAD	M	S2	10,420.60	468
33	B	BAD	M	S3	10,862.40	1,005.20
34	B	BAD	L	S1	28,543.40	746.9
35	B	BAD	L	S2	43,349.60	1,054.30
36	B	BAD	L	S3	41,087.00	1,170.60

3.6 Technical specifications for operators – RS

In the supplementary study 6 operators have been taking part (see table: Tab 16 (GIS specialist, student of Academy of Economy, AE, AST-AGH senior students of technical studies (not surveying)).

Tab 16. List of operators

Operator	Name	education
OP1	Wojciech Drzewiecki	GIS
OP2	Małgorzata Borowiec	AE student
OP3	Tomasz Pirowski	GIS
OP4	Ewa Głowienka	GIS
OP5	Ania Głowienka	AST – AGH student
OP6	Dariusz Nowak	AST – AGH student

Each operator obtained for each day prepared files:

- list of parcels to be measured on which orto (Fig. 25)
- geoworkspace: *.gws,
  - with configured ready to display images
  - number of all parcels (without reference parcels)
  - letters (a, b, c…) marking parcels building reference parcel (Fig. 26)
  - letters (x) marking parcels NOT to be measured (Fig. 26).
- warehouse: *.mdb
  - empty feature class – in the feature class operator digitized parcels according list of parcels to be measured on which orto

After measured, each operator each day provided the results, which were controlled and after control they could obtain the data for next day.

4	1	4	SPOT_5
4	1	11	EROS_1A
4	1	2	EROS_1A
4	1	5	EROS_1A
4	1	7	EROS_1A
4	1	26	SPOT_5
4	1	17	EROS_1A
4	1	31	SPOT_5
4	1	18	SPOT_5
4	1	23	SPOT_5
4	1	16	EROS_1A
4	1	34	EROS_1A
4	1	15	SPOT_5
4	1	13	EROS_1A
4	1	6	EROS_1A
4	1	10	SPOT_5
4	1	32	SPOT_5
4	1	29	EROS_1A
4	1	1	EROS_1A
4	1	14	EROS_1A
4	1	20	SPOT_5
4	1	21	EROS_1A
4	1	30	EROS_1A
4	1	19	SPOT_5
4	1	25	EROS_1A
4	1	22	EROS_1A
4	1	33	SPOT_5
4	1	35	EROS_1A
4	1	28	EROS_1A
4	1	3	SPOT_5
4	1	36	SPOT_5
4	1	27	SPOT_5
4	1	12	SPOT_5
4	1	8	EROS_1A
4	1	24	SPOT_5
4	1	9	SPOT_5

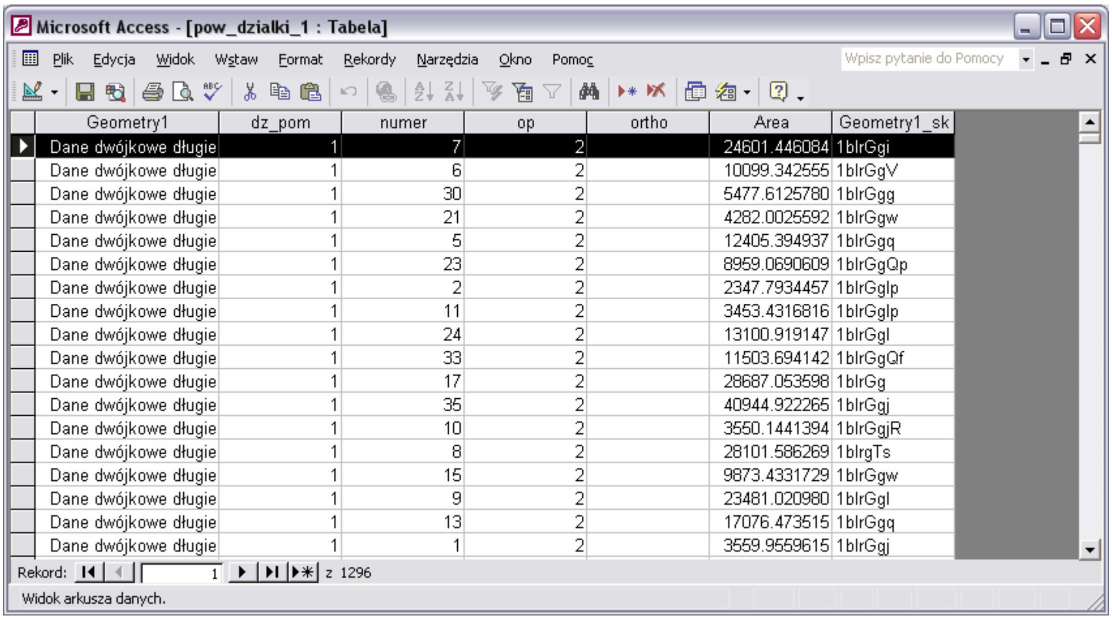
Fig. 25. List of parcels to be measured on which orto

Fig. 26. Letters marking parcels building reference parcel (additional marks: “x” for parcel not included in reference one)

3.7 Data gathering, initial preparation

Data were gathered in separate files for each operator and each day. Than all data was combined in file **pomiar_all_ext.mdb** contains attribute (parcel number, day, operator and ortho) and graphic (coordinates of parcel vertexes).

Finally all files from 6 days were combined to one file and parcels areas were calculated. The file is on the attached CD. Than data were automatically exported for statistical analysis like in main study.



Microsoft Access - [pow_dzialki_1 : Tabela]

Plik Edycja Widok Wstaw Format Rekordy Narzędzia Okno Pomoc

Geometry1	dz_pom	numer	op	ortho	Area	Geometry1_sk
Dane dwójkowe długie	1	7	2		24601.446084	1blrGgi
Dane dwójkowe długie	1	6	2		10099.342555	1blrGgV
Dane dwójkowe długie	1	30	2		5477.6125780	1blrGgg
Dane dwójkowe długie	1	21	2		4282.0025592	1blrGgw
Dane dwójkowe długie	1	5	2		12405.394937	1blrGgq
Dane dwójkowe długie	1	23	2		8959.0690609	1blrGgQp
Dane dwójkowe długie	1	2	2		2347.7934457	1blrGglp
Dane dwójkowe długie	1	11	2		3453.4316816	1blrGglp
Dane dwójkowe długie	1	24	2		13100.919147	1blrGgl
Dane dwójkowe długie	1	33	2		11503.694142	1blrGgQf
Dane dwójkowe długie	1	17	2		28687.053598	1blrGg
Dane dwójkowe długie	1	35	2		40944.922265	1blrGgj
Dane dwójkowe długie	1	10	2		3550.1441394	1blrGgjR
Dane dwójkowe długie	1	8	2		28101.586269	1blrgTs
Dane dwójkowe długie	1	15	2		9873.4331729	1blrGgw
Dane dwójkowe długie	1	9	2		23481.020980	1blrGgl
Dane dwójkowe długie	1	13	2		17076.473515	1blrGgq
Dane dwójkowe długie	1	1	2		3559.9559615	1blrGgj

Rekord: 1 z 1296

Widok arkusza danych.

Fig. 27. Data base in Access containing all measurements (pomiar_all_ext.mdb)

4. Statistical analysis of a new RS data

4.1 Critical examination of the data

The pooling factor is the factor "operator". Each photo has been examined by 6 operators on three different days. The 1296 observations (36 parcels × 2 photos × 6 operators × 3 days) are allocated into 432 groups. The 18 observations related to a given photo of a given parcel are analysed separately. So, the identification of outliers and other irregularities is repeated 72 times (36 parcels × 2 photos).

Out of 432 groups, 23 are identified as outliers (5.3 %). For each of these groups, all observations are discarded (69 observations). Most of the groups are identified by COCHRAN's test (18 groups), due to too large standard deviation within repetitions for a given operator. Five groups are identified by GRUBB's tests, due to too extreme mean values for one or two operators.

For operator 4 and operator 6, six groups (among 72 groups) are discarded. For operators 1, 3 and 5, three groups are discarded and for operator 2, two groups are discarded.

Regarding the photos, 12 groups for EROS_1A and 11 groups for SPOT_5 are identified.

For parcel 15, three groups are discarded. For parcels 16, 22 and 33, two groups are discarded and for parcels 1, 7, 8, 17, 18, 19, 21, 25, 26, 29, 30, 31, 32 and 34, one group is identified.

The complete list of all the 69 observations that are discarded is given in Chapter 7.

Figures (Fig. 28 - Fig. 31) give the boxplots of the h_i and k_i values defined by MANDEL, before and after discarding these observations. These plots show that operators 3 and 4 often overestimate and operators 5 and 6 often underestimate the area. Operators 3 and 5 show a slightly smaller variability.

As a conclusion of this critical examination of observations, we propose to discard all the identified observations by ISO 5725-2 procedure (69 observations) and we consider that no operator shows a special pattern giving us a reason to discard him or her.

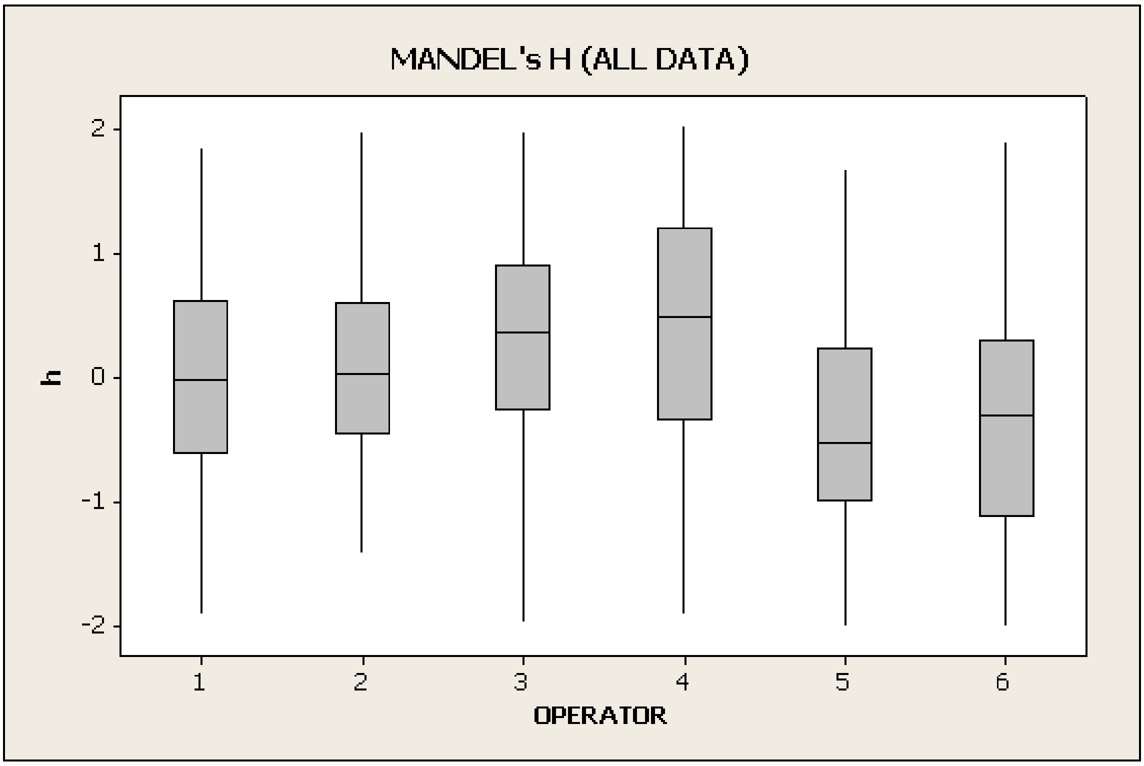


Fig. 28. Boxplot of MANDEL's h_i values as a function of operators (before discarding observations).

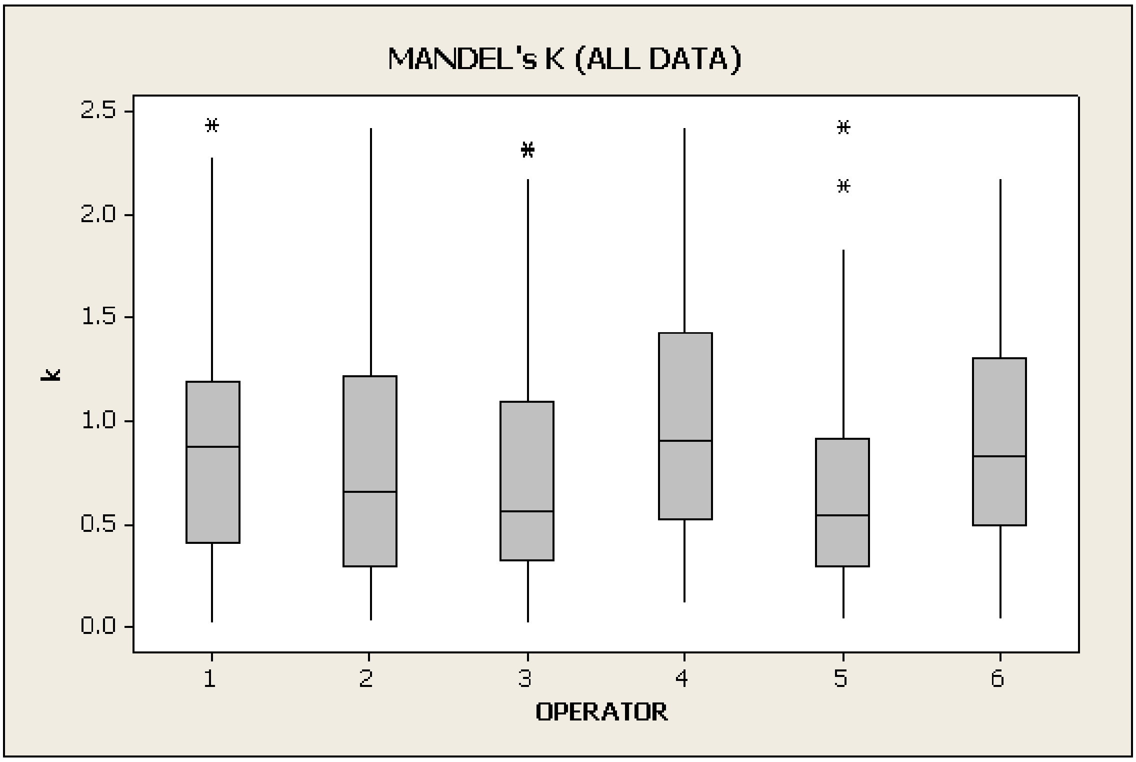


Fig. 29. ***2.*** Boxplot of MANDEL's k_i values as a function of operators (before discarding observations).

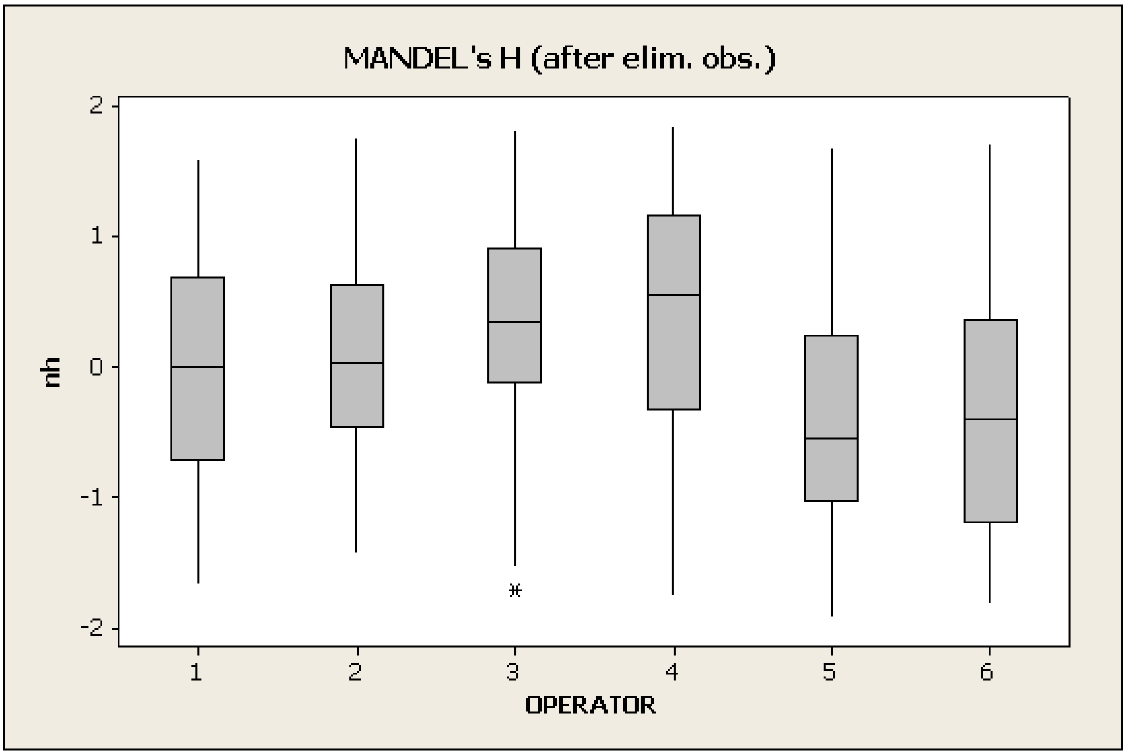


Fig. 30. ***3***. Boxplot of MANDEL's h_i values as a function of operators (after discarding 69 observations).

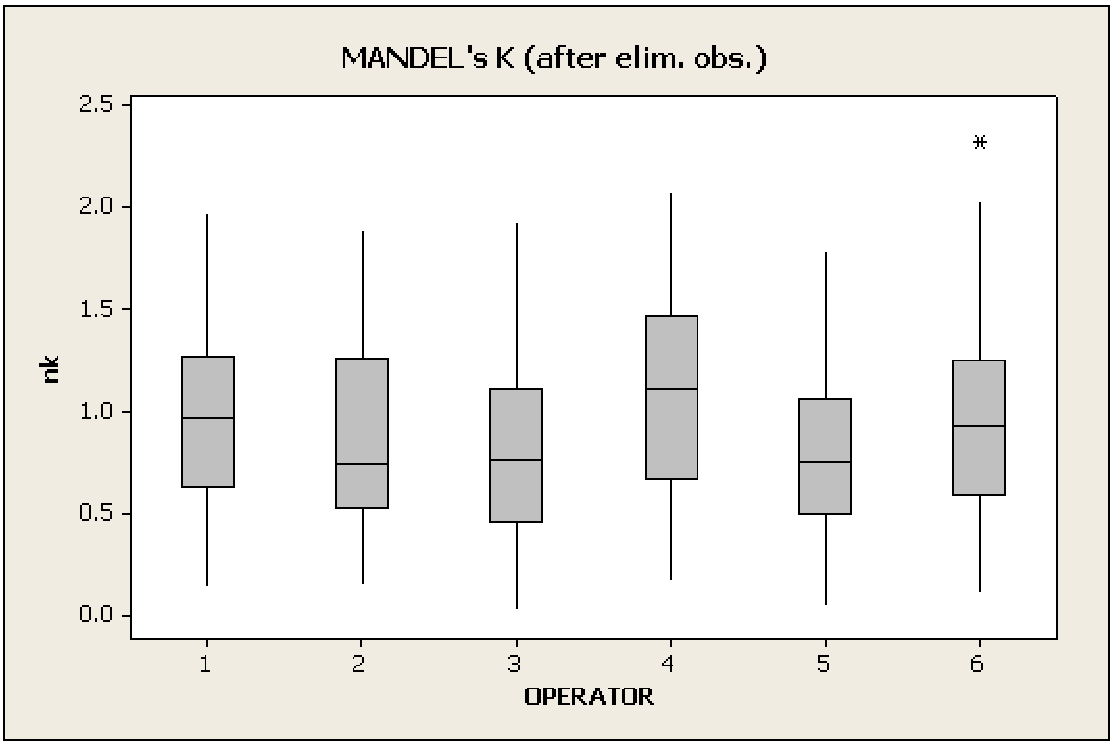


Fig. 31.. Boxplot of MANDEL's k_i values as a function of operators (after discarding 69 observations).

4.2 Individual relative errors

Figures (Fig. 32 - Fig. 35) give the distributions of the errors (in percent). Figure (Fig. 32) and figure (Fig. 33) give the differences between observations and reference areas, in percent of the reference areas for all data (Fig. 32) and after discarding 69 observations (Fig. 33):

(2) relative error = 100 (observation – reference area)/reference area.

Figure (Fig. 34) and figure (Fig. 35) give the differences between observations and the general mean (of all observations made on the parcel for a given photo), for all the data (Fig. 34) and after discarding 69 observations (Fig. 35).

(3) relative error = 100 (observation – general mean)/general mean.

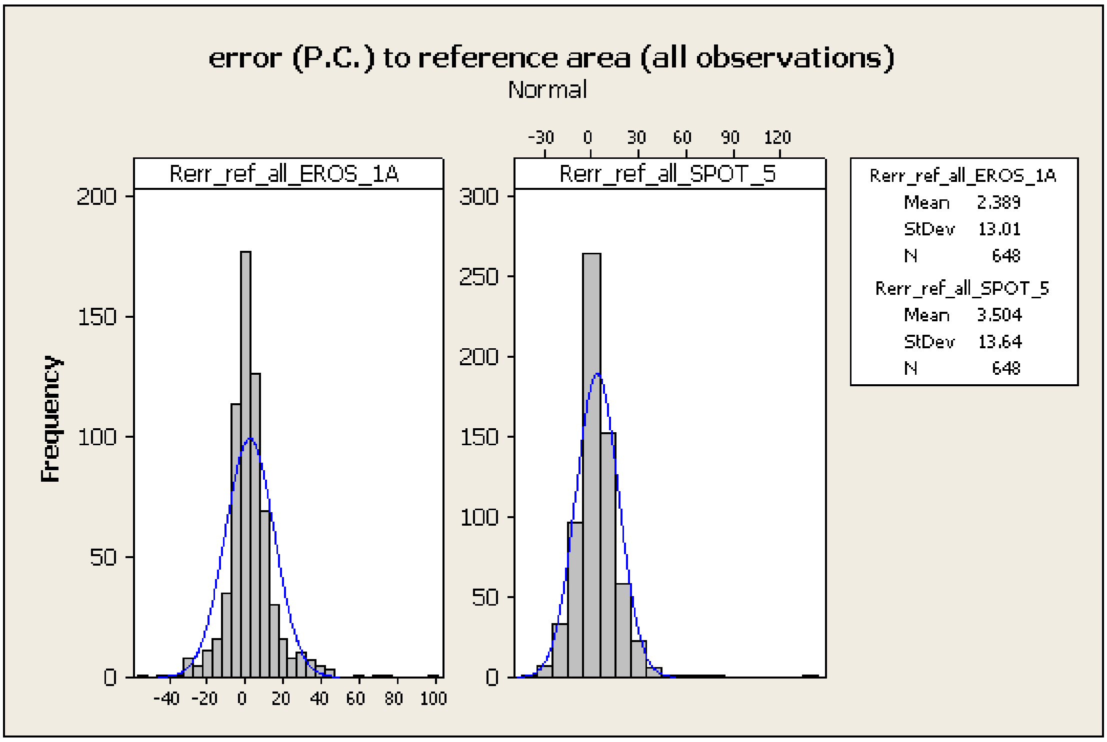


Fig. 32. Histogram of the errors (in percent) to reference area for all observations.

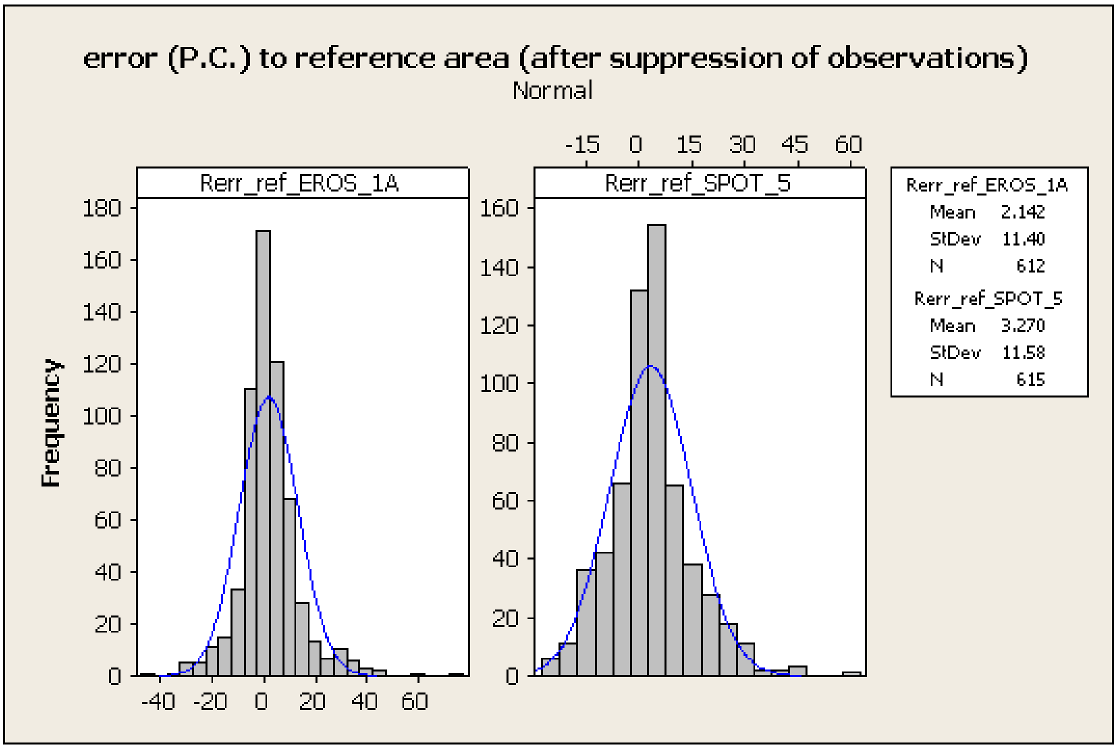


Fig. 33. Histogram of the errors (in percent) to reference area after discarding 69 observations.

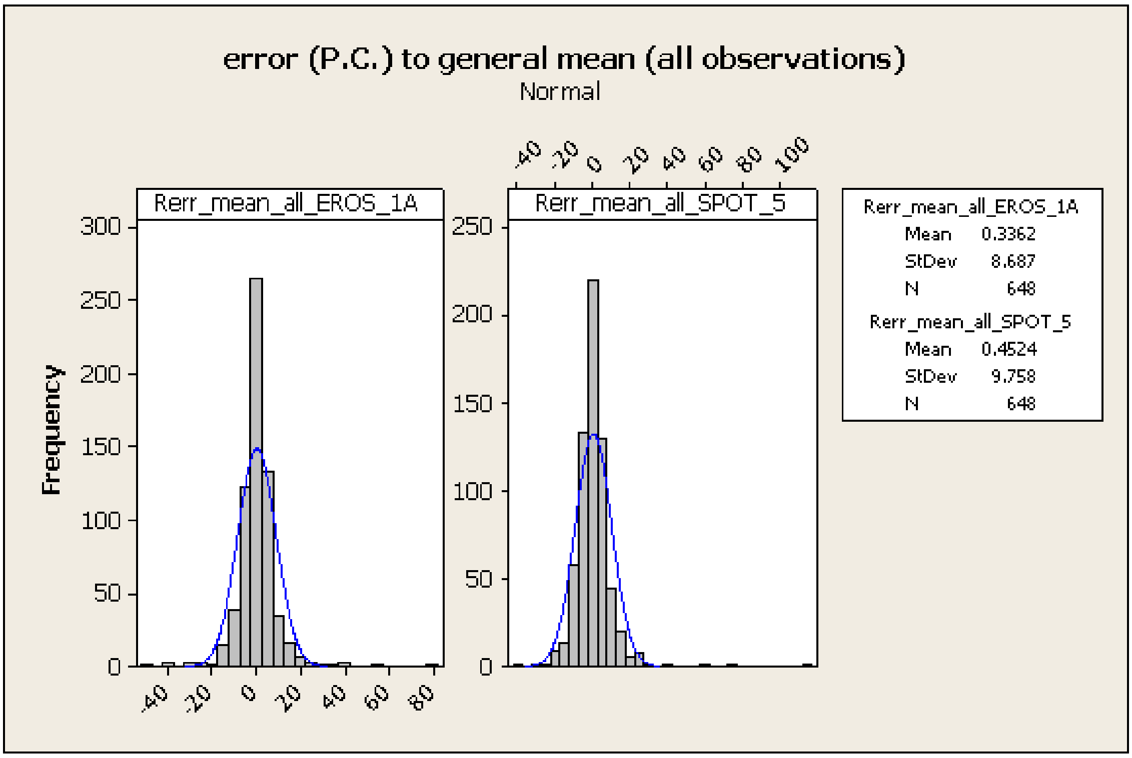


Fig. 34. Histogram of the error (in percent) to the general mean for all observations.

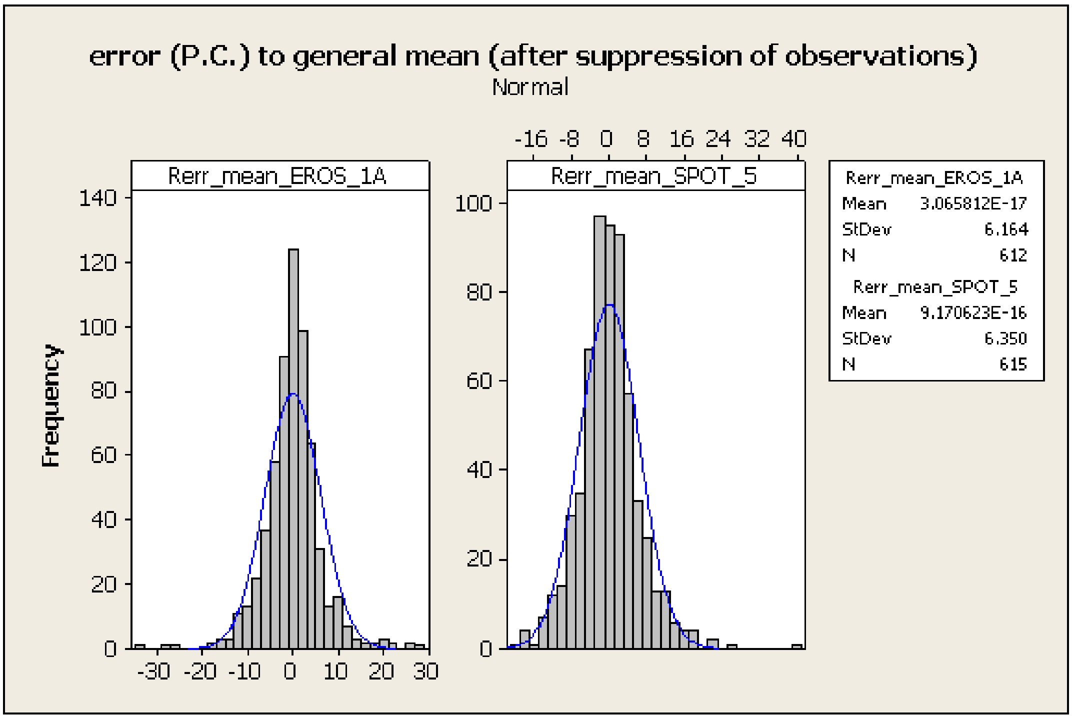


Fig. 35.. Histogram of the error (in percent) to the general mean after discarding 69 observations.

Table (Tab 17) gives the percentage of observations with a (absolute) relative error less than a given value. The errors are computed as follows, after discarding 69 observations :

(4) (absolute) relative error = 100 | observation – general mean | /general mean.

From this table, we can see, for example, that 51.3 percents of observations for EROS-1A show a deviation from the mean smaller or equal to 3 percents. For SPOT-5 this percentages is 46.3. We also can see that about 10 % of the observations show a deviation from the mean larger than 10 %.

Tab 17. Cumulative percentages of observations as a function of the error (%).

Error (%)	EROS-1A	SPOT-5
1	20.3	15.5
2	38.1	33.5
3	51.3	46.3
4	63.6	57.7
5	71.2	66.5
6	76.1	72.2
7	82.4	77.6
8	86.3	82.9
9	88.1	86.5
10	91.0	89.1
11	92.8	90.9
12	94.8	93.3
13	95.8	95.0
14	96.4	95.8

15	96.7	97.1
16	97.4	97.6
17	97.6	97.9
18	98.0	98.5
19	98.2	99.2
20	98.4	99.4

4.3 Bias of the methods

For each kind of photo and for each parcel, the ratio between the general mean and the reference area is computed. These ratios are given in table (Tab 18) and figure (Fig. 36) gives the histograms of the ratios.

The 95 % confidence intervals are:

- 0.9901 – 1.0538 for EROS_1A,
- and 1.0029 – 1.0655 for SPOT_5.

The interval includes the value 1 for EROS_1A. For this photo, the mean value of the ratio for the 36 parcels is not significantly different from 1 and, consequently, we do not conclude that there is a bias.

For SPOT_5, the interval does not include the value 1 and we conclude that this photo overestimates, on average, the parcel area.

Tab 18. Mean values of the observations and ratios mean value/reference area.

Parcels	EROS_1A	SPOT_5	EROS_1A/Ref	SPOT_5/Ref
1	3609	3876	1.05	1.13
2	2748	2623	0.86	0.82
3	4457	3835	1.09	0.94
4	8668	8950	1.03	1.06
5	12850	12434	1.04	1.00
6	9238	7913	1.08	0.92
7	24126	24462	1.03	1.04
8	29427	28575	1.05	1.02
9	23929	24674	0.98	1.01
10	4157	4382	1.00	1.06
11	3697	3566	0.96	0.92
12	5099	5243	1.07	1.10
13	16412	17824	0.92	1.00
14	13354	13529	1.05	1.06
15	10458	10774	0.95	0.98
16	41377	42081	0.99	1.01
17	30390	28923	0.98	0.94
18	25923	25891	1.07	1.07

19	3606	3578	0.95	0.94
20	2668	3000	0.77	0.87
21	4237	4507	1.14	1.21
22	8497	8971	0.96	1.02
23	9468	9557	1.07	1.08
24	11675	13355	1.00	1.15
25	35163	35591	1.04	1.06
26	25556	25528	0.93	0.93
27	27734	26786	1.06	1.03
28	6855	6640	1.07	1.04
29	2275	2667	0.97	1.14
30	5776	5157	1.34	1.20
31	12357	12855	1.00	1.04
32	12731	13207	1.22	1.27
33	10567	11820	0.97	1.09
34	30031	30142	1.05	1.06
35	43086	42740	0.99	0.99
36	41863	42789	1.02	1.04

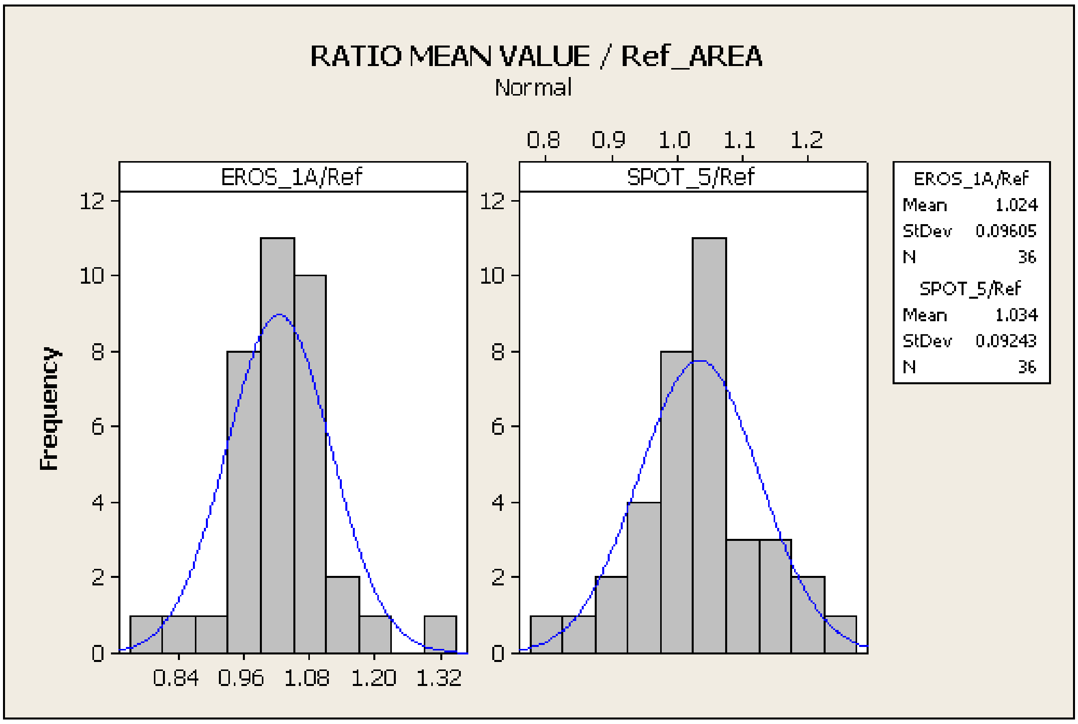


Fig. 36.. Histogram of the ratios mean value/reference area.

4.4 Variance components and reproducibility

For each parcel and each photo, a one-way analysis of variance has been performed and the variance components have been estimated.

The "between groups" variance, $\hat{\sigma}^2_{group}$ is the variance between operators and the "within groups" variance $\hat{\sigma}^2_2$ is the variance of the replicates related to the days. The negative estimations have been set to zero. The sum of these two variances gives the reproducibility variance $\hat{\sigma}^2_R$.

Tables (Tab 19) and (Tab 20) give the variance components and the reproducibility for each parcel (labelled Bop, Wop and Repr). The variance components have also been expressed in percentage of the reproducibility.

The average proportions of "between" and "within" variance components, for each photo, are:

- 29 % between and 71 % within for EROS_1A,
- 22 % between and 78 % within for SPOT_5.

Tab 19. Between operators and within operators variance components for EROS_1A

Parcels	Bop	Wop	Repr	B %	W %
1	68147	63961	132108	52	48
2	19884	13345	33229	60	40
3	0	401875	401875	0	100
4	3777	30193	33970	11	89
5	114366	220731	335097	34	66
6	0	645185	645185	0	100
7	14685	24610	39295	37	63
8	468023	271567	739590	63	37
9	76079	200079	276158	28	72
10	11657	30814	42471	27	73
11	0	22287	22287	0	100
12	0	63429	63429	0	100
13	334856	2067923	2402779	14	86
14	653040	270284	923324	71	29
15	0	200100	200100	0	100
16	66943	246618	313561	21	79
17	0	618526	618526	0	100
18	151237	1013710	1164947	13	87
19	21128	44861	65989	32	68
20	76657	52433	129090	59	41
21	15426	31547	46973	33	67
22	48115	26561	74676	64	36
23	130462	98060	228522	57	43
24	0	906664	906664	0	100
25	161804	954745	1116549	14	86
26	0	113410	113410	0	100

27	409266	1228575	1637841	25	75
28	61338	12576	73914	83	17
29	0	13780	13780	0	100
30	0	436059	436059	0	100
31	89181	143948	233129	38	62
32	2353901	836855	3190756	74	26
33	0	257707	257707	0	100
34	175888	236355	412243	43	57
35	1743281	243627	1986908	88	12
36	146757	2669357	2816114	5	95

Tab 20. Between operators and within operators variance components for SPOT_5

Parcels	Bop	Wop	Repr	B %	W %
1	0	91429	91429	0	100
2	0	37416	37416	0	100
3	94890	35682	130572	73	27
4	2930	74920	77850	4	96
5	23909	111284	135193	18	82
6	274644	93873	368517	75	25
7	72279	94454	166733	43	57
8	14915	1385640	1400555	1	99
9	2591	439897	442488	1	99
10	150177	96727	246904	61	39
11	0	121682	121682	0	100
12	1727	136363	138090	1	99
13	0	1587969	1587969	0	100
14	143487	487432	630919	23	77
15	0	37321	37321	0	100
16	0	3755533	3755533	0	100
17	544080	1296995	1841075	30	70
18	0	3731865	3731865	0	100
19	34878	67283	102161	34	66
20	0	22486	22486	0	100
21	0	90403	90403	0	100
22	46503	65165	111668	42	58
23	0	590399	590399	0	100
24	1300098	2358918	3659016	36	64
25	725812	1508531	2234343	32	68
26	209183	507796	716979	29	71
27	23682	122748	146430	16	84
28	61798	252424	314222	20	80
29	65627	20725	86352	76	24
30	52724	49758	102482	51	49
31	0	445841	445841	0	100

32	0	1257883	1257883	0	100
33	0	210970	210970	0	100
34	24752	138063	162815	15	85
35	2478002	1038761	3516763	70	30
36	747476	1212519	1959995	38	62

Several transformations of the reproducibility have also been computed:

- the reproducibility standard deviation, $\hat{\sigma}_R$ (labelled SDev);
- the reproducibility coefficient of variation (standard deviation divided by the reference area of the parcel, labelled CoefVar);
- the buffer (standard deviation divided by the perimeter of the parcel);
- the standard deviation divided by a constant (labelled HB) depending on the parcel geometry; this constant is the factor which is multiplied by the point position error to give the area error.

The results are given in tables Tab 21 and Tab 22.

Tab 21. Transformations of the reproducibility variance for EROS_1A.

Parcels	SDev	Buffer	CoefVar	Sdev/HB
1	363	1.461	0.106	5.688
2	182	0.463	0.057	1.437
3	634	0.974	0.155	5.121
4	184	0.474	0.022	2.221
5	579	1.114	0.047	3.964
6	803	0.698	0.094	5.173
7	198	0.318	0.008	1.320
8	860	1.209	0.031	7.190
9	526	0.585	0.021	3.711
10	206	0.747	0.050	2.869
11	149	0.397	0.039	1.280
12	252	0.353	0.053	1.620
13	1550	2.839	0.087	12.192
14	961	1.960	0.075	8.576
15	447	0.704	0.041	2.748
16	560	0.589	0.013	2.858
17	786	0.814	0.025	4.245
18	1079	0.878	0.045	6.292
19	257	1.039	0.068	4.153
20	359	0.829	0.104	3.149
21	217	0.289	0.058	1.954
22	273	0.689	0.031	2.894
23	478	0.988	0.054	3.352
24	952	1.168	0.082	4.683
25	1057	1.439	0.031	5.758

26	337	0.384	0.012	2.057
27	1280	1.333	0.049	6.489
28	272	0.791	0.043	2.984
29	117	0.423	0.050	1.996
30	660	1.317	0.153	4.363
31	483	1.025	0.039	3.898
32	1786	3.817	0.171	14.672
33	508	0.505	0.047	3.275
34	642	0.860	0.022	4.779
35	1410	1.337	0.033	8.883
36	1678	1.434	0.041	12.811

Tab 22. Transformations of the reproducibility variance for SPOT_5

Parcels	SDev	Buffer	CoefVar	SDev/HB
1	302	1.216	0.088	4.732
2	193	0.491	0.061	1.525
3	361	0.555	0.089	2.919
4	279	0.718	0.033	3.362
5	368	0.708	0.030	2.518
6	607	0.528	0.071	3.910
7	408	0.655	0.017	2.718
8	1183	1.664	0.042	9.894
9	665	0.741	0.027	4.698
10	497	1.800	0.120	6.917
11	349	0.929	0.090	2.990
12	372	0.521	0.078	2.390
13	1260	2.308	0.071	9.911
14	794	1.620	0.062	7.089
15	193	0.304	0.018	1.187
16	1938	2.038	0.046	9.891
17	1357	1.405	0.044	7.324
18	1932	1.571	0.080	11.262
19	320	1.293	0.084	5.167
20	150	0.346	0.044	1.314
21	301	0.401	0.081	2.711
22	334	0.842	0.038	3.540
23	768	1.589	0.087	5.388
24	1913	2.346	0.164	9.408
25	1495	2.036	0.044	8.145
26	847	0.966	0.031	5.173
27	383	0.399	0.015	1.940
28	561	1.631	0.088	6.153
29	294	1.058	0.126	4.997
30	320	0.638	0.074	2.115

31	668	1.417	0.054	5.390
32	1122	2.396	0.108	9.212
33	459	0.457	0.042	2.963
34	404	0.540	0.014	3.004
35	1875	1.779	0.043	11.817
36	1400	1.196	0.034	10.688

For these four variables, the boxplots are given by types of "size", "shape" and "border". These plots, given in appendix in chapter 7, show that :

- the standard deviation and the ratio standard deviation/HB increase with size;
- the coefficient of variation decreases with size;
- the buffer seems only to be slightly related to size;
- shape has not an important influence;
- border is a important factor.

Generally speaking, the border has an effect on the median and on the variability of all variables, particularly for photo SPOT_5.

Buffer is the transformation for which the results are the least influenced by the characteristics of the parcels. For this reason, buffer is the best parameter for describing variability.

Tables Tab 23 and Tab 24 give the results of several attempts of modelling the buffer.

Tab 23. Modelling buffer for EROS_1A.

All	Buffer = 1.007 (0.704)
Good border	Buffer = 0.859 (0.387)
Bad border	Buffer = 1.155 (0.908)
All	Buffer = 0.912 + 0.000006 Ref_Area (0.710)
Good border	Buffer = 0.781 + 0.000006 Ref_Area (0.394)
Bad border	Buffer = 1.091 + 0.000004 Ref_Area (0.934)

Tab 24. Modelling buffer for SPOT_5.

All	Buffer = 1.142 (0.635)
Good border	Buffer = 0.972 (0.594)
Bad border	Buffer = 1.312 (0.645)
All	Buffer = 0.896 + 0.000016 Ref_Area (0.612)
Good border	Buffer = 0.737 + 0.000017 Ref_Area (0.582)
Bad border	Buffer = 1.097 + 0.000012 Ref_Area (0.640)

The first three lines in these tables give the general mean and the means for parcels with good and bad border. The next lines show regression equations giving the buffer as a function of reference area. The related scatter plots are given in figures (Fig. 37 andFig. 38). For each model the (residual) standard deviation is given in parentheses.

For the two types of photo, the factor "border" is important: buffer is larger for parcels with bad border and the standard deviation is larger for parcels with bad border.

Using the reference area in addition to the factor "border" does not significantly reduce the standard deviation.

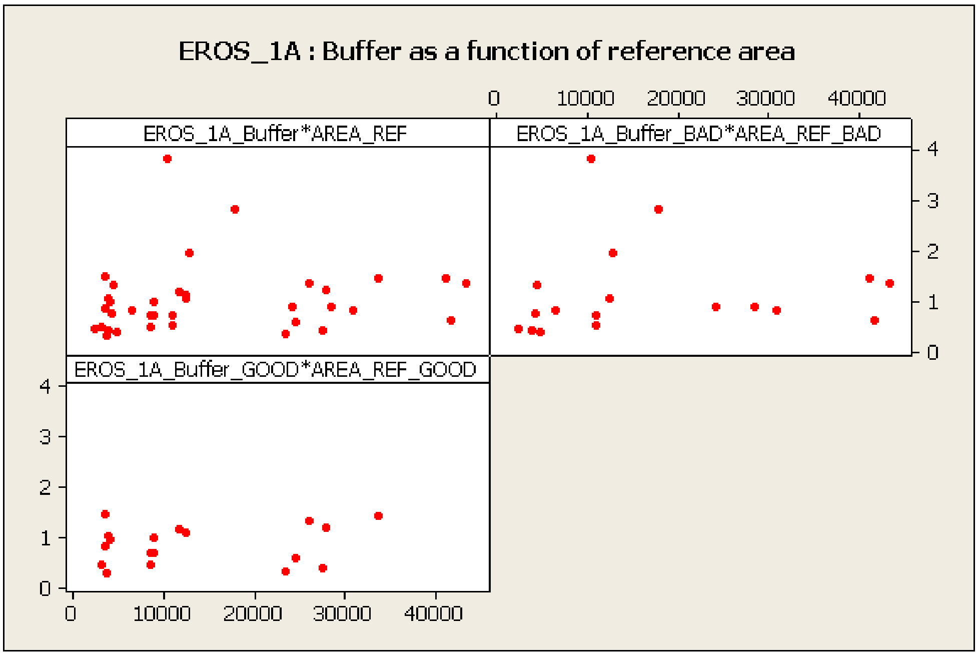


Fig. 37. Buffer as a function of reference area for photo EROS_1A.

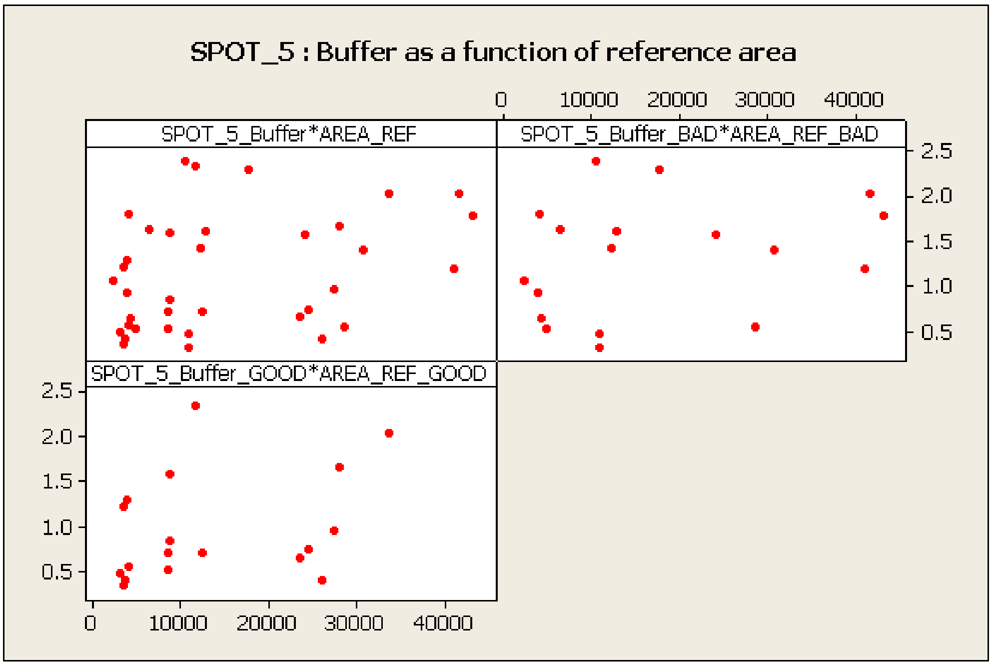


Fig. 38. Buffer as a function of reference area for photo SPOT_5.

4.4.1 Point position error analyse

Apart from buffer point position error were also analyzed. Histograms of point position error from EROS and SPOT were on the figure (Fig. 39) presented. In about 35% cases point position error were between: 2-4 m for both EROS and SPOT. For SPOT also second pick were observed for 8-10m (probably because of border recognition). Point position error increase slightly with area for EROS and SPOT (but the relationship was more significant for SPOT), see figures: Fig. 40 and Fig. 41.

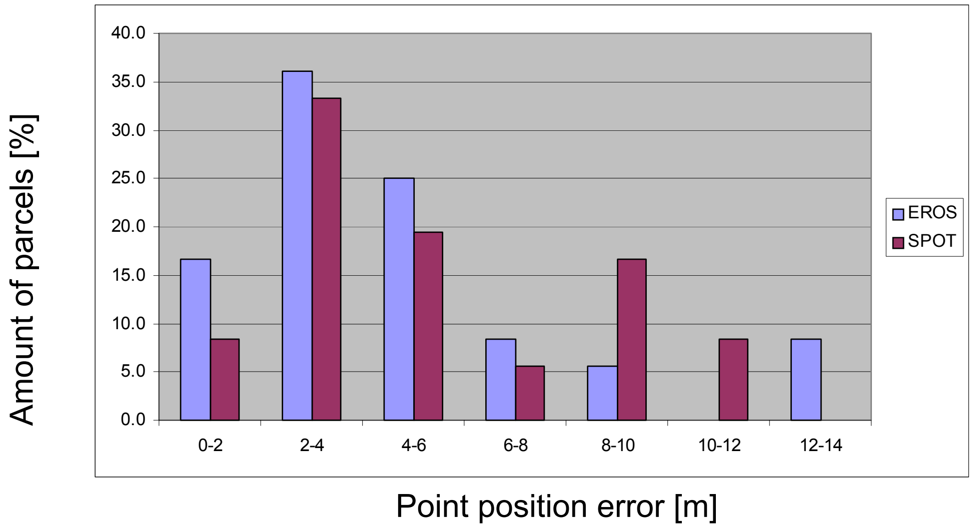


Fig. 39. Point position error analysis

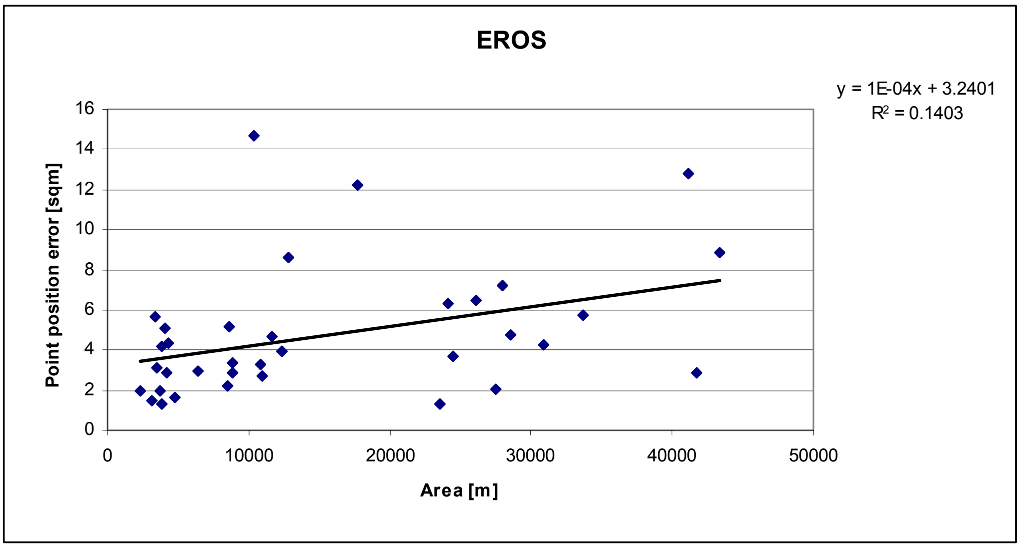


Fig. 40. Relationship between point position error and parcel area (EROS).

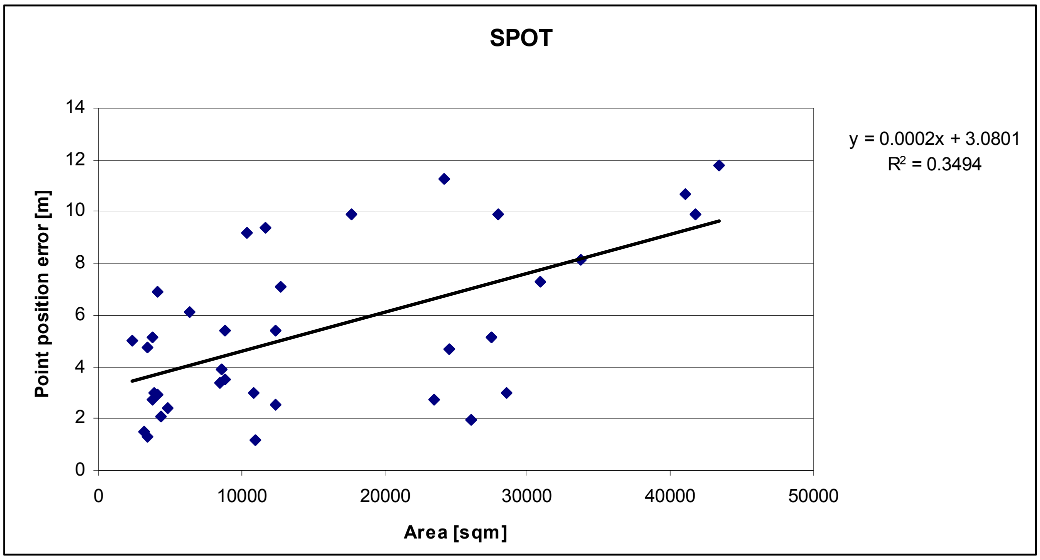


Fig. 41. Relationship between point position error and parcel area (SPOT).

5. Results and discussion

Main and supplementary studies allow analyzing RS data in full spatial resolution range, from VHR until near VHR satellites (0.2m – 2.0 m of pixel size).

On the figure (Fig. 42) buffer for all RS data are shown. There are RMS for each ortho in parentheses. RMS was calculated as 2.5 times of pixel size.

Comparison between point position errors calculated from SDv of parcel area measurements and a'priori assumed values basing on pixel size are on the figure (Fig. 43) possible. We can conclude:

- Errors assumed and obtained from experiments are similar for IKONOS (2.5 m)
- For airborne ortho we underestimated the point position error assuming RMS as 2.5 time pixels size
- For near VHR (EROS and SPOT) we overestimated the point position error assuming RMS as 2.5 time pixels size

Explanation of the underestimation of point position error in the case of airborne ortho might be the influence on the resultant error the parcel edge recognition that shouldn't be neglected.

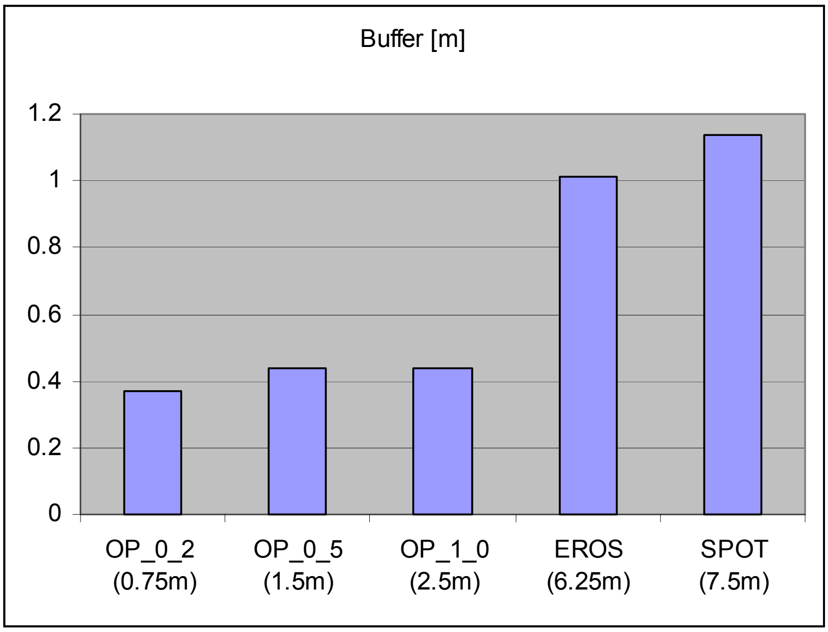


Fig. 42. Buffer for all RS data, in parentheses assumed RMS for ortho

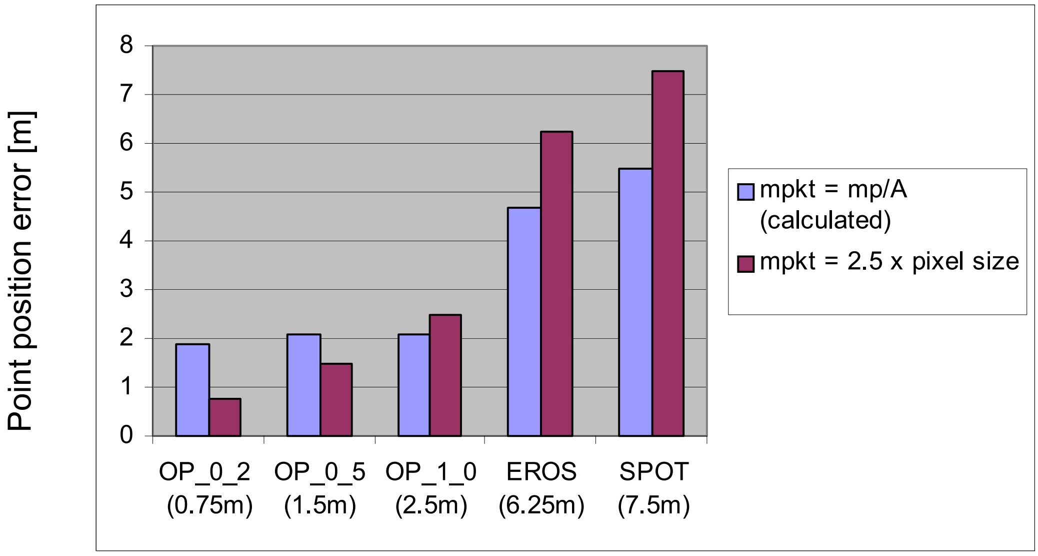


Fig. 43. Point position error for all RS data, in parentheses assumed RMS for ortho

In all cases in RS measurements the following ascertainment are valid:

- the standard deviation and the ratio standard deviation/HB increase with size;
- the coefficient of variation decreases with size;
- the buffer seems only to be slightly related to size;
- shape has not an important influence;
- border is a important factor.

6. Validation method - proposal

According main study and supplementary extension of the research the following could be concluded:

- Parcel area measurements characterize significant variance of parcel area (Tab 25)
- For GPS measurements the pooling factor is the factor day
- For RS measurements the pooling factor is the factor operator
- Parcel size or shape have not an important influence of the estimation of parcel area accuracy basing on buffer or point position error
- Simulation study for remote sensing shows that reducing the number of observations in a given parcel only slightly increases the confidence interval of the buffer.

Tab 25. Standard deviation analyze

instrument	Buffer [m]	SDV [m]	**SDV/buffer [%]**	m_{pkt} [m]	SDv [m]	**SDv/m_{pkt} [%]**
OP_0_2	0.37	0.26	**70**	1.86	1.85	**99**
OP_0_5	0.44	0.25	**57**	2.14	1.39	**65**
OP_1_0	0.44	0.33	**75**	2.12	1.65	**78**
Garmin	0.76	0.32	**42**	21	11	**52**
Satcon	0.34	0.08	**24**	9	3	**33**
Thales	0.52	0.34	**65**	14	10	**71**
EROS	1	0.7	**70**	4.7	3.23	**69**
SPOT	1.14	0.64	**56**	5.4	3.16	**59**

Elaboration of validation procedure for parcel area measurements must take into account “nature” of parcel area measurement, especially distribution of measurement variance. For accuracy estimation buffer and point position error were chosen. Standard deviation of buffer is significant (24 – 75% of the buffer) and even more significant for point position error (33 – 99% of the value of point position error) (see Tab 25 and Fig. 44). In all cases (except EROS) SDv of point position error is greater than SDv of buffer. For RS (except OP_0_2) these two SDvs are similar.

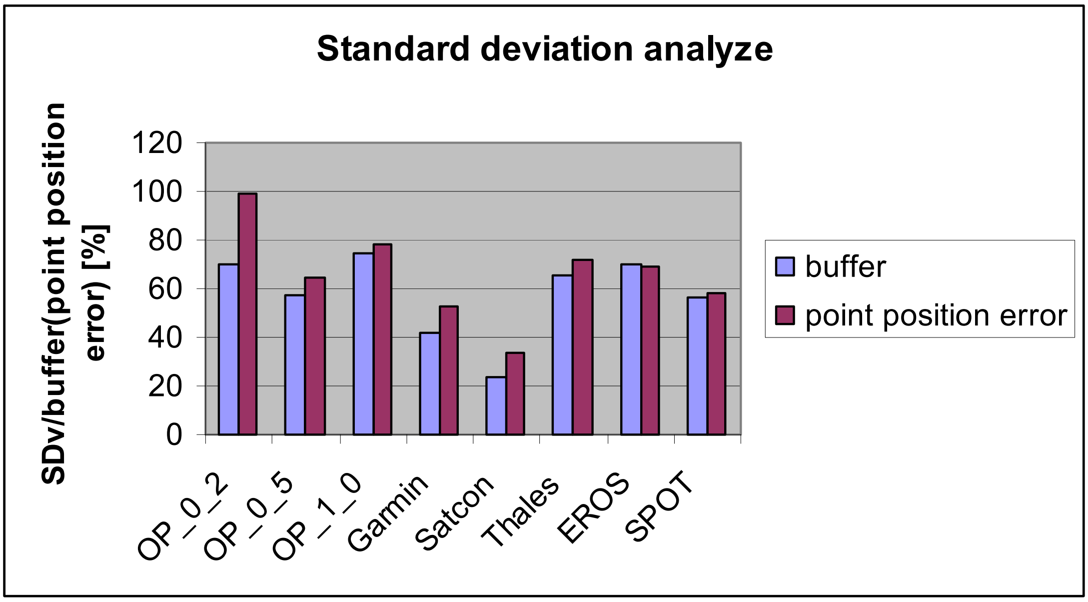


Fig. 44. Standard deviation depending on error estimation method and on the instrument

Simulation in supplementary study for remote sensing shows that reducing the number of observations in a given parcel only slightly increases the confidence interval of the buffer. This result was expected (page 134 of the final report of main). Regarding the number of observations for a given parcel, our suggestion would be for RS 3 or 4 operators x 3 days, for GPS 3 operators x 3 or 4 days. The difference between GPS and RS is that for GPS, the pooling factor is the factor day, but for RS, this pooling factor is the factor operator. It wouldn't be proper reducing more the number of levels for the pooling factor because if there are only two levels (2 days for GPS or 2 operators for photos), and if the observations related to one level are discarded (as it happens) it is no longer possible to compute the "between" variance for the parcel. Concerning the parcels, as already explained, the variability between parcels is large and, consequently, the number of parcels to get a precision of 10 % is large (see table: Tab 26 column N=10). For obtaining precision of 10 %, the number of parcel should be large, regardless of the technical problems with finding the reference parcels.

If it is not possible to find so many reference parcels, one might accept increasing the length of the confidence interval (multiplying length of the confidence interval by a factor 2 allows us to divide the number of parcels by a factor 4).

Finally in both methods 3 operators and 3 measurement days are proposed. It means that each parcel is measured 9 times. Basing on the mentioned above statements the two variants of validation method are proposed. The difference between RS and GPS is amount of the parcels.

Tab 26. Number of PARCELS needed to get a precision of 10 % for the actual number of observations (N = 36), for 10 observations, for 4 observations and for 1 observation per parcel (Tab 60 from final report - main study).

Method	N	N = 10	N = 4	N = 1
OP_0_2_ALL	202	217	247	397
OP_0_2_GOOD	48	62	92	242
OP_0_2_BAD	192	206	236	386
OP_0_5_ALL	125	140	170	320
OP_0_5_GOOD	180	194	224	374
OP_0_5_BAD	82	96	126	276
OP_1_0_ALL	219	234	264	414
OP_1_0_GOOD	62	77	107	257
OP_1_0_BAD	225	240	270	420
G_ALL/A	71	86	116	266
G_GOOD/A	63	78	108	258
G_BAD/A	87	101	131	281
S_ALL/A	22	37	67	217
S_GOOD/A	14	29	59	209
S_BAD/A	20	35	65	215
T_ALL/A	171	185	215	365
T_GOOD/A	31	45	75	225
T_BAD/A	120	135	165	315
S3_ALL/B	29	41	71	221
S3_GOOD/B	8	20	50	200
S3_BAD/B	34	46	76	226
S4_ALL/B	41	53	83	233
S4_GOOD/B	42	53	83	233
S4_BAD/B	39	50	80	230
T3_ALL/B	94	106	136	286
T3_GOOD/B	59	71	101	251
T3_BAD/B	47	59	89	239
T4_ALL/B	67	79	109	259
T4_GOOD/B	25	36	66	216
T4_BAD/B	54	66	96	246
Average all	**82**	**95**	**125**	**276**
Average RS	**148**	**163**	**193**	**343**
Average GPS	**54**	**67**	**97**	**247**
4 time less (all)	**21**	**24**	**31**	**69**
RS	**37**	**41**	**48**	**86**
GPS	**14**	**17**	**24**	**62**

Validation method assuming precision of 10%

Precision 10% needs many parcels:

- Average about 100 (95 for N=10 Tab 26)
- For RS about 163
- For GPS about 67

Validation method assuming precision of 20%

Precision 20% needs limited parcels sets:

- Average about 25 (24 for N=10 Tab 26)
- For RS about 41
- For GPS about 17

Taking into account real measurements conditions we propose for RS measurements: 30-40 parcels and for GPS: 15 parcels. Note that planning parcel sets is easer in compare to the experiments in the study, because the size and shape are not important factors.

Tab 27. Validation procedure

Instrument	No of parcels	No of repetitions (how many time is one parcel measured)	No of operators	No of days
RS	30-40	9	3	3
GPS	18-20	9	3	3

The validation procedure was proposed in main study and should be like in following diagram.

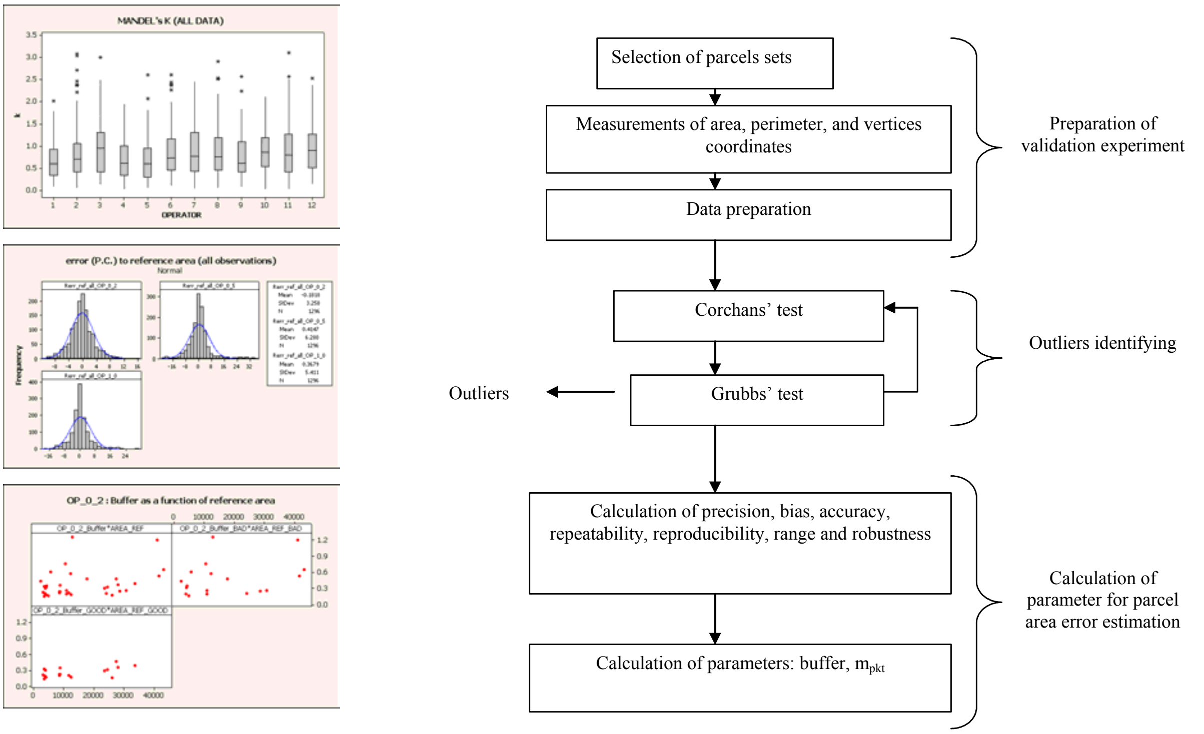


Fig. 45. Validation procedure schema

7. Appendix – statistic analysis

7.1 List of discarded observations for remote sensing data. Explanation of the codes used in column COCHRAN's, GRUBBS/1 and GRUBBS/2 is given in part 1.4.3 of the previous report.

Row	Parcel	Photo	Operator	Data	Cochran	Grubbs1	Grubbs2
1	1	EROS_1A	3	6842.6	2	0	0
2	1	EROS_1A	3	3719.3	2	0	0
3	1	EROS_1A	3	4102.6	2	0	0
4	7	EROS_1A	1	23216.9	2	0	0
5	7	EROS_1A	1	23996.7	2	0	0
6	7	EROS_1A	1	24326.5	2	0	0
7	8	EROS_1A	2	28101.6	2	0	0
8	8	EROS_1A	2	29554.6	2	0	0
9	8	EROS_1A	2	32389.6	2	0	0
10	15	EROS_1A	4	6384.7	2	0	0
11	15	EROS_1A	4	10537.1	2	0	0
12	15	EROS_1A	4	10156.2	2	0	0
13	16	EROS_1A	5	41906.9	2	0	0
14	16	EROS_1A	5	38398.1	2	0	0
15	16	EROS_1A	5	29160.4	2	0	0
16	17	EROS_1A	6	26773.6	1	10	0
17	17	EROS_1A	6	22257.4	1	10	0
18	17	EROS_1A	6	27406.3	1	10	0
19	21	EROS_1A	6	5277.8	2	0	0
20	21	EROS_1A	6	3991.7	2	0	0
21	21	EROS_1A	6	4291.9	2	0	0
22	22	EROS_1A	1	8706.2	2	0	0
23	22	EROS_1A	1	4054.6	2	0	0
24	22	EROS_1A	1	8532.5	2	0	0
25	25	EROS_1A	2	35691.3	2	0	0
26	25	EROS_1A	2	33655.9	2	0	0
27	25	EROS_1A	2	57069.8	2	0	0
28	29	EROS_1A	4	3386.0	1	10	0
29	29	EROS_1A	4	2867.1	1	10	0
30	29	EROS_1A	4	2748.7	1	10	0
31	32	EROS_1A	5	12563.5	2	0	0
32	32	EROS_1A	5	14374.6	2	0	0
33	32	EROS_1A	5	7331.2	2	0	0
34	33	EROS_1A	6	14438.8	2	0	0
35	33	EROS_1A	6	11178.3	2	0	0
36	33	EROS_1A	6	10386.0	2	0	0
37	15	SPOT_5	4	8356.2	0	0	10
38	15	SPOT_5	4	10763.7	0	0	10
39	15	SPOT_5	4	10763.3	0	0	10
40	15	SPOT_5	6	10770.7	0	0	10
41	15	SPOT_5	6	8336.2	0	0	10
42	15	SPOT_5	6	8071.6	0	0	10
43	16	SPOT_5	5	29197.0	0	10	0

44	16	SPOT_5	5	29749.6	0	10	0
45	16	SPOT_5	5	37861.1	0	10	0
46	18	SPOT_5	3	42986.2	2	0	0
47	18	SPOT_5	3	30359.9	2	0	0
48	18	SPOT_5	3	27195.3	2	0	0
49	19	SPOT_5	4	6318.9	2	0	0
50	19	SPOT_5	4	4138.8	2	0	0
51	19	SPOT_5	4	3606.3	2	0	0
52	22	SPOT_5	1	11912.9	2	0	0
53	22	SPOT_5	1	9434.1	2	0	0
54	22	SPOT_5	1	9348.8	2	0	0
55	26	SPOT_5	4	32258.3	2	0	0
56	26	SPOT_5	4	25011.7	2	0	0
57	26	SPOT_5	4	25336.8	2	0	0
58	30	SPOT_5	6	5729.3	2	0	0
59	30	SPOT_5	6	4321.2	2	0	0
60	30	SPOT_5	6	4195.3	2	0	0
61	31	SPOT_5	4	29749.9	2	0	0
62	31	SPOT_5	4	12903.8	2	0	0
63	31	SPOT_5	4	12584.7	2	0	0
64	33	SPOT_5	3	12128.2	2	0	0
65	33	SPOT_5	3	11909.0	2	0	0
66	33	SPOT_5	3	7026.5	2	0	0
67	34	SPOT_5	6	29391.6	2	0	0
68	34	SPOT_5	6	30587.4	2	0	0
69	34	SPOT_5	6	27409.8	2	0	0

7.2 Boxplots of four transformations of the reproducibility as a function of size, shape and border for EROS_1A and for SPOT_5

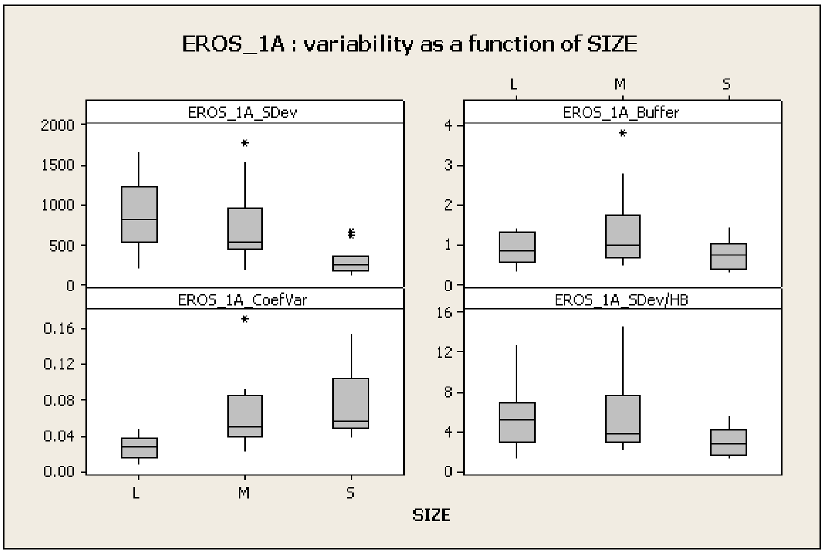


Fig. 46. EROS_1A (size)

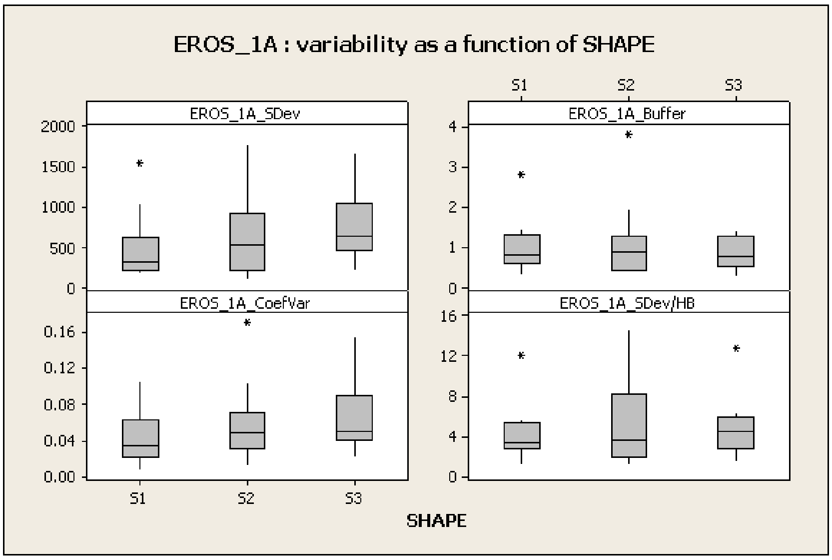


Fig. 47. EROS_1A (shape)

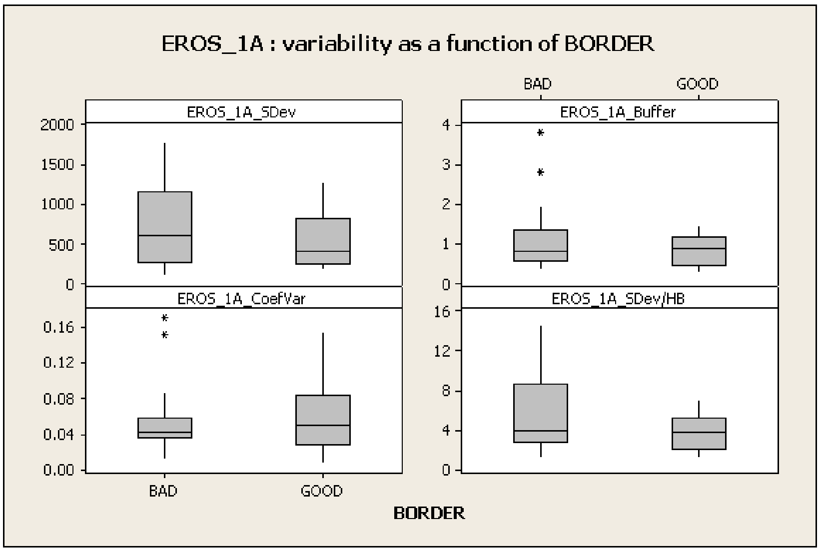


Fig. 48. EROS_1A (border)

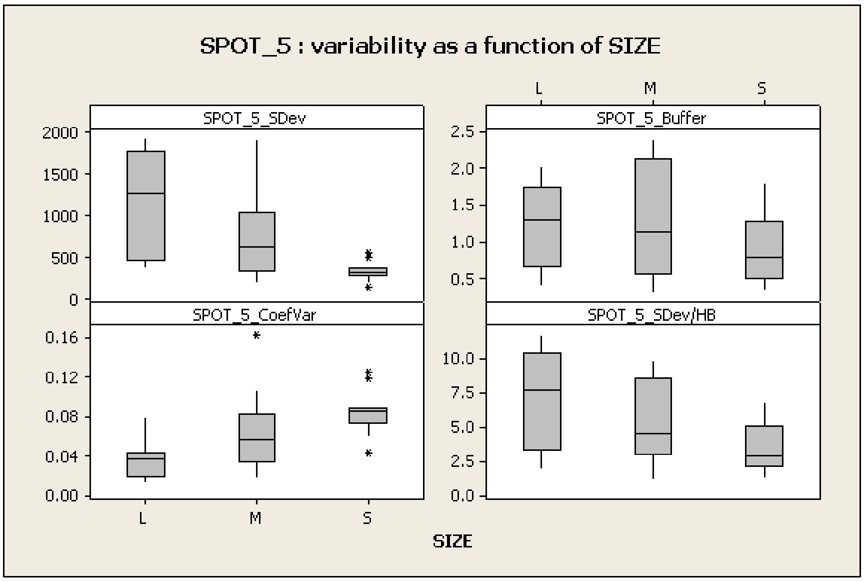


Fig. 49. SPOT (size)

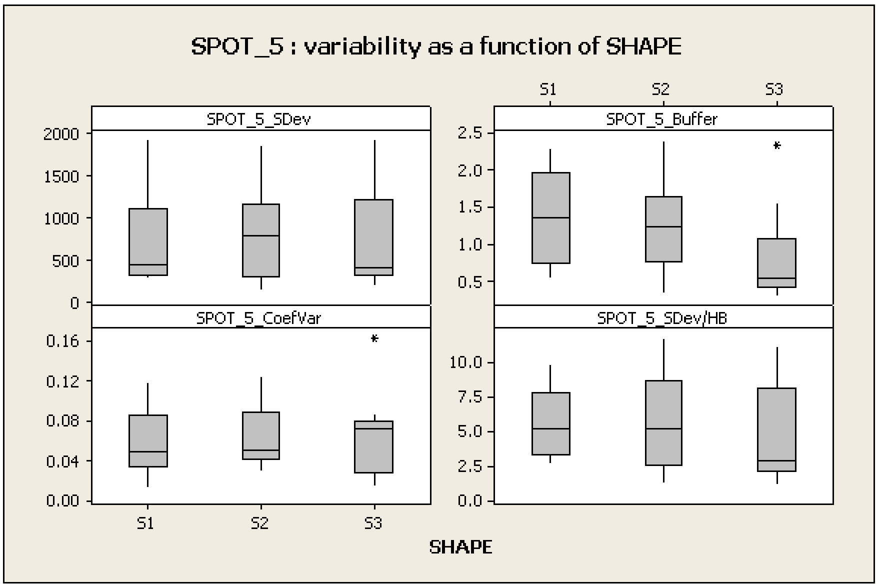


Fig. 50. SPOT (shape)

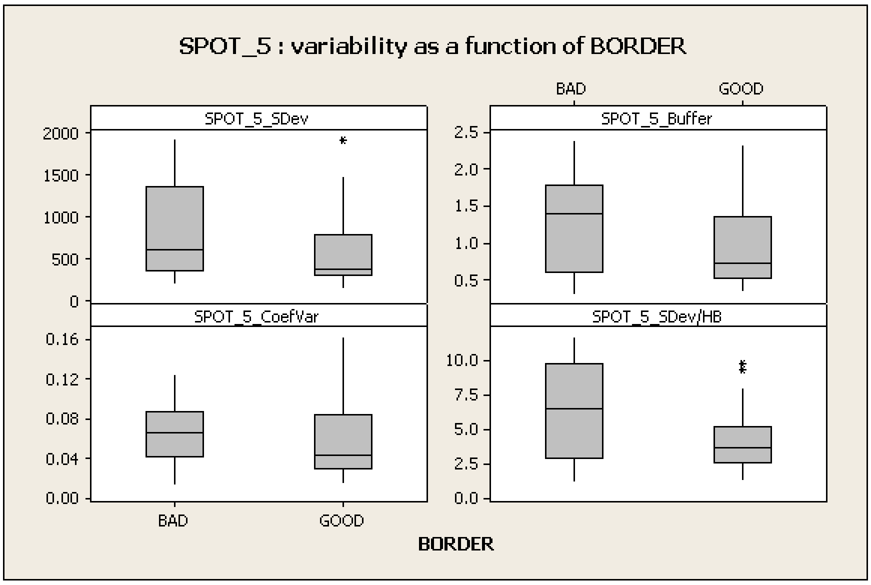


Fig. 51. SPOT (border)