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Validation of methods for measurement of land parcel areas

FINAL REPORT

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Content

1. Introduction

Aim of the project was elaboration of validation methods for measurement of land parcels areas. 2 measurement experiments were performed in the project: remote sensing (RS) and GPS. RS experiment was made at AGH - UST Kraków, and GPS at UWM Olsztyn. The experiment was prepared and statistical analyzed at USI Gembleux. We had three meetings during the project's duration: two in AGH -UST Kraków and one at UWM Olsztyn. The following persons took part in all meetings: B.Hejmanowska, S.Oszczak, R.Palm, A.Ciećko and S.Kay. During the meeting in Olsztyn we visited two GPS test sites.

Report is composed of 10 chapters and Appendix. In chapter 2 made a review of existing approaches and discuss the Polish experience in the possibility of adapting cadastre regulations.

Chapters 3, 4, 5 and 6 include description of experimental design, workflow of measurements and statistical data analyze.

In chapter 7 results of RS and GPS experiment are presented.

Discussion about the point position error as an area accuracy parameter is in chapter 8 presented.

Assessment of parcel area error prediction basing on point position error can be found in chapter 8.4.

In chapter 9 proposal of validation method for measurements of land parcel area is daftly presented, describing some accruing problems.

Detailed statistical data are annexed in the appendix.

Other electronic data are attached to the report (data base of RS and GPS measurements).

2. Review of existing approaches to validation of measurement methods

2.1 Review of approaches in IACS (JRC)

The following information are extracted from: “Technical tolerances for On the Spot checks”

Technical tolerance is applied to estimation available difference between the declared and measured land parcel area. Tolerance may be defined by buffer or percentage of measured area on 95% probability level. Buffer is the empiricaly found value multiplied by parcel perimeter to obtain possible discrepancies between parcel area measured and declared by farmer.

Tab 1. Area measurement tolerance for maps and ortophotomaps

Map scale	Pixel size [m]	Tolerance [%]	Tolerance [m]
1: 10 000	1	5	1.5
1: 5 000	0.5	2.5	0.75
1: 2 500	0.25	1.25	0.4

Tab 2. Area measurement tolerance for direct measurements

Map scale	Tolerance [%]	Tolerance [m]
GPS standalone	-	1.25
Geodetic surveying	2	0.35
Wheel, tape	2 (up to 50m) or 5	0.4

Remote sensing control: “measurement tolerance of any parcel may not exceed either 5% of the parcel area or perimeter buffer of 1.5m”.

The following information is extracted from “On-the-spot checks of area according to articles 15-23 of Commission regulation (ec) no 419/2001”.

“According to Article 22 of Regulation 2419/2001, agricultural parcel areas shall be determined by any appropriate means defined by the competent authority which ensure measurement of a precision at least equivalent to that required for official measurements under the national rules. Furthermore, the competent authority shall set a tolerance margin taking account of the measuring method used, the accuracy of the official documents available, local factors such as slope and shape of parcel”.

- The method of measurement should be adapted to the expected agricultural parcel size in the region concerned. The technical tolerance in relation to each declared parcel should not exceed 5% of the agricultural parcel area measured. Alternatively, a technical tolerance based on a perimeter buffer of up to 1,5 m may be used.

- Instead of the 5 % or 1,5 m buffer described above, an absolute tolerance of 0,02 ha may be applied to take account of errors in rounding.
- The maximum technical tolerance for each agricultural parcel measured should not exceed in absolute terms 1.0 ha.
- For preliminary measurements on LPIS documents, the area measured should not exceed the official area (land registry, LPIS reference areas).

According to Article 18(3) of Regulation 2419/2001, the extent and scope of the sample shall be extended appropriately if the checks on the initial sample cases reveal irregularities. The Commission services take the view that the following should, in general, be considered as being appropriate:

- if an over-declaration of more than 3% of the area is determined in the measurement of the sampled agricultural parcels for a specific crop group, the sample should be extended to include all the remaining parcels of the crop group concerned.
- if an over-declaration of more than 30% of the overall area is determined in the measurement of the sampled agricultural parcels, the sample shall be extended to include all the remaining parcels of the aid application concerned.

2.2 Validation of GPS measurements - JRC approach

Proposal of validation GPS measurements was presented in JRC document [Kay S., Spruyt P. 2002]. Availability of cheep GPS instruments for rapid area measurements and lack of methods of their accuracy assessments was the main motivation for elaboration the background of validation procedure. The statistical framework for the validation of measurement methods was laid out in ISO-5725, usually applied in chemical measurements and in surveying not used as yet. Series parameters from ISO-5725 have been adapted to the statistical analysis of area measurements: precision, bias, accuracy, repeatability, reproducibility, range and robustness.

Validation procedure was proposed as a preliminary testing for determining the basic suitability of the instrument and wider scale validation phase. Phase 1 is proposed to run in JRC and phase 2 in several Member States countries. Experiment design includes: 1 parcel (ex. football field), 2-6repetitions in short time, 8-10 independent measurements (ex. days). Experimental design in phase 2 is similar to phase1 but reference parcel might be modified according local purposes.

Workflow of validation procedure: preparation, operator training, protocols, instrument preparation, data analysis and evaluation of the results are in the document described.

2.3 Validation of GPS measurements - UWM approach

In 2004 at UWM the following project was performed: "Assessment and development of selection criteria for GPS measurement methods and equipment to ensure required accuracy and reliability of area-bases subsidies control in IACS system" [Oszczak S et. al. 2004]. The main goal of the work was to perform necessary practical tests in order to select appropriate

GPS equipment and methods of parcel area measurement. Five different GPS receivers were tested in detail during the experiments. The test field consisted of 5 parcels with various shape, area and obstructions of celestial sphere. The reference areas were determined with the use of precise electronic tachymeter.

Due to the very short period of implementation of the project the tests lasted only for 8 days in unfavorable weather conditions. Everyday each of the parcels was measured twice with each of the receiver. It gave us 16 independent measurements for the pair of each parcel and each receiver.

The obtained results were quite promising, confirming that the GPS technique can be widely used in the IACS system. However, according the project, it must be emphasized that for precise and reliable measurement - DGPS real-time method should be used, either using DGPS corrections from reference station (via GPRS platform) or at least using EGNOS corrections. The selection of DGPS method is especially important for the re-checks procedure where the inspector should use precise GPS equipment with reliable technique of measurement.

2.4 Review of approaches in cadastre (Poland)

2.4.1 Technical specification

Accuracy of cadastre parcel measurement is described by technical regulation [G5, 2003], technical guidelines [G 5.4, 1992] and publication [Maps for law tasks, splitting and merging of real estate, 1993]:

(1) $$\Delta P = 0.001 \cdot P + 0.2 \cdot \sqrt{P})$$

(2) $$\Delta P = 0.4 \cdot \sqrt{2P} \cdot \sqrt{\frac{1+K^2}{2K}}$$

(3) $$\Delta P = 0.001 \cdot P + 0.0002 \cdot M \cdot \sqrt{P})$$

(4) $$\Delta P = 2 \cdot (0.002 \cdot P + 0.2 \cdot \sqrt{P})$$

where:

ΔP – allowed discrepancies between area in cadastre and area measured in control measurement [m^2],

P – land parcel area [m^2].

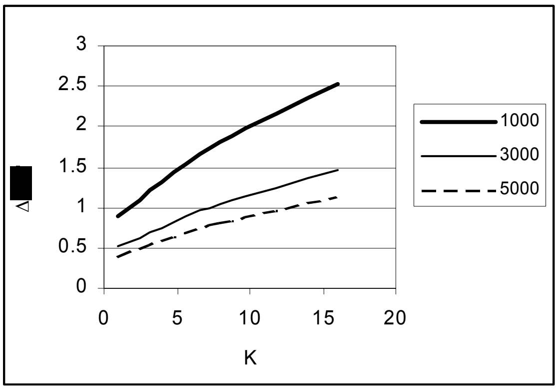


Fig. 1. Relationship between ΔP/P and elongation factor (K) for area: 1000, 3000, 5000 m^2 [%]) – formula(2)

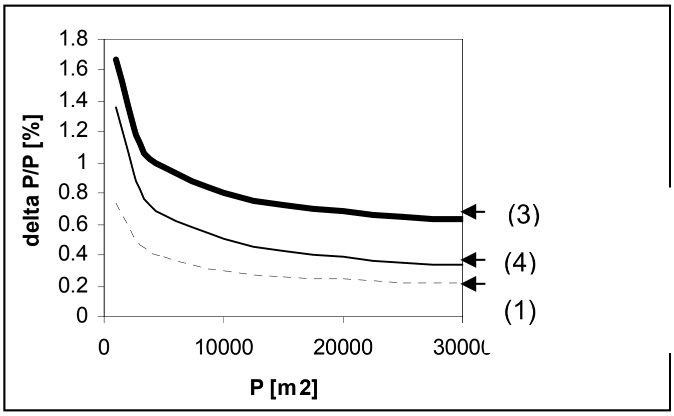


Fig. 2. Relationship between ΔP/P and elongation factor (K) for area: 1000, 3000, 5000 m^2 [%] – formula: (1), (3), (4)

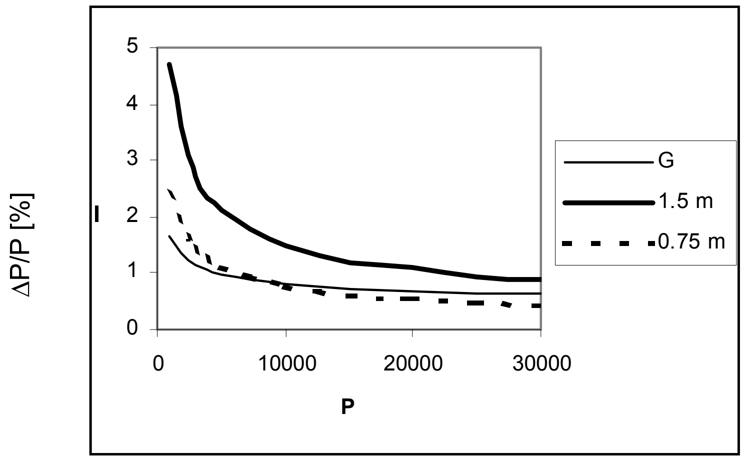


Fig. 3. Relationship between the relative area discrepancies (ΔP/P) and area(P); G – formula (3) and Gauss formula assuming m_{pkt} = 1.5m and 0.75m

Let us input to formula (1) parcel area of 0.1 ha. We obtained allowed area discrepancy of 7.3 m^2. If we apply inversely formula from Gauss (5) (invert to formula: (25) in chapter 5.3.1) we obtained point position error m_{pkt} = +/- 0.1m. It is not possible to measure land parcel area without stones.

(5) $$m_{pkt} = 2\sqrt{2}m_p \sqrt{\sum_{i=1}^{n} \frac{1}{(y_{i+1} - y_{i-1})^2 + (x_{i-1} - x_{i+1})^2}}$$

Usually, regulations applied in surveying, concern the case that we have stones on the parcel edges. Therefore the accuracy limits for surveying are very rigor and couldn't be adapted in IACS control procedure.

2.5 Parameter describing area accuracy

The following parameters are applied to the area accuracy estimation:

- Buffer width (value obtaining empirically) - method used in IACS
- Relative area error (difference between area measured in control procedure and area declared divided by measured area; value assumed arbitrary) - method used in IACS
- Allowed discrepancy between area measured and existing in data base or on the map (empirical formula, ex. (1))– method used in cadastre

Alternative approach bases of physical source of area errors: point position error. Test works were performed and provided promising results, [Hejmanowska B. 2003, Bogaert P., Delinc´e J., Kay S. 2005].

Background of the method is calculation of the parcel area from coordinates: Cartesian (x,y) or polar (R, α), (Fig. 4).

Parcel area on the basis of Cartesian coordinates can be calculated from the Gauss formula:

(6) $$P = \frac{1}{2}\sum_{i=1}^{n} x_i (y_{i+1} - y_{i-1})$$

where:

P – polygon area,

x_i, y_i – coordinate of polygon vertices,

n – numbers of vertices.

Parcel area on the basis of polar coordinates can be calculated from the formula:

(7) $$S = \left(\sum_{i=1}^{n-1} S_{i,i+1}\right) + S_{n,1}$$

where:

- S – polygon area
- $S_{i,i+1}=0.5R_iR_{i+1}\sin(A_{i+1}-A_i)$
- $S_{n,1}=0.5R_nR_1\sin(A_1-A_n)$

- R- radius
- A azumuth
- numbers of vertices

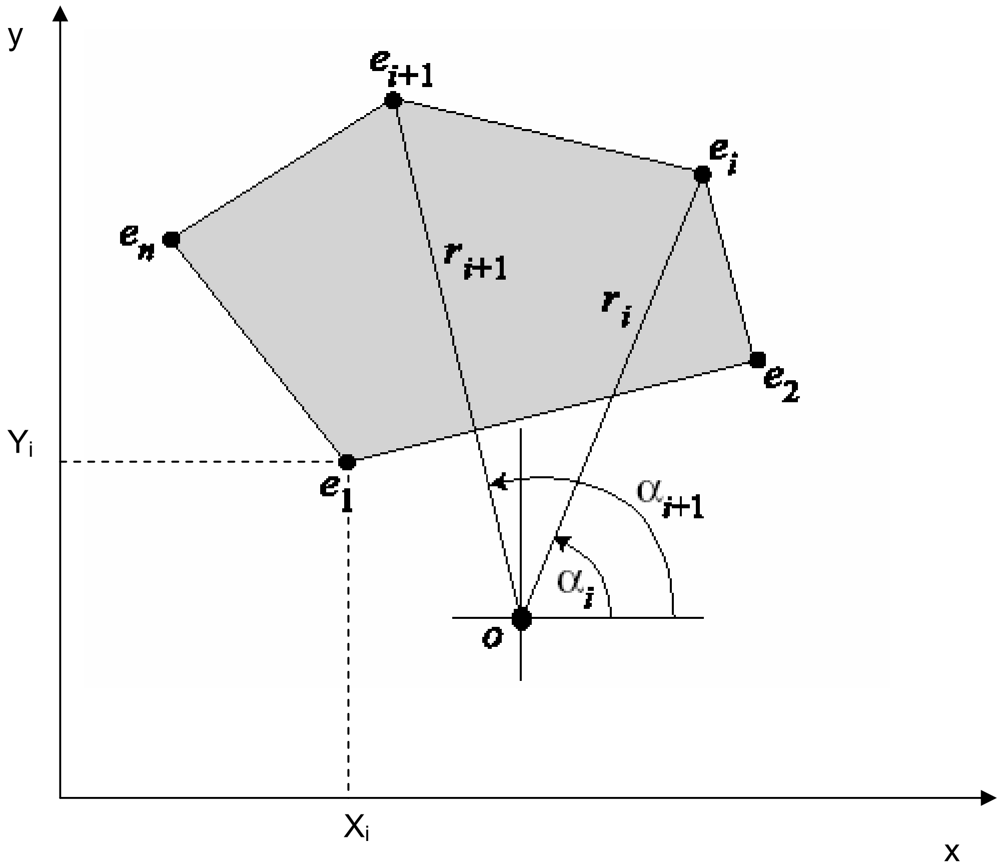


Fig. 4. Parcel area as a polygon defined by coordinates of vertices: Cartesian coordinates (x,y), or polar coordinates (R, α)

Analyzing above formula for parcel area calculation assuming point position error allows us to provide the formulas for area error calculations:(25) and (26).

In the project both parameters: buffer and point position error were tested. Relative area error was also calculated for final results evaluation.

3. Steps in the statistical analysis of a precision experiment

3.1 Introduction

ISO 5725-2 gives the "basic method for the determination of repeatability and reproducibility of a standard measurement method". It is typically designed for interlaboratory experiments in order to estimate repeatability and reproducibility of measurement methods for chemical contents for example. But it can also be used for other purposes.

Hereafter we explain how we propose to analyze the data collected through an experiment for validation of methods for measurement of land parcel areas with respect to the standard norm.

First of all, we present the typical experimental design and the principles of statistical data analysis used for the estimation of repeatability and reproducibility (part 3.2), then we give a short description of the statistical tools used in order to identify and treat outliers or other irregularities in the data (part 3.3), and we explain how these tools are used in a step-by-step procedure (part 3.4).

Robustness of the measurements method was estimated analyzing additional information from the field about the difficulties accruing during the GPS measurements and on the basis of numbers of outliers for given receiver. For RS measurements robustness was only estimated analyzing outliers.

3.2 Layout of the precision experiment and overview of statistical analysis

3.2.1 Layout of the experiment

In a typical basic interlaboratory experiment, samples from q batches of materials representing q different levels of the content to be measured are sent to p laboratories which each obtain n replicate results under repeatability conditions at each of the q levels.

For a given method of area measurement (GPS device, orthophoto), several land parcels are measured on different days by different operators.

3.2.2 Critical examination of the results

In a typical interlaboratory experiment, critical examination of the data is based on a "pooling factor": the observations are grouped according to this factor and the mean and the standard deviation within a given group is compared to the means and the standard deviations within the other group. The statistical tools used for critical examination of the data are described in part 3.4.

In typical interlaboratory experiments, the pooling factor is the factor "laboratory" because in each laboratory replicated results are obtained under repeatability conditions.

In the experiment for validation of method for measurement of land parcels areas described in part 4, we have two factors: the factor day and the factor operator. The question is: which factor should be considered for pooling the data ?

The answer to this question depends on the method of measurements. For remote sensing methods, we expect that the factor "day" does not have an important effect on the results and measurements made by an operator on several days can be considered as made under repeatability conditions. As a consequence, the data should be pooled by operators. On the other hand, for GPS measurements, we expect the factor "day" to be a more important source of variation than the factor operator. So we consider that measurements made the same day by several operators are measurements made under repeatability conditions and the data are pooled by days.

3.2.3 Variance components, repeatability and reproducibility

As explained in part 1.2.2, the observations for a given parcel are allocated in groups according to a pooling factor which is the factor "day" for GPS observations and the factor "operator" for remote sensing data.

A one-way analysis of variance (random model) is performed on each column which contents the observations made on a given land parcel. This analysis of variance gives the mean square value between groups MS_{group} and the mean square within groups, MS_r The mean square within groups is an estimation of the between replicates variance $\hat{\sigma}_r^2$:

(8)
$$\hat{\sigma}_r^2 = MS_r \, .$$

and the between groups variance between groups $\hat{\sigma}_{group}^2$ is given by the equation :

(9)
$$\hat{\sigma}_{group}^2 = \frac{MS_{group} - MS_r}{n} \, .$$

It may happen that the number of replicates varies from one group to another due to technical problems or because of discarding some results considered as outliers when using statistical tests are used (see point 3.4). So the experimental design is no longer a balanced uniform-level experiment. In this case, the value of n in formula (9) should be replaced by n':

(10) $$n' = \left(n_{.}^{2} - \sum_{i=1}^{p} n_{i}^{2} \right) \left[n_{.} \, (p-1) \right].$$

In this formula, n_i is the number of replicates for level i (i = 1, , p) of the pooling factor and $n_.$ is the total number of results for the land parcel:

(11) $$n_{.} = \sum_{i=1}^{p} n_{i} \, .$$

Should MS_{group} be smaller than MS_r, formula (9) would give a negative value for the between groups variance. In this case, the between groups variance is set to zero.

The variance components are related to the repeatability variance and reproducibility variance: the repeatability variance is the between replicates variance and the reproducibility variance is the sum of the between groups variance and the within groups variance:

(12) $$\hat{\sigma}_{R}^{2} = \hat{\sigma}_{group}^{2} + \hat{\sigma}_{r}^{2} \, .$$

3.2.4 Establishing a functional relationship between precision values and the characteristics of the parcels

When analysing data from interlaboratory, the repeatability and reproducibility variance sometimes vary with the mean level of content. If so, the relationship should be determined. This can be done by fitting regression equations, for example a straight line or an exponential relationship.

For the land parcel measurement methods, the values of repeatability and reproducibility are expected to vary from one parcel to another, due to the characteristics of the parcels. The relation between precision and size, shape or environmental conditions should be analyzed by means of statistical tools: plots and summaries, analysis of variance or regression.

The analysis should be performed not only on repeatability and reproducibility standard deviations but also on transformations of these values: standard deviation divided by the perimeter of the parcel, standard deviation divided by the true area error (obtained by Gauss formula assuming a given error on vertices measurements).

3.3 Statistical tools for critical examination of the data

3.3.1 Preliminary considerations

The first stage of the analysis of the data is the critical examination of the data in order to identify and treat outliers or other irregularities and to test the suitability of the model.

Outliers are original data or derived data that deviate so much from the comparable data that they are considered irreconcilable with the other data. They are taken into consideration in a similar way to the treatment of missing data.

To apply ISO 5725-2 for detection of outliers, the observations are pooled into groups according a pooling factor. In a typical interlaboratory experiment, this pooling factor is the factor "laboratory". As explained in par 3.2.3, we propose to consider the factor "operator" for remote sensing observations and the factor "days" for GPS observations as the pooling factor.

When several unexplained abnormal results occur at different land parcels for the same level of the pooling factor level then this level of the pooling factor may be considered to be an outlier having too high value a within variance (between replicates) and/or to large a systematic error in the level of its measurement results. It may be reasonable to discard some or all of the data from such an outlying level of the pooling factor.

Several statistical tools are used in order to identify outliers and outlying levels of the pooling factor. These tools are described hereafter (points 3.3.2, 3.3.3, 3.3.4) and the way they are used in the step-by-step procedure of statistical analysis is given in point 3.4.

3.3.2 Mandel's h and k statistics

For a given land parcel, the statistics h and k are computed for each level of the pooling factor. The between-group consistency statistic, h, is given by the following formula:

(13)
$$h_i = \left(\bar{y}_i - \bar{\bar{y}}\right) \Big/ \left[\sum_{i=1}^{p} \left(\bar{y}_i - \bar{\bar{y}}\right)^2 \Big/ (p-1) \right].$$

In this formula p is the number of levels of the pooling factor, $\bar{y}_i$ is the mean value for level i of the pooling factor and $\bar{\bar{y}}$ is the grand mean for the parcel:

(14)
$$\bar{y}_i = \frac{1}{n_i} \sum_{k=1}^{n_i} y_{ik} \quad \text{and} \quad \bar{\bar{y}} = \frac{1}{n_.} \sum_{k=1}^{p} \sum_{i=1}^{n_i} y_{ik}.$$

For level i, h_i is a measurement of the standardized distance of the mean value observed for the level from the general mean.

The within-group consistency statistic, k compares the within standard deviation for level i to the mean value of the within standard deviation of each level:

(15)
$$k_i = \sqrt{\frac{\hat{\sigma}_i^2}{\tilde{\sigma}^2}}.$$

where $\hat{\sigma}_i^2$ is the within variance for level i and $\tilde{\sigma}^2$ is the arithmetic mean of all within variances:

(16) $$\hat{\sigma}_i^2 = \sum_{k=1}^{n_i} (y_{ik} - \bar{y}_i)^2 / (n_i - 1)$$

and

(17) $$\tilde{\sigma}^2 = \frac{1}{p} \sum_{i=1}^{p} \hat{\sigma}_i^2 .$$

If all levels have a constant number of replicates ($n_i = n$ for all i), then $\tilde{\sigma}^2$ is the repeatability variance.

Statistics h and k are calculated for each parcel (k = 1, …, q) and therefore noted h_{ij} and k_{ij}. These statistics are then plot, in order of the level of the pooling factor, in groups for each parcel. Lines are drawn on the h and k plots. Theses lines correspond to critical values (at 1 % level and at 5 % level), given in X [2000].

Examination of h and k plots may indicate that specific levels of the pooling factor exhibit patterns of results that are markedly different from the others in the study. This is indicated by consistently high or low between replicates variation and/or extreme mean values for a given level across many parcels. Notice that ISO 5725-2 does not provide a statistical test by which suspected operators may be judged. The h and k plots are only a graphical consistency technique. The decision of discarding a level is left to the statistical expert.

3.3.3 Cochran's test

The COCHRAN's test is designed to check if it can be assumed that the variances between replicates are equal for each level of the pooling factor in a given land parcel.

Let $\hat{\sigma}_1^2, \ldots, \hat{\sigma}_p^2$ be the variances between replicates for level i in a given land parcel and $\hat{\sigma}_{max}^2$ the largest variance. The Cochran's test statistics C is:

(18) $$C = \hat{\sigma}_{max}^2 \Big/ \sum_{i=1}^{p} \hat{\sigma}_i^2 .$$

If the test statistic C is less than or equal to its 5 % critical value, the item tested is accepted as correct.

If the test statistic is greater than its 5 % critical value, but smaller than or equal to its 1 % critical value, then the item tested is called a straggler and is indicated by a single asterisk. If the test statistic is greater than its 1 % critical value, the item tested is called a statistical outlier and is indicated by a double asterisk. The critical values are given in X [2000].

Cochran's criterion applies strictly only when all the variances are derived from the same number of replicates ($n_i = n$). In actual cases, this number may vary due to missing or discarded data. If the variation in the number of replicates is limited it can be ignored and Cochran's criterion is applied using for n the number of replicates occurring for the majority of operators.

3.3.4 Grubbs' test for one outlying observation

Given a set of n data arranged in ascending order $x_{[1]}, x_{[2]} \ldots, x_{[n]}$ with mean $\overline{x}$ and standard deviation $\hat{\sigma}$. Let :

(19) $$G1_{min} = \frac{\overline{x} - x_{[1]}}{\hat{\sigma}} \quad \text{and} \quad G2_{max} = \frac{x_{[n]} - \overline{x}}{\hat{\sigma}}.$$

$G1_{min}$ and $G2_{max}$ are the standardized distances from the mean for the largest and the smallest values.

Let G1 be the largest of the two values:

$$G1 = \max[G1_{min}, G1_{max}].$$

The extreme value ($x_{[1]}$ if $G1 = G1_{min}$ or $x_{[n]}$ if $G1 = G1_{max}$) is called a straggler and is indicated by a single asterisk if G1 is greater than its 5% critical value and less than or equal to its 1% critical value. It is called an outlier and is indicated by a double asterisk if G1 is greater than its 1% critical value. Critical values are given in X [2000].

3.3.5 Grubbs' test for two outlaying observations

The aim is to check if the two largest observations, $x_{[n-1]}$ and $x_{[n]}$, or the two smallest observations, $x_{[1]}$ and $x_{[2]}$, may be considered as outliers.

Let SS be the sum of squares for all the n observations:

(20) $$SS = \sum_{i=1}^{n} (x_i - \overline{x})^2 \quad \text{with} \quad \overline{x} = \frac{1}{n} \sum_{i=1}^{n} x_i .$$

Let SS' be the sum of squares after having discarded the two largest observations:

(21) $$SS' = \sum_{i=1}^{n-2} (x_i - \overline{x}')^2 \quad \text{with} \quad \overline{x}' = \frac{1}{n-2} \sum_{i=1}^{n-2} x_i ,$$

and SS'' the sum of squares after having discarded the two smallest observations:

(22) $$SS'' = \sum_{i=3}^{n} (x_i - \overline{x}'')^2 \quad \text{with} \quad \overline{x}'' = \frac{1}{n-2} \sum_{i=3}^{n} x_i .$$

Let

(23) $$G2_{max} = \frac{SS'}{SS} \quad \text{and} \quad G2_{min} = \frac{SS''}{SS},$$

and define G2 as the smallest of the two values:

(24) $$G2 = \min\left(G2_{min}, G2_{max}\right).$$

The two observations related to G2 ($x[1]$ and $x[2]$ if $G2 = G2_{min}$ or $x[n-1]$ and $x[n]$ if are called straggler and are indicated by a single asterisk if G2 is smaller than its 5% critical value and larger than or equal to its 1% critical value. They are called outliers and are indicated by a double asterisk if G2 is smaller that its 1% critical value. Critical values are given in X [2000].

3.4 Step-by-step procedure of analysis

3.4.1 Preliminary considerations

ISO 5725-2 gives the different steps of the statistical analysis of the data. We explain hereafter the main steps which lead to the determination of repeatability and reproducibility for each land parcel.

The analysis of the data begins with a visual inspection of the data for any obvious irregularities or erroneous data. These obvious discordant data may be corrected if possible or immediately discarded.

The Mandel's h and k plots are then prepared (see point 3.3.2).These plots may indicate the suitability of the data for further analysis, the presence of any outlying values or outlying level of the pooling factor. However no definite decisions are taken at this stage but are delayed until the statistical tests for outliers have been performed.

In the next stage, the numerical techniques described in point 3.3.3, 3.3.4 and 3.3.5 are used for the identification of outliers. The procedure of identification of outliers is explained in details in point 3.4.2 and 3.4.3. All the observations identified at this step as outliers are reported as well the reason why they are considered as outliers.

After discarding the outliers the analysis of variance, is calculated, the variance components are estimated and repeatability on reproducibility standard deviations are obtained as explained in point 3.2.1. Then the repeatability and reproducibility standard deviations are analyzed in order to determined how the variation of these values may be explained by the characteristics of the land parcels (see point 3.2.4).

3.4.2 Identifying outliers

Identification of outliers is done by the following steps.

1) Cochran's C statistic is computed for the level of the pooling factor showing the largest variance (between replicates). If this statistic is smaller than the 5 % critical value, go to step 5.

2) If the C statistic is larger than the 5 % critical value, the observations for the level with the largest variance are carefully examined in order to identify possible outliers which inflate the variance between replicates. This identification is based on the GRUBBS' tests as described in point 3.4.3 hereafter. If observations are identified as outliers, they are discarded and COCHRAN's test is applied again (back to step 1).

3) If no outlier is identified at step 2 and if the COCHRAN's C statistic is larger than the 5 % critical value but smaller than or equal to the 1 % critical value, go to step 5.

4) If no outliers is identified at step 2 and if the COCHRAN's C statistic is larger than the 1 % critical value, all the observations for the level of the pooling factor showing the largest variance are discarded and COCHRAN's test is applied again (back to step 1).

5) If, possibly after having discarded outliers, the COCHRAN's C statistic is smaller than or equal to the 1 % critical value, the means for each level of the pooling factor are carefully examined in order to identify outlying means. This identification is based on the GRUBBS' tests as described in point 3.4.3 hereafter. If mean values are identified as outliers, all the observations related to the level with an outlying mean are discarded.

3.4.3 Application of Grubbs' tests

We have already presented the Grubbs' tests (point 3.2.3and 3.2.4). The first test, called hereafter Grubbs/1, checks whether or not the largest or the smallest observation should be considered as an outlier. This test is based on the statistic G1. The second test, called hereafter Grubbs/2, checks whether or not the two largest or the two smallest observations should be considered as outliers. The associated statistic is G2.

The identification of outliers is performed on the observations related to the level of the pooling factor where COCHRAN's test has shown the variance between replicates variance to be suspect (point 3.4.2 step 2). It is also performed on the means per level (point 3.4.2, step 5).

If an individual observation is identified as an outlier (significant at 1% level), the observation is discarded. If a mean value is identified as an outlier (significant at 1% level) all the observations for the given level are discarded.

In the two situations the following procedure is used.

The GRUBBS/1 test is applied.

1) If the G1 statistic is smaller than or equal to the 1% critical value, go to step 6.

2) If the G1 statistic is larger than the 1% critical value, the extreme observation or mean is discarded and the Grubbs/1 test is applied again at the other extreme observation or mean

(if the extreme value discarded is the maximum, then look at the minimum; if the extreme value discarded is the minimum, then look at the maximum).

3) If the G1 statistic for this second Grubbs/1 test is smaller than the 1% critical value, the detection of outliers is stopped.

4) If the G1 statistic for this second Grubbs/1 test is larger than the 1% critical value, the observation or mean is discarded and the detection of outliers is stopped.

5) If no outlier has been identified by Grubbs/1 test, the Grubbs/2 test is applied.

6) If the G2 statistic is larger than or equal to the 1% critical value, the detection of outliers is stopped.

7) If the G2 statistic is smaller than the 1% critical value, the two largest (if G2 is related to the largest) or the two smallest (if G2 is related to the smallest) observations or means are discarded. The Grubbs/2 test is applied again at the other extreme (if the two largest observations or means have been discarded, the test is applied to the two smallest observations or means; if the two smallest observations or means have been discarded, the test is applied to the two largest observations or means). If the G2 statistic for the second Grubbs/2 test is larger than or equal to the 1% critical value, the detection of outliers is stopped.

8) If the G2 statistic for the second Grubbs/2 test is smaller than the 1% critical value the two observations or means are discarded and the detection of outliers is stopped.

3.4.4 Coding the results of the statistical tests

Three variables are defined in order to code the results of the statistical tests for the observations identified as outliers. These variables, called COCHRAN, GRUBBBS/1 and GRUBBS/2, are related to COCHRAN's test, to GRUBBS' test for one outlying observation and to GRUBBS test for two outlying observations.

The following codes are used:

COCHRAN: code related to the result of COCHRAN's test:

- 0 : statistic smaller than the 5% critical value,
- 1 : statistic larger than the 5% critical value but smaller than or equal to the 1% critical value,
- 2 : statistic larger than the 1% critical value.

GRUBBS/1: code related to the result of GRUBBS' test for one outlying observation:

- 0 : statistic non significant at level of 1%,

- 1 : statistic significant at the level of 1%, for a test performed on the observations within a given level of the pooling factor,
- 2 : statistic significant at the level of 1% for a test performed on the observations within a given level of the pooling factor and after having already identified one extreme value as an outliers,
- 10 : statistic significant at the level of 1% for a test performed on the mean values for the levels of the pooling factor,
- 20 : statistic significant at the level of 1% for a test performed on the mean values for the levels of the pooling factor and after having already identified one extreme mean as an outlier.

GRUBBS/2 code related to the result of GRUBBS' test for two outlying observations:

- 0 : statistic non significant at level of 1%,
- 1 : statistic significant at the level of 1%, for a test performed on the observations within a given level of the pooling factor,
- 2 : statistic significant at the level of 1% for a test performed on the observations within a given level of the pooling factor and after having already identified two extreme values as outliers,
- 10 : statistic significant at the level of 1% for a test performed on the mean values for the levels of the pooling factor,
- 20 : statistic significant at the level of 1% for a test performed on the mean values for the levels of the pooling factor and after having already identified two outlying means.

4. Detailed presentation of the validation approach to be applied in the study

4.1 Assumption of the validation experiment

Validation experiment detailing two example applications based upon a GPS system and a VHR orthoimage system

4.2 Description of the parcel set

36 parcels were measured. Parcels were characterized by different size, shape and measurement's conditions. Different amount of operators and repetitions are applied for RS and GPS. For RS we have 12 operators and 3 repetitions, for GPS we have 23 operators and 2 repetition. Detailed description of the issue: teams, operators and repetitions are presented below.

4.2.1 Size

For the RS and GPS measurements the following parcel size was chosen:

- S : small (0.3 – 0.5 ha)
- M : medium (0.8 – 1.2 ha)
- L : large (2.4 – 4 ha)

4.2.2 Shape

Parcel compactness: whilst it is easier to comprehend the description of a parcel in terms of its ratio width: length, in practical terms this cannot be calculated. It was agreed therefore to work with the Shape Factor (SF) = $(\text{perimeter}/4)^2$ / parcel area. The thresholds to be used for the categorization of reference parcel (>1:3, 1:3 to 1:6, <1:6) are parcel ratio 1:3 gives an SF = 1.33, and the ratio of 1:6 gives an SF 2.04.

- S1 : form factor – level 1 < 1:3
- S2 : form factor – level 2 < 1:6
- S3 : form factor – level 3 > 1:6

4.2.3 Measurement's conditions

In the experiment parcels are measured in good and bad conditions:

- GOOD: good conditions
- BAD: bad conditions.

Good and bad conditions were understood in different way for RS and GPS measurements. Bad border was understood in RS measurements as difficulties in recognized parcel edge (trees along the border or poor contrast between the crops). Bad border in GPS means obstructions for GPS signal (parcel near forest). We didn't consider in this case parcel edge interpretation because we would like to avoid too many disturbance factors in GPS measurements.

4.3 Measurement workflow

Measurements are prepared 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. Besides parcels were completed according assumption that they should be independent, so they must have own border, not sharing it with other one.

4.4 Control procedure

Before measurements operators were short trained and precisely instructions were them provided. Main recommendations are placed for each kind of measurements and full version of it was prepared in Polish and is attached as an appendix.

Measurements are controlled and gross errors (mainly mistakes of chosen parcel to measuring) are currently corrected.

5. Detail description of two example applications, based upon a GPS system and a VHR orthoimage system

5.1 Design of experiments – remote sensing

5.1.1 Initial phase

Preparing the main experiment we performed sample tests. 3 Operators performed measurements on 2 scale orto using 2 software: Microstation (Bentlley) and Geomedia (Intergarph). 41 parcels were measured 3 or 4 times. Measurements in Microstation need writing calculated in MS area and perimeter on the paper. In Geomedia all values are stored in file. Therefore for the main experiment Geomedia was chosen as a GIS software tool and other than measured in initial phase parcel set was prepared.

5.1.2 Main experiment

RS land parcel area measurements were performed on 3 kinds of ortofotomaps in different scales. 36 test land parcels were measured by 12 operators 3 times on each ortofotomaps Generally 3888 RS measurements are performed. Cadastre parcel is assumed as a reference parcel in land parcel measurements. Reference parcels were digitized on screen on the cadastre maps and land parcels on the ortho using GIS software: GeoMedia Professional (Intergraph). Results of measurements were automatically gathered in file, graphical and descriptive information were saved in one file.

12 operators were chosen to the experiment: 6 skilled and 6 unskilled. Test parcels are composed from one or more land parcels because assumption of ranges of parcels' size and shape. Completing the parcels sets was complicated under assumption that test parcels should:

- be composed from one cadastre parcel or more cadastre parcels without necessity to correct it
- fulfilled précised measurements conditions (bad and good border) and
- be characterized by the same measurements conditions on all ortho scales.

Parcel for measurements was marked uniquely on the screen but operators didn't know any cadastre borders.

Two kinds of parcels are chosen concerning the border conditions: good and bad. Parcel of good border condition means parcel edge easy to interpreted by operator (good contrast and strong brightest, color changes). Bad border condition means mainly trees along the edge.

Implementation the same conditions for all parcels on all ortophotomap were very difficult and in pair cases not possible to fulfill (ex. Fig. 5).

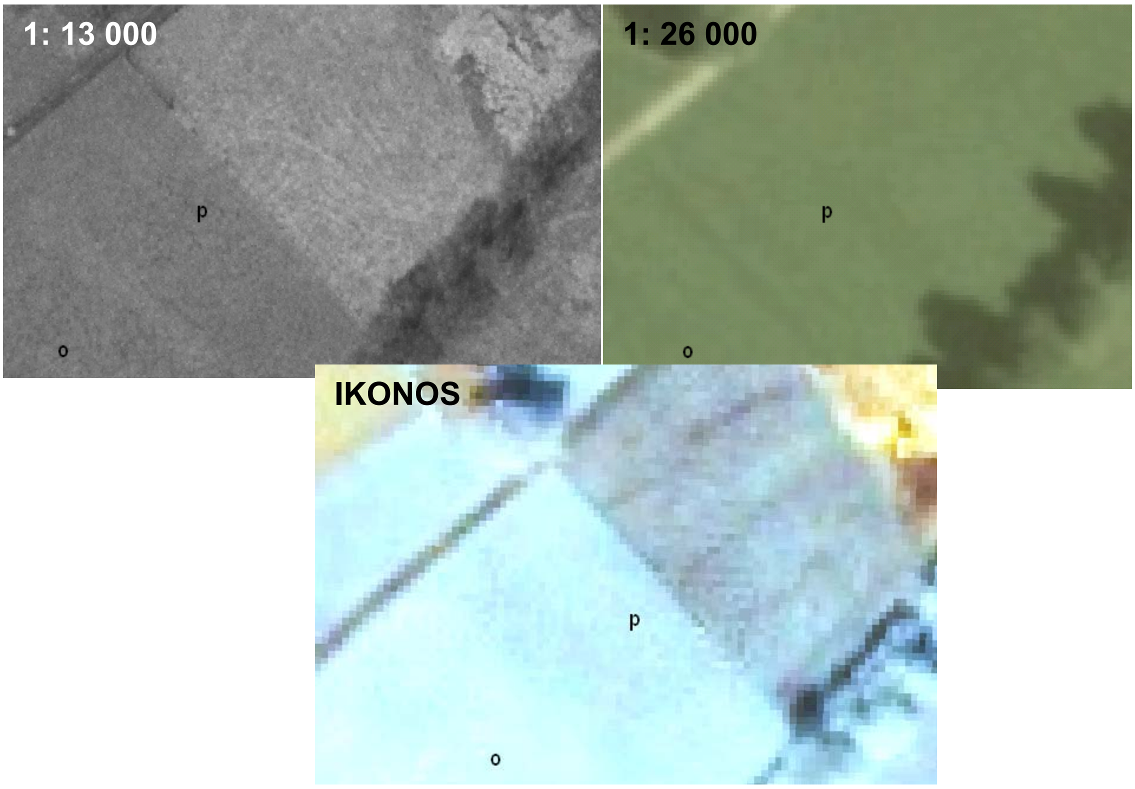


Fig. 5. Comparison of border condition on 3 ortophoto

5.1.3 Cadastre parcels as reference parcels

For the project 49 cadastre map sheets in national coordinate system 2000 were obtained from ARMA (Agency of Restructuring and Modernization of Agriculture in Poland). Reference parcels were digitized on the screen using Geomedia drawing tools (ex. snaping to the middle of line, or vertex). Parcels were defined by as minimum points as possible, only necessary edge breaks are noticed. Test parcels could be composed by one cadastre parcel (Fig. 6) or by few one (Fig. 7). It was not possible to choose cadastre parcels of so defined M or L size because of generally small parcels (or bigger than L) on the south of Poland.

Than area and perimeter of reference parcels were calculated in GeoMedia.

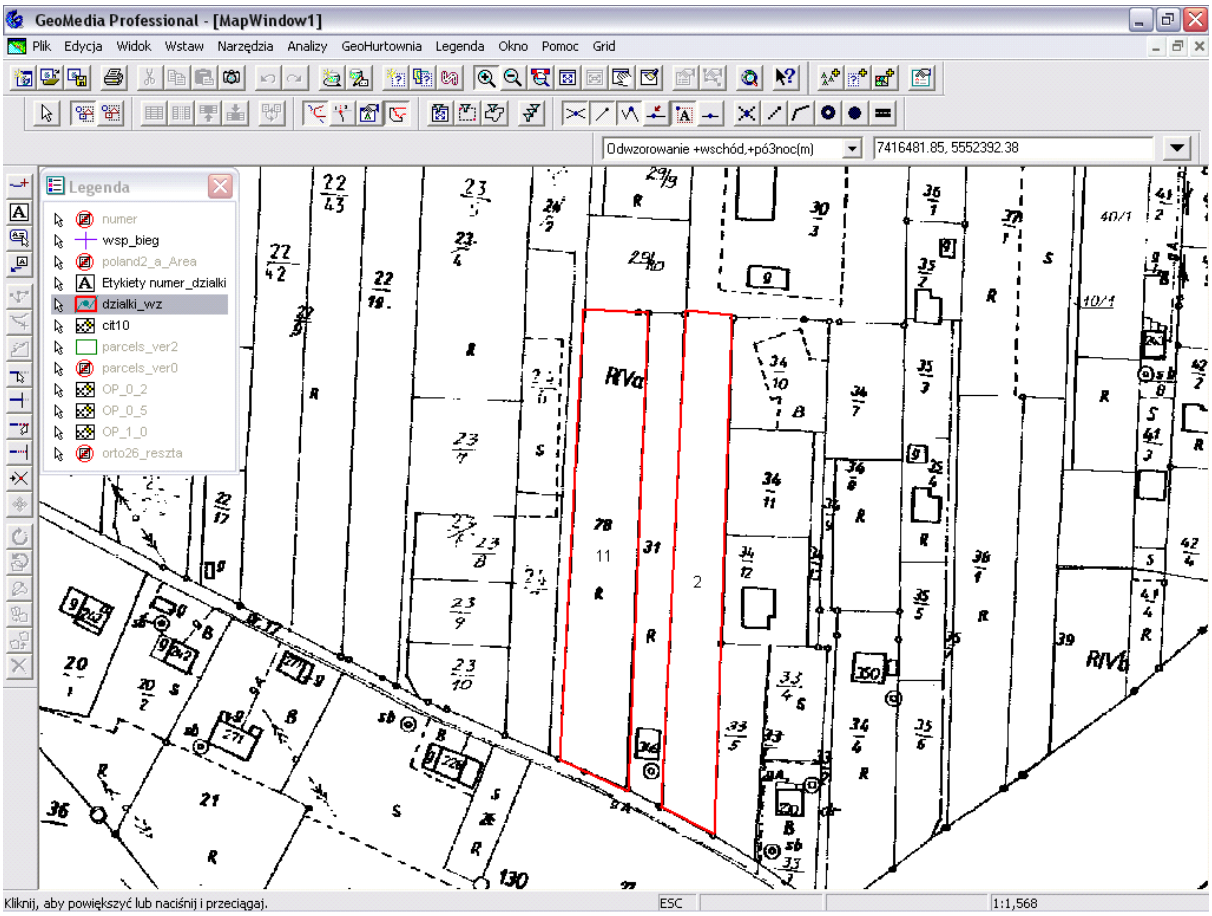
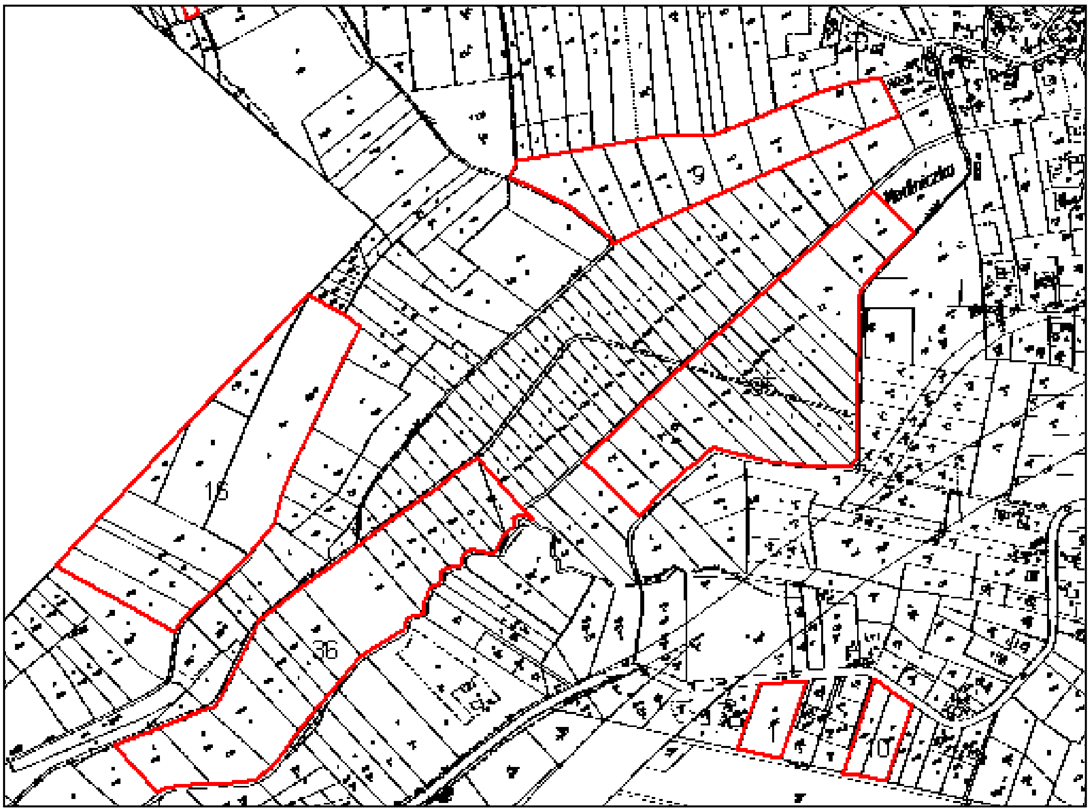


Fig. 6. Raster cadastre map – one cadastre parcel=one test parcel



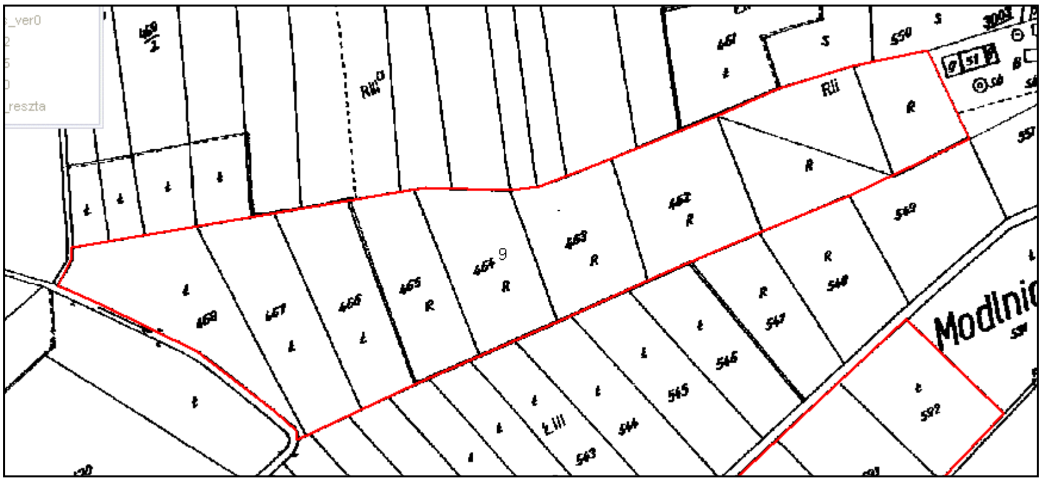


Fig. 7. Raster cadastre map – few cadastre parcels=one test parcel

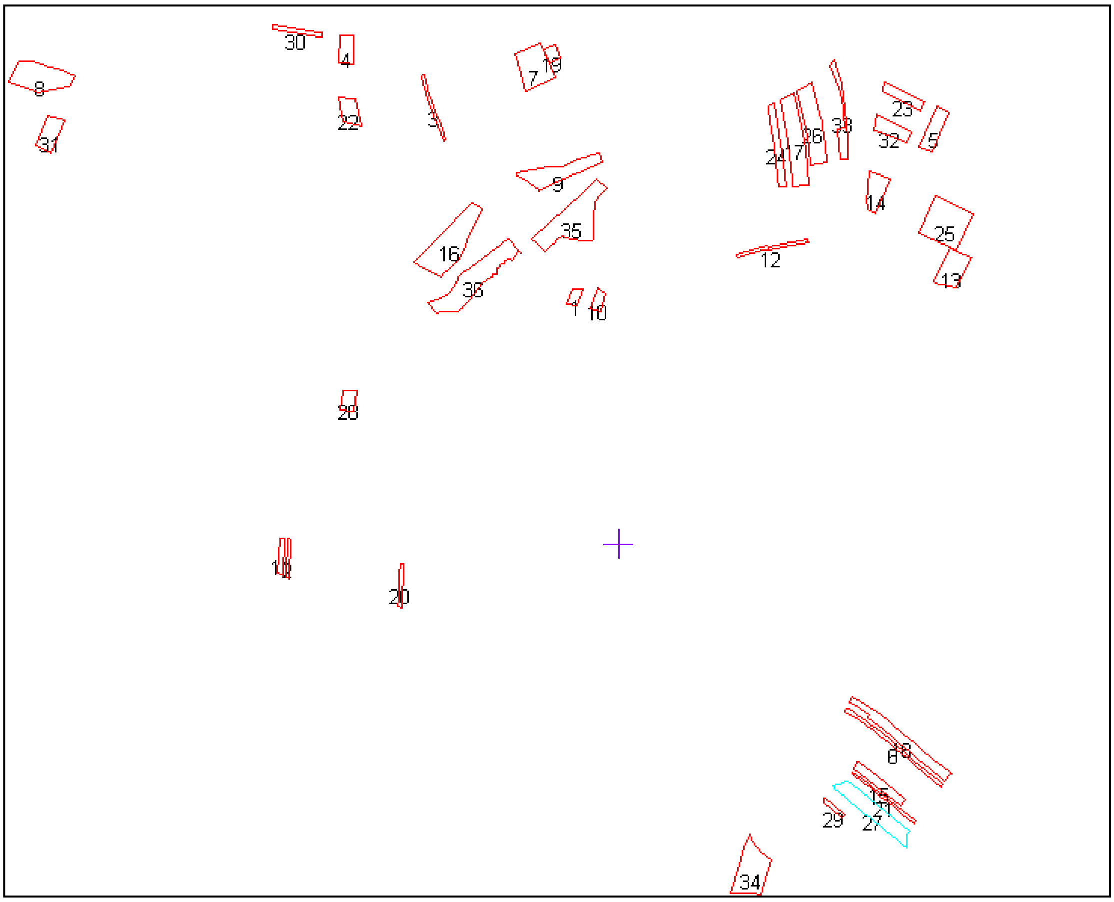


Fig. 8. Set of reference parcels composed by cadastre parcels

Tab 3. 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	5,710.50	307.5
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

5.1.4 Applied remote sensing imagery

During the experiment following RS imageries were applied:

- Panchromatic ortofotomaps from airborne photos of 1:13 000 (OP_0_2)
  - obtained from ARMA
  - pixels size: 0.2 m
- Color ortophotomaps from airborne photos of 1: 26 000 (OP_0_5)
  - Obtained from Centre of Surveying and Cartographic Documentation in Malopolska Region http://mapy.wrotamalopolski.pl/wrotamalopolski.htm
  - Pixel size: 0.75 m
- IKONOS pansharpening natural color composition (OP_1_0)
  - Pixel size: 1m

Test area is located near Krakow (commune: Zabierzów, on the north-east from Krakow).

Fig. 9. Panchromatic ortofotomap from airborne photos of 1:13 000

Fig. 10. Color ortophotomaps from airborne photos of 1: 26 000

Fig. 11. IKONOS pansharpening natural color composition

5.1.5 Technical specifications for operators – RS

Two kinds of operators participate in the experiment: skilled and unskilled. Operators (OP1, OP3, OP4, OP5) are working at Department of Photogrametry and Remote Sensing Informatics at AST – AGH Kraków. They are photogrammetry specialists (PH) or GIS. Operator OP2 is diploma student of our specialization (10th semester). Two unskilled operators (OP7 and OP8) are junior students on the 2nd and 4th semester of technical (surveying) and economy study (Academy of Economy, AE). Two others (OP9, OP10) are AST-AGH senior students of technical studies (not surveying). Last two (OP11, OP12) graduated in technical studies (not surveying), Tadeusz Kościuszko Cracow University of Technology (TKCUT).

Tab 4. List of operators

Operators skilled	Name	education	Operators unskilled	Name	education
OP1	Marta Borowiec	PH	OP7	Małgorzata Borowiec	AE student

OP2	Piotr Czajkowski	PH	OP8	Piotr Tokarczyk	AST - AGH student Surveying
OP3	Wojciech Drzewiecki	GIS	OP9	Anna Głowienka	AST – AGH student
OP4	Adam Boroń	PH	OP10	Dariusz Nowak	AST – AGH student
OP5	Andrzej Wróbel	PH	OP11	Hubert Wąsek	TKCUT graduate
OP6	Wladysław Mierzw	PH	OP12	Adam Szryniawski	TKCUT graduate

Operators had short lecture about the background of the project. The idea of measurements was presented, especially background of parcels' sequences to be measured.

Operators were trained in Geomedia software. Each operator obtained for each day prepared files:

- list of parcels to be measured on which orto (Fig. 12)
- geoworkspace: *.gws,
  - with configured ready to display images
  - number of all parcels (without reference parcels)
  - letters marking parcels building reference parcel (Fig. 13)
- 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 could obtain the data for next day.

OPERATOR_1

DAY_1

10	OP_1_0
22	OP_0_2
3	OP_0_2
6	OP_1_0
20	OP_0_5
30	OP_0_2
36	OP_1_0
35	OP_0_5
26	OP_0_5
17	OP_0_2
25	OP_0_2
28	OP_0_5
16	OP_0_2
12	OP_0_5
32	OP_1_0
15	OP_1_0
14	OP_1_0
33	OP_1_0
27	OP_0_5
18	OP_1_0
4	OP_0_5
31	OP_1_0
2	OP_0_2
19	OP_0_5
34	OP_0_5
11	OP_0_5
8	OP_0_2
5	OP_0_5
29	OP_1_0
7	OP_1_0
23	OP_1_0
24	OP_1_0
1	OP_0_2
21	OP_0_2
13	OP_0_5
9	OP_1_0

Fig. 12. List of parcels to be measured on which orto

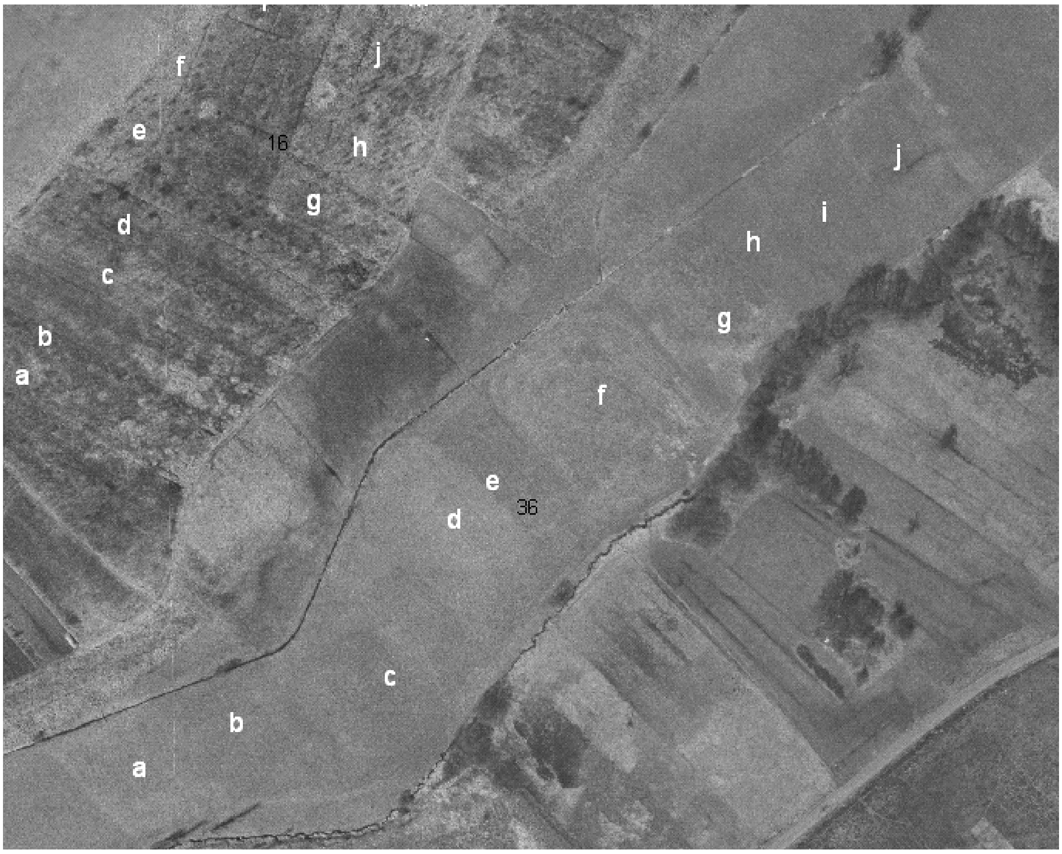


Fig. 13. Letters marking parcels building reference parcel

5.1.6 Data gathering

Data were gathered in separate files for each operator and each day. Than data were controlled, eventually corrected by operator and files from all operators were combined to one file for one day. File *.mdb contains attribute (parcel number, day, operator and ortho) and graphic (coordinates of parcel vertexes).

Tab 5. Example of *.mdb file

ID1	Geometry1	numer	dz_pom	op	ortho	Geometry1_sk
1		32	4	1		1blrGgQp
2		6	4	1		1blrGgV
3		13	4	1		1blrGgq
4		22	4	1		1blrGgF
5		10	4	1		1blrGgjR
6		11	4	1		1blrGglp
7		21	4	1		1blrGgw
8		9	4	1		1blrGgl
9		5	4	1		1blrGgq
10		28	4	1		1blrGgf

Finally all files from 9 days were combined to one file, area and perimeter were calculated. The file is on the attached CD.

5.1.7 Data export for statistical analyses

Data preparation for statistical analysis was provided automatically using macro in Excel, (Fig. 14, Fig. 15). EXP3PARCEL_MACRO.xls is on the attached CD.

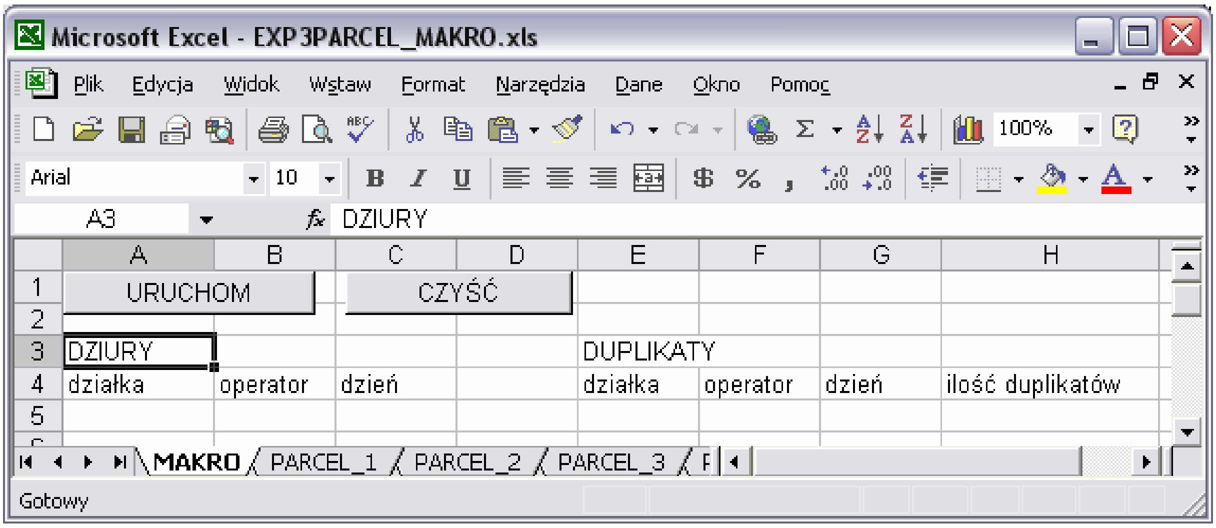


Fig. 14. Macro

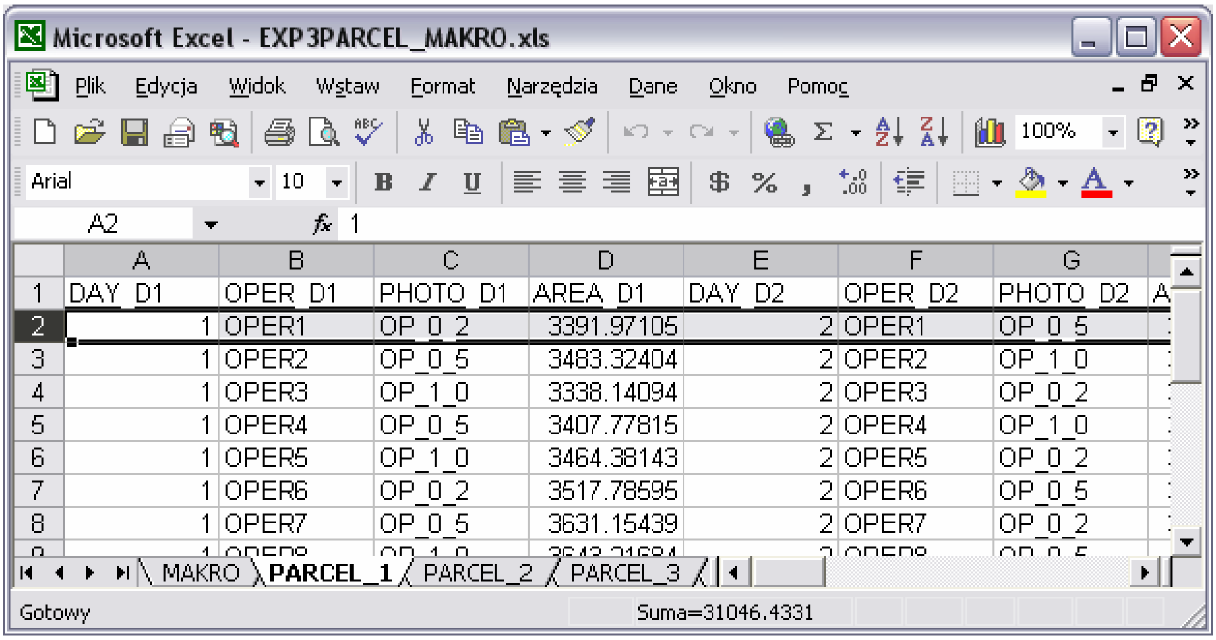


Fig. 15. Automatic fulfilled xls fields

5.2 Design of experiments – GPS

5.2.1 Introduction

During kick off meeting the preliminary decisions concerning GPS measurements were made. It was agreed that GPS measurement test would be performed by the University of Warmia and Mazury in Olsztyn in the Chair of Satellite Geodesy and Navigation. The GPS part of the project was supervised by **Prof. Stanisław Oszczak, PhD** and **Adam Ciećko, PhD**.

This was a very important task and also very difficult. Since, according to decisions made at the meetings total number of parcels was 36, an area of about 80-100 hectares was needed. Obviously no farmer would allow establishing hundreds of stakes on his field; therefore an airfield in Gryzliny (about 25 km from Olsztyn) was taken into consideration. It appeared to be a very good object, flat and vast area, free form electromagnetic fields. Nevertheless it appeared to be too small; especially there was a lack of obstructed (close to the woods) fields. After establishing of 27 parcels in the airfield and surroundings, a new object was strongly needed.

The large field of wasteland was found in Stawiguda and selected as second object. This area is rather hilly and irregular. There was an electrical line in the close neighborhood of the parcels as well as the GSM mast within the sight.

5.2.2 Reference parcels

According to the agreements made at the meetings the parcels were established in the field and marked with wooden stakes. The stakes on the corners were 1 meter long and the stakes about 35cm long were placed every 15-20 meters along the borders. Each parcel had its own color of stakes, which was especially important when the borders of 2 parcels were close to each other.

It was agreed that no border can be the same for 2 parcels; the minimum distance between two borders was set to 20 meters. In peculiar situations an intersection of the borders was acceptable. In several cases (especially for the obstructed parcels) the intersection was inevitable. Altogether over 850 stakes were used!

5.2.2.1 Design of reference parcels

The graphical presentation of the parcels is given in the Figures Fig. 17 and Fig. 18.

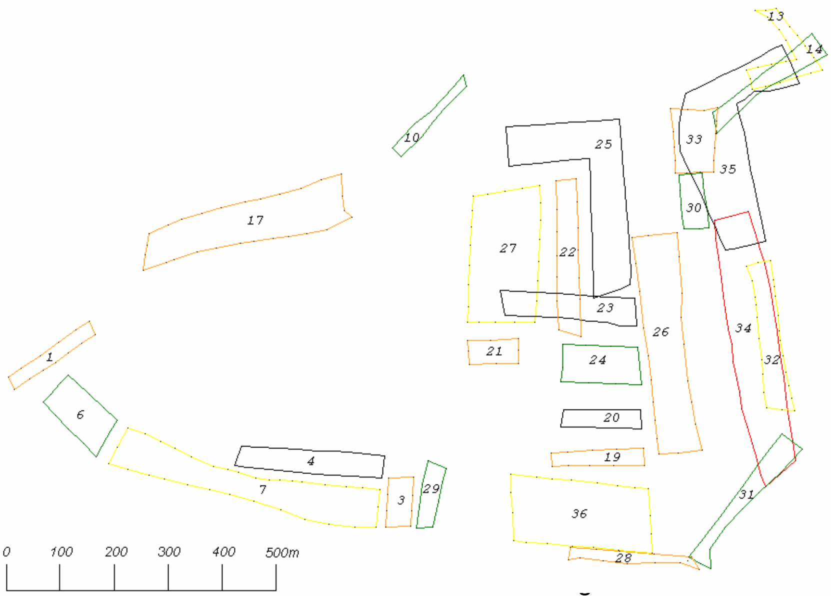


Fig. 17. Test object in the airfield in Gryźliny

Fig. 18. Test object in Stawiguda

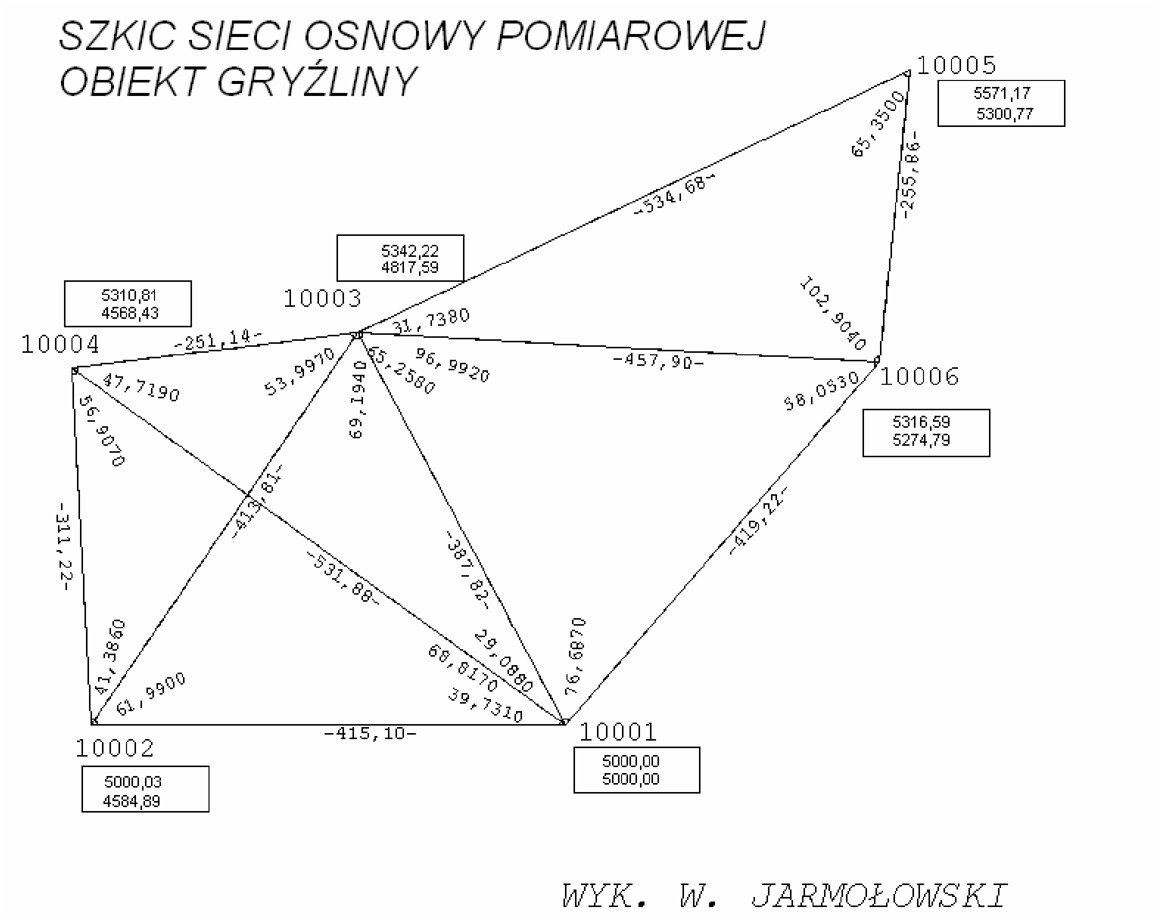
5.2.2.2 Geodetic measurements of reference parcels

The network was referred to Polish geodetic network POLREF. The coordinates of the parcels were calculated in Polish reference system 2000/21. The field work and calculation concerning preparation phase of experiment were made by the team of workers and PhD students of Chair of Satellite Geodesy and Navigation under leadership of **Wojciech Jarmołowski, MSc.**

The preparation phase of the test objects (marking the parcels and total station measurements) **took 2 weeks of hard work.** The reference values of the 36 parcels are given below:

Tab 6. Reference parcels – Total station measurements

IDENT	REPLIC	BORDER	SIZE	SHAPE	AREA_REF [ha]	PERIM [m]
1	A	GOOD	S	S1	0.4840	416.85
2	A	GOOD	S	S2	0.4079	378.56
3	A	GOOD	S	S3	0.4250	275.21
4	A	GOOD	M	S1	1.1217	617.79
5	A	GOOD	M	S2	1.2506	594.56
6	A	GOOD	M	S3	0.9641	412.34
7	A	GOOD	L	S1	2.9678	1145.47
8	A	GOOD	L	S2	2.8344	999.51
9	A	GOOD	L	S3	2.9342	736.62
10	A	BAD	S	S1	0.3690	413.54
11	A	BAD	S	S2	0.3882	358.33
12	A	BAD	S	S3	0.4229	287.38
13	A	BAD	M	S1	0.7056	569.08
14	A	BAD	M	S2	0.7740	576.82
15	A	BAD	M	S3	1.0274	438.40
16	A	BAD	L	S1	3.3783	1038.56
17	A	BAD	L	S2	2.8458	935.47
18	A	BAD	L	S3	2.9569	748.93
19	B	GOOD	S	S1	0.4856	400.96
20	B	GOOD	S	S2	0.4928	359.66
21	B	GOOD	S	S3	0.4112	278.42
22	B	GOOD	M	S1	1.1290	650.74
23	B	GOOD	M	S2	1.1463	593.68
24	B	GOOD	M	S3	1.0049	428.96
25	B	GOOD	L	S1	3.1311	1075.00
26	B	GOOD	L	S2	3.0116	979.18
27	B	GOOD	L	S3	3.0878	737.41
28	B	BAD	S	S1	0.4233	522.25
29	B	BAD	S	S2	0.4016	306.44
30	B	BAD	S	S3	0.4635	293.72
31	B	BAD	M	S1	0.9028	669.58
32	B	BAD	M	S2	1.1362	648.04
33	B	BAD	M	S3	0.9012	397.16
34	B	BAD	L	S1	3.9512	1113.94
35	B	BAD	L	S2	3.9169	1055.88
36	B	BAD	L	S3	3.0999	758.10



5.2.3 Applied GPS system

It was stated that equipment owned by University of Warmia and Mazury in Olsztyn can be used in the tests. These were:

- 4 Thales Mobile Mapper receivers
- 4 Satcon receivers
- 1 Garmin GPSMap 76S receiver

It was also mentioned that an extra Garmin receiver can be obtained from Polish dealer of Garmin - EXCEL Systemy Nawigacyjne Sp. Jawna, ul. Monte Cassino 24, 70-467 SZCZECIN, http://www.garmin.pl.

It was said that the receivers of one kind should have the same options, firmware and accessories. Garmin and Thales receivers were updated using firmware obtained from WebPages. Satcon GPS receivers (Ricaline 6010) were sent to Germany to the manufacturer of SatconSystem to upload the newest firmware.

5.2.4 GPS measurements team

Field measurements were made by each of the team independently. Operators were divided to skilled and unskilled. The operators were selected from the students of Geodesy and Land Management Faculty, Specialization: Geodesy and Satellite Navigation. The full list of the observers is given below:

TEAM	STATUS	IDENT	NAME
TEAM_1	Unskilled	OPER_11	Paweł Klockowski
	Unskilled	OPER_12	Daniel Leleniewski
	Unskilled	OPER_13	Joanna Janowiec
	Skilled	OPER_14	Zinkiewicz Daniel
	Skilled	OPER_15	Arkadiusz Przesmycki
	Skilled/Leader	OPER_16	Rafał Gregorczyk
TEAM_2	Leader	-	Marcin Uradziński
	Unskilled	OPER_21	Marcin Gryszko
	Unskilled	OPER_22	Wojciech Augustyniak
	Unskilled	OPER_23	Michał Czajkowski
	Skilled	OPER_24	Przemysław Wasilczyk
	Skilled	OPER_25	Łukasz Grądzki
	Skilled	OPER_26	Tomasz Gronostajski
TEAM_3	Leader	-	Arkadiusz Tyszko
	Unskilled	OPER_1	Andrzej Pawlak
	Unskilled	OPER_2	Radosław Cecot
	Skilled	OPER_3	Paweł Ronowicz
	Skilled	OPER_4	Maciej Rudziński
TEAM_4	Leader	-	Arkadiusz Tyszko
	Unskilled	OPER_5	Jakub Rojek
	Unskilled	OPER_2	Radosław Cecot
	Skilled	OPER_6	Mirosław Depta
	Skilled	OPER_4	Maciej Rudziński

5.2.5 Experimental design

After the second meeting the final experimental design was established. Two experiments were carried out on 36 land parcels (18 parcels for each experiment).

5.2.6 Material

5.2.6.1 Land parcels

The 36 different land parcels are measured. These parcels are selected according to:

- size : 3 levels (labelled 1, 2, 3)
- shape : 3 levels (labelled 1, 2, 3)
- border : 2 levels (labelled 1, 2)
- replication : 2 levels (labelled 1, 2).

5.2.6.1.1 Size

- S : small (0.3 – 0.5 ha)
- M : medium (0.8 – 1.2 ha)
- L : large (2.4 – 4 ha)

5.2.6.1.2 Shape (ratio of width:length)

- S1 : form factor – level 1 < 1:3
- S2 : form factor – level 2 < 1:6
- S3 : form factor – level 3 > 1:6

5.2.6.1.3 Border

- GOOD : good conditions (open horizon)
- BAD : bad conditions (obstructions by the trees)

5.2.6.1.4 Replic

- A : first replication (parcels allocated to Experiment A)
- B : second replication (parcels allocated to Experiment B)

5.2.7 Instruments

The10 instruments are available. They are of the following makes

- Garmin (2 instruments): G1, G2 – one borrowed from EXCEL Systemy Nawigacyjne
- Thales (4 instruments): T1, T2, T3, T4
- Satcon (4 instruments): S1, S2, S3, S4

It was agreed that all observations will be downloaded on PC. The exception was the Garmin instrument which can store results of only 10 parcels and the download speed is very limited. Garmin results were only written down in the field notes.

5.2.8 Teams of operators

The 20 operators are allocated to 4 teams.

- Team 1 : 6 operators (3 skilled + 3 unskilled) using instruments : G1, T1, S1

- Team 2 : 6 operators (3 skilled + 3 unskilled) using instruments : G2, T2, S2
- Team 3 : 4 operators (2 skilled + 2 unskilled) using instruments : T3, S3, T4, S4
- Team 4 : 4 operators (2 skilled + 2 unskilled) using instruments : T3, S3, T4, S4

5.2.9 Designs

5.2.9.1 Introduction

The 36 land parcels are allocated to two sets, set 1 and set 2, according to the level of replication: parcels of replication level equal to 1 are allocated to the set 1 (18 parcels) and parcels of replication level equal to 2 are allocated to set 2 (18 parcels).

Two separate designs are proposed. Experiment A is designed for the first set of 18 parcels and Experiment B is designed for the second set of 18 parcels.

- parcels 1-18 Experiment A (team 1 and 2),
- parcels 17-36 Experiment B (team 3 and 4).

Experiment A gives 1944 independent results and Experiment B gives 1728 results. So, all together 3672 GPS measurements will be available.

5.2.9.2 Experiment A

5.2.9.2.1 Material

Experiment A is designed for the 18 land parcels of set 1. This experiment is carried out by team 1 and team 2. Three instruments are used by each team. They are labelled G1, T1 and S1 for team 1 and G2, T2 and S2 for team 2. Only one team makes measurements in a given land parcel.

5.2.9.2.2 Experimental design for a given land parcel

The same design is used for each land parcel. So the design is replicated 18 times. We first give the design for a given land parcel then, we will consider the whole experiment.

Suppose that team 1 is allocated to land parcel 1. On this land parcel, and on a given day each operator makes the measurement with each instrument. So 6 x 3 = 18 results are obtained on this given day. The same measurements are repeated on day 2, day 3, day 4, day 5, day 6. So, for parcel 1, 18 x 6 = 108 measurements are made.

5.2.9.2.3 Measurements of all the land parcels

The design described for a given land parcel is repeated on each of the 18 land parcels. Since two teams are available, each team will perform the measurements on 9 parcels, during 6 days.

Measurement days have to be independent but there is no need to measure during 6 days in a row.

5.2.9.3 Experiment B

5.2.9.3.1 Material

Experiment B is designed for the 18 land parcels of set 2. This experiment is carried out by team 3 and team 4, with four instruments, labelled T3, S3, T4 and S4.

5.2.9.3.2 Experimental design for a given land parcel

The same design is used for each land parcel. So the design is replicated 18 times. We first give the design for a given land parcel. Then we consider the whole experiment.

On a given land parcel and a given day each operator makes the measurement with each instrument. So, 4 x 4 = 16 results are obtained on this given day. The same measurements are repeated on day 2, day 3 and day 4, day 5, day 6. So, for a given land parcel 16 x 6 = 96 measurements are made.

5.2.9.3.3 Measurement of all the land parcels

The design described for a given parcel is repeated on each of the 18 land parcels. The measurements are made during a time period of 12 days (6 days – team 1 and 6 days – team 2), 9 parcels have to be measured on a first period of six days and 9 parcels have to be measured on a second period of six days. Measurement days have to be independent but there is no need to measure during 12 days in a row.

5.2.10 Order of measurements.

The order of the parcel measurements for each of the days is random. It was stressed that given order can not be changed. Also order of measurements for each given parcel was random and can not be changed. This is also a very important factor for observers to keep them vigilant and prevent from boredom. The order of measurements for each day for every team is given below:

team 1					
DAY_1	DAY_2	DAY_3	DAY_4	DAY_5	DAY_6
10	6	14	10	14	3
13	3	17	7	4	1
7	1	4	13	17	6
1	14	13	14	3	7
3	4	10	17	6	10
6	17	7	4	1	13
14	13	1	1	10	4
17	10	3	6	13	17
4	7	6	3	7	14
team 2					
DAY_1	DAY_2	DAY_3	DAY_4	DAY_5	DAY_6
9	16	18	11	8	15
5	12	8	5	18	16
11	15	2	9	2	12
15	18	11	8	16	5
12	2	9	18	15	11
16	8	5	2	12	9
8	5	16	16	5	18
2	9	15	15	11	8
18	11	12	12	9	2

team 3					
DAY_1	DAY_2	DAY_3	DAY_4	DAY_5	DAY_6
19	36	31	32	32	19
20	26	26	23	29	24
24	31	36	29	23	20
36	20	32	36	20	23
26	19	23	26	24	29
31	24	29	31	19	32
32	32	20	24	36	26
23	29	24	19	26	36
29	23	19	20	31	31
team 4					
DAY_1	DAY_2	DAY_3	DAY_4	DAY_5	DAY_6
35	33	21	27	34	35
25	28	25	34	27	25
21	22	35	30	30	21
22	25	34	28	25	27
28	21	30	33	21	30

33	35	27	22	35	34
27	30	33	35	33	33
30	34	28	21	22	28
34	27	22	25	28	22

5.2.11 Technical specifications for operators GPS

Before the actual measurements short training and written instructions were given to the observers. In the instructions, each of the observers got detailed:

- Information about parcels
- Information about instruments
- Description of Experiment A and 2
- Detailed explanation of field measurement
- Naming of the parcel files
- Schedule of measurements

Due to unstable EGNOS performance it was agreed to perform all the measurements without the EGNOS corrections. The EGNOS option was switched off in each of the receivers.

Special filed notes tables were prepared for each of the teams. The results (area measured and perimeter) were noted in the field. The graphical example of field measurement is presented in Fig. 20.

Fig. 20. Parcel measurement. Team_4.

Very often the field measurements were performed in unfavorable weather conditions. There was also totally unexpected problem with the tear gas which was used by the police practicing some tactical maneuvers, nearby our test objects (Fig. 8)

One day observation took about 10-12 hours, each of the operators walked along the borders on a single day about 20 kilometers!

Altogether the total distance walked by the operators during GPS measurements of all teams exceeded 2250 km!!!.

Fig. 21. . Parcel measurement. Police tactical exercises can be seen in the background

5.2.12 Data gathering

5.2.12.1 Detailed information about Experiment A

Operators unskilled: **11, 12, 13** (team_1), **21, 22, 23** (team_2). Operators skilled: 14, 15, 16 (team_1), 24, 25, 26 (team_2). Working days for teams 1 and 2 were the same and they were:

- Day_1 – 20. 04. 2005
- Day_2 – 22. 04. 2005
- Day_3 – 25. 04. 2005
- Day_4 – 26. 04. 2005
- Day_5 – 27. 04. 2005
- Day_6 – 28. 04. 2005

All parcels were prepared according to given instructions.

Parcels measured by team_1 (1, 3, 4, 6, 7, 10, 13, 14, 17) are located in airfield in Gryźliny.

Parcels measured by team_2 (2, 5, 8, 9, 11, 12, 15, 16, 18) are located in the second object in Stawiguda.

5.2.12.2 Detailed information about Experiment B

Operators unksilled: **1, 2** (team_3), **5, 2** (team_4). Operators skilled: **3, 4** (team_3), **6, 4** (team_4). Operators **2 and 4** were working in both **team 3** and **team 4.**

Working days:,

Team 3:

- Day_1 – 20. 04. 2005
- Day_2 – 22. 04. 2005
- Day_3 – 25. 04. 2005
- Day_4 – 26. 04. 2005
- Day_5 – 27. 04. 2005
- Day_6 – 28. 04. 2005

Team 4:

- Day_1 – 05. 05. 2005
- Day_2 – 06. 05. 2005
- Day_3 – 09. 05. 2005
- Day_4 – 10. 05. 2005
- Day_5 – 12. 05. 2005
- Day_6 – 13. 05. 2005

All parcels were prepared according to given instructions.
Parcels measured by both team_**3** (19, 20, 23, 24, 26, 29, 31, 32, 36) and **team_4** (21, 22, 25, 27, 28, 30, 33, 34, 35) are located in airfield in Gryźliny.

The test objects were visited by the contactors of the project on 11th of May 2005 – Fig. 22. There was also a meeting with the operators and team leaders on the same day .

Fig. 22. Inspection in the field by the project's contractors.

5.2.13 Data preparation for statistical analyses

After the field measurements all collected data were entered from the filed notes into a spreadsheet. The entered data were double checked and special spreadsheets were prepared for further calculation.

All the observation files (from Thales and Satcon) collected during measurements were downloaded to the PC, sorted and prepared for further analyses.

5.3 Coefficient calculations for accuracy estimations

5.3.1 Backgrounds

Accuracy estimation was based on point position error using following formulas (Hejmanowska B. 2003, Bogaert P., Delinc´e J., Kay S. 2005):

(25) $$m_p = m_{pkt}\sqrt{\sum_{i=1}^{n}\frac{(y_{i+1}-y_{i-1})^2+(x_{i-1}-x_{i+1})^2}{8}}$$ (BH)

(26) $$m_P = m_{pkt}\sqrt{\frac{1}{2}\sum_{i=1}^{n}(r_i^2 - r_i r_{i+2}\cos(\alpha_{i+2}-\alpha_i))}$$ (BDK)

where:

m_P – area error,

m_{pkt} – point position error

x, y – Cartesian coordinate of parcel vertices

r, α – polar coordinate of parcel vertices.

n – number of parcels vertices.

Generally we can write:

(27) $m_P = m_{pkt}$ Area_error_cofficient

Area_error_coefficient calculated from Cartesian coordinates is almost always the same as calculated from polar coordinates. In some cases (very coincidence geometry, 2 points very near each other on vertex) formula (26) gives bad results.

All analysis was performed assuming $m_{pkt} = 1$, it means that only Area_error_coefficient was calculated. For calculation own software was used.

5.3.2 Workflow

Area_error_coefficients are calculated using own prepared software:

- Area error calculation xy.exe – version1 for formula ((25)
- Area error calculation xy_polar – version2 for formulas: ((25) and (26)

To apply the software data preparation is needed. Area_error_coefficients are calculatede on the basis of reference parcels. From GIS software: GeoMedia, coordinate of reference parcels are exported to text. Than polar coordinates are calculated (see 5.3.2.1.2). Finally Area_error_coefficients are calculated (see 5.3.2.1.3).

5.3.2.1 Preparing text files for calculations.

5.3.2.1.1 The file of Cartesian coordinates calculations

Parcels are described in object model, it means that parcel are identified by ID and x,y coordinate of each vertices. Land parcel is an polygon, so the first point and the last one has the same coordinates (X_0,Y_0).

ID

X_0 Y_0

....

X_0 Y_0

1

7417724.0295 5553736.2709

7417772.4838 5553741.0013

7417744.2319 5553661.0135

7417700.3765 5553669.8735

7417724.0295 5553736.2709

2

7416418.7351 5552595.3742

7416435.2316 5552593.7601

7416428.7019 5552411.8346

7416409.9633 5552421.0627

7416418.7350 5552595.3727

7416418.7351 5552595.3742

File for measurements:

- AGH CD\Area error calculation\AGH_xy.txt
- UWM CD\Area error calculation\ UWM_xy.txt

5.3.2.1.2 Polar coordinates calculation

Cartesian coordinates can be easily recalculated into polar coordinate system:

- AGH CD\Area error calculation\AGH_polar_calculation.xls
- UWM CD\Area error calculation\UWM_polar_calculation.xls

7417936.2	5552573.07				
1				1	
7417724.03	5553736.27	-212.1705	1163.2009	-0.18042	1182.393
7417772.48	5553741	-163.7162	1167.9313	-0.13927	1179.35
7417744.23	5553661.01	-191.9681	1087.9435	-0.17465	1104.75
7417700.38	5553669.87	-235.8235	1096.8035	-0.21179	1121.869
7417724.03	5553736.27	-212.1705	1163.2009	-0.18042	1182.393

File of polar coordinates:

- AGH CD\Area error calculation\ AGH_polar.txt
- UWM CD\Area error calculation\ UWM_polar.txt

5.3.2.1.3 Area_error_coefficient calculation

Area_error_coefficient was calculated applying following software:

- Area error calculation xy.exe for calculation of area error coefficient based on Cartesian coordinates

- Area error calculation xy_polar.exe for calculation of area coefficient based on polar coordinates

Tab 7. Area error coefficient AGH

Tab 8. ID AREA BH BH/A BDK

Id	Pole[m2]	Blad[m2]	BladWzgl[%]	BladBieg[m2]
1	3431.78	63.9	1.862	63.9
2	3179.49	126.87	3.99	2144.81
3	4081.83	123.79	3.033	123.79
4	8450.68	83	0.982	83
5	12387.27	146.03	1.179	146.03
6	8567.1	155.27	1.812	155.27
7	23511.33	150.22	0.639	150.22
8	27960.71	119.61	0.428	119.61
9	24503.28	141.59	0.578	141.59
10	4145.92	71.84	1.733	71.84
11	3856.83	116.65	3.025	2191.88
12	4785.93	155.46	3.248	155.46
13	17747	127.14	0.716	127.14
14	12768.24	112.04	0.878	112.04
15	10955.06	162.78	1.486	162.78
16	41745.43	195.93	0.469	195.93
17	30883.16	185.27	0.6	185.27
18	24143	171.54	0.711	171.54
19	3795.68	61.86	1.63	61.86
20	3446.28	114.11	3.311	114.11
21	3722.3	110.9	2.979	110.9
22	8807.86	94.41	1.072	94.41
23	8832.43	142.61	1.615	142.61
24	11658.05	203.32	1.744	203.32
25	33676.91	183.52	0.545	183.52
26	27455.06	163.69	0.596	163.69
27	26106.52	197.21	0.755	197.21
28	5710.47	78.14	1.368	78.14
29	2338.73	58.81	2.514	58.81
30	4312.32	151.34	3.509	151.34
31	12334.07	123.88	1.004	123.88
32	10420.59	121.75	1.168	121.75
33	10862.41	155.03	1.427	155.03
34	28543.4	134.34	0.471	134.34
35	43349.56	158.69	0.366	158.69
36	41087.04	130.99	0.319	130.99

Tab 9. Area error coefficient UWM

Tab 10. ID AREA BH BH/A BDK

Id	Pole[m2]	Blad[m2]	BladWzgl[%]	BladBieg[m2]
1	4840.33	77.62	1.604	77.62
2	4078.53	58.42	1.432	58.42
3	4249.97	58.17	1.369	58.17
4	11217.49	95.3	0.85	95.3
5	12505.57	91.8	0.734	91.8
6	9640.73	74.53	0.773	74.53
7	29677.78	141.76	0.478	141.76
8	28343.55	135.38	0.478	135.38
9	29342.36	98.96	0.337	98.96
10	3689.74	77.63	2.104	77.63
11	3882.17	67.56	1.74	67.56
12	4229.26	48.81	1.154	48.81
13	7056.18	79.22	1.123	79.22
14	7740.37	83.94	1.084	83.94
15	10273.58	79.47	0.774	79.47
16	33783.29	120.98	0.358	120.98
17	28458.24	123.05	0.432	123.05
18	29569.13	90.53	0.306	90.53
19	4855.66	83.8	1.726	83.8
20	4927.9	71.73	1.456	71.73
21	4111.65	63.46	1.543	63.46
22	11289.99	113.72	1.007	113.72
23	11463.02	102.57	0.895	102.57
24	10049.25	89	0.886	89
25	31310.78	130.69	0.417	130.69
26	30115.77	147.26	0.489	147.26
27	30878.09	107.72	0.349	107.72
28	4232.64	104.72	2.474	104.72
29	4016.29	67.83	1.689	67.83
30	4634.89	54.45	1.175	54.45
31	9027.64	109.93	1.218	109.93
32	11361.55	91.12	0.802	91.12
33	9012.34	67.55	0.75	67.55
34	39512.02	135.04	0.342	135.04
35	39169.17	116.85	0.298	116.85
36	30998.68	117.82	0.38	117.82

6. The statistical analysis of a trial datasets

6.1.1 Remote sensing

6.1.1.1 Critical examination of the data

The method proposed in ISO 5725-2 and described in part 3.3 is used to identify outliers and other irregularities.

The pooling factor is the factor "operator". Each photo has been examined by each operator on three different days. So, the observations are allocated into 1296 groups (12 operators × 36 parcels × 3 photos). The 36 observations related to a given photo of a given parcel (12 operators × 3 days) are analyzed separately. So the identification of outliers and other irregularities is repeated 108 times (36 parcels × 3 photos).

Out of 1296 groups, 28 are identified as outliers (2,16 %). For each of these groups, all the observations are discarded (84 observations). Most of these groups are identified by COCHRAN's test (22 groups), due to too large standard deviation within repetitions for a given operator. Only six groups are identified by GRUBB's tests, due to too extreme mean values for one or two operators.

For operator 2 and operator 11, five groups (among 108 groups) are discarded. For operators 3, 6, 8 and 12, three groups are discarded. For the other operators, two or less than two groups are discarded.

Regarding the photos, 10 groups for photo OP_0_2, 6 groups for photo OP_0_5 and 12 groups for photo OP_1_0 are identified.

For parcel 24, four groups are discarded. For parcel 5 and parcel 17, three groups are discarded and for the other parcels only two or less than two groups are identified.

The complete list of all the 84 observations that are discarded is given in Appendix 11.

Figures: Fig. 23-Fig. 26give to boxplots of the h_i and k_i values defined by MANDEL, before and after discarding these observations. The definition of h_i and k_i values are given in part 3.3.2. Let us recall that h_i is a measurement of the standardized distance of the mean value observed for the operator i from the general mean of all observations for a given parcel and a given photo, and k_i is the ratio of the within operator i standard deviation to the mean value of the within standard deviation of all operators.

The h_i plots show that operator 11 often overestimates and that operator 12 often underestimates the area of the parcels. Comparing the boxplots drawn before and after discarding 84 observations shows that there are slightly less extreme values after having discarded these observations.

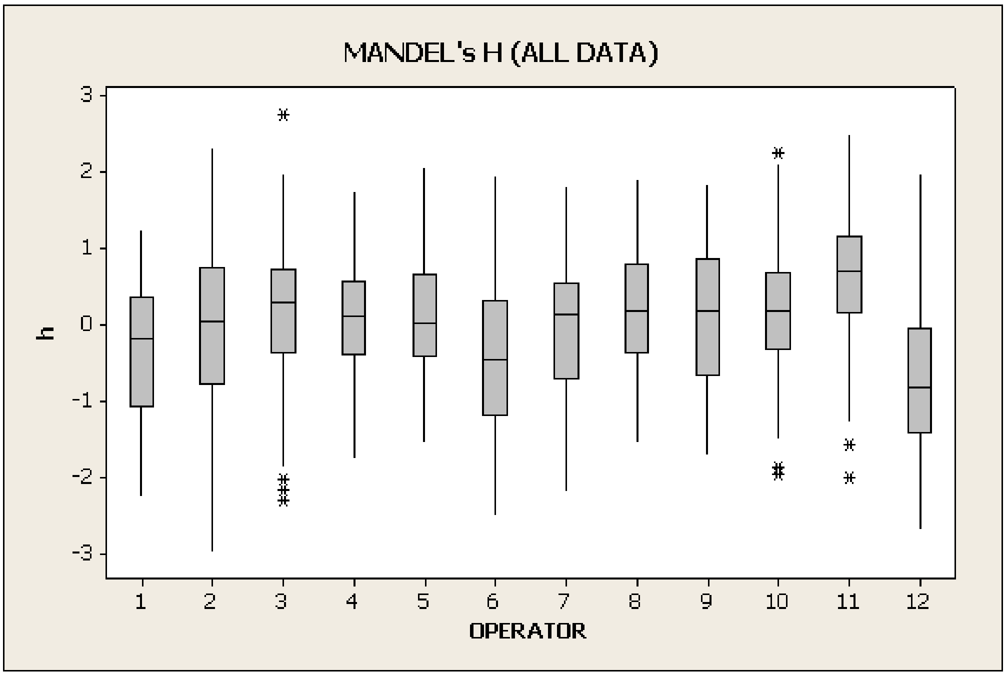


Fig. 23. Boxplot of MANDEL's h_i values as a function of operators (before discarding observations).

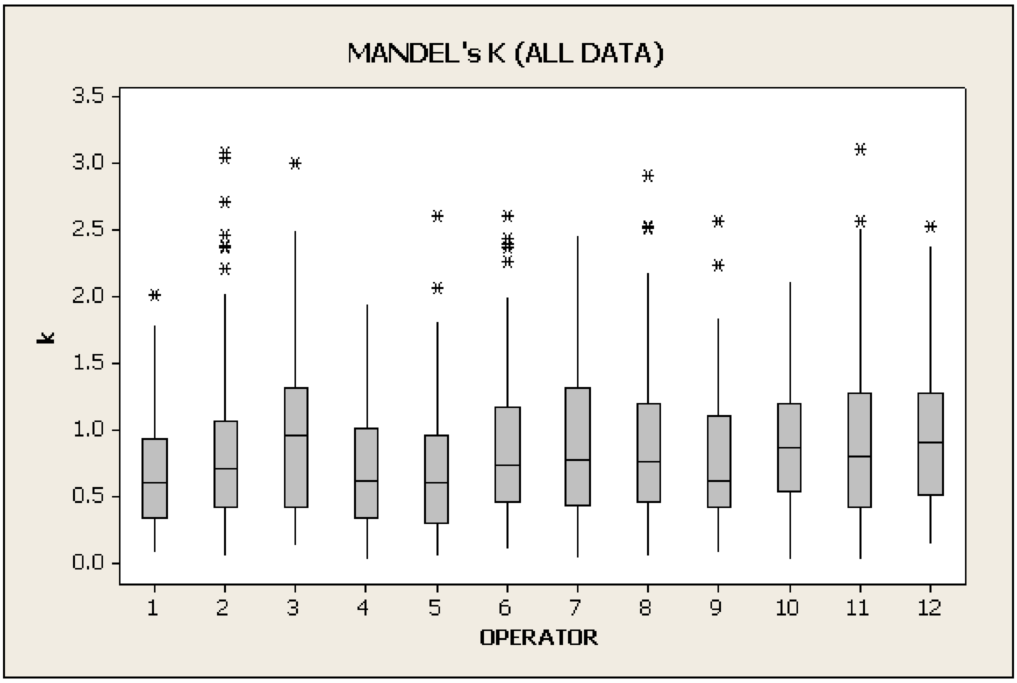


Fig. 24. Boxplot of MANDEL's k_i as a function of operators (before discarding observations).

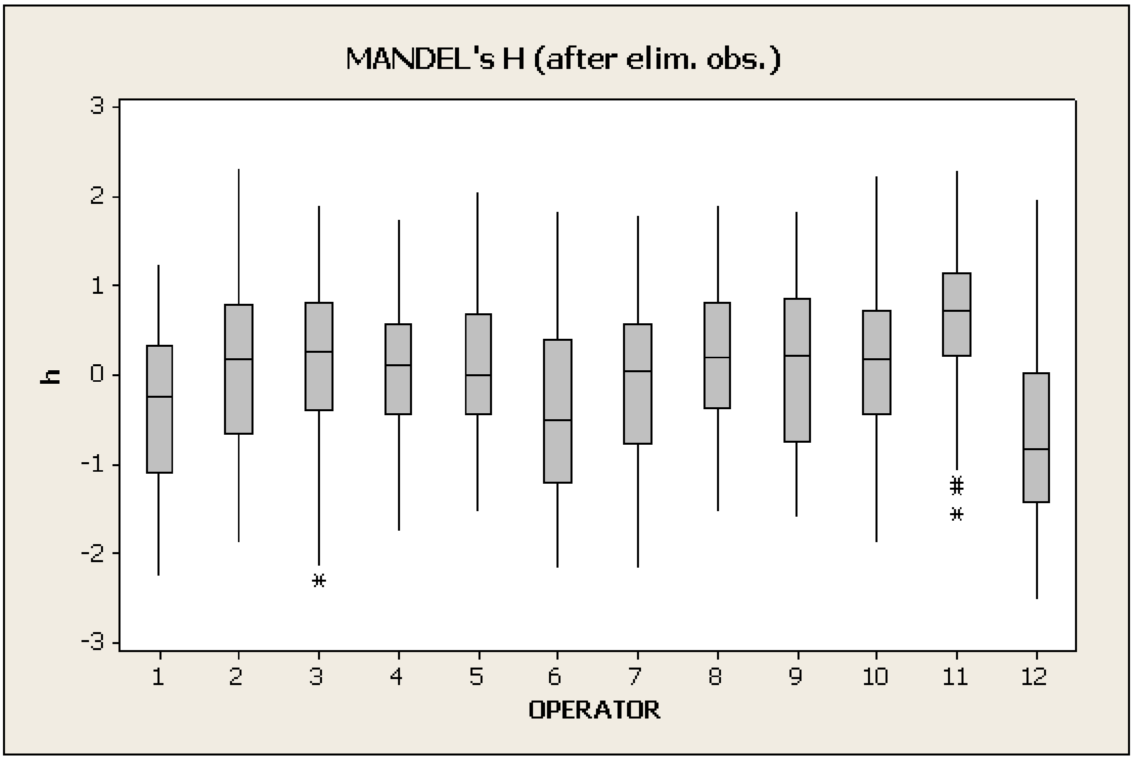


Fig. 25. Boxplot of MANDEL's h_i values as a function of operators (after a discarding 84 observations).

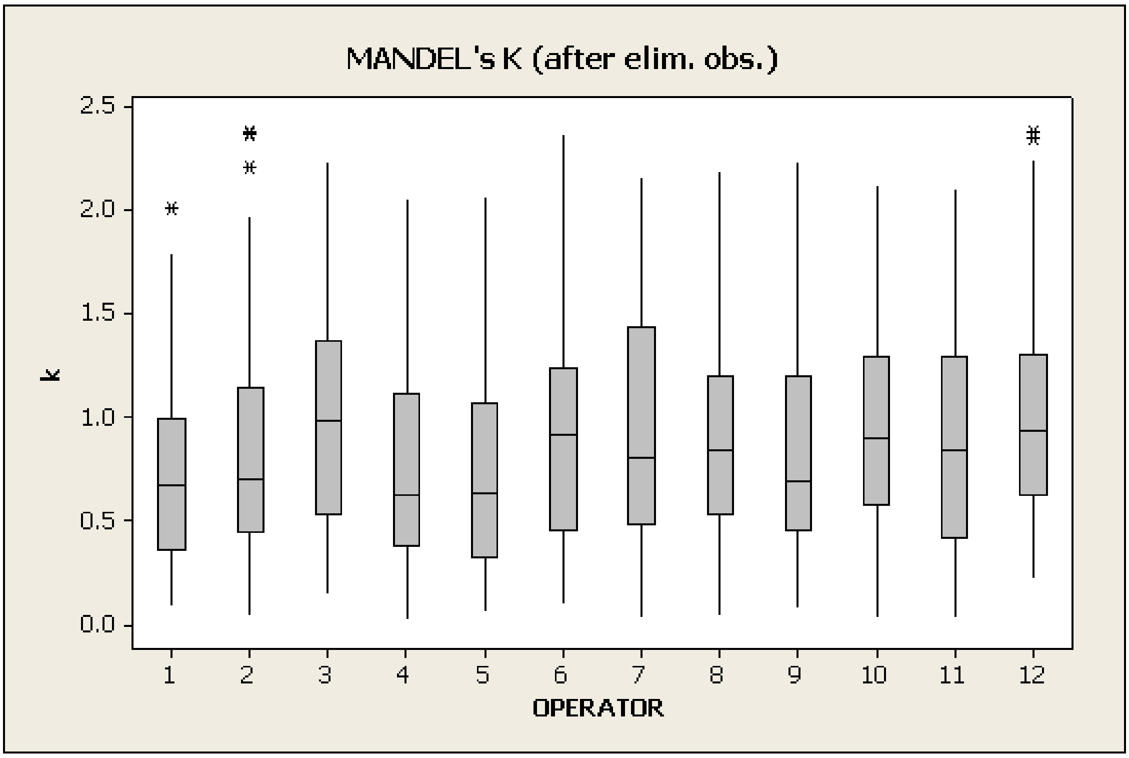


Fig. 26. Boxplot of MANDEL's k_i values as a function of operators (after discarding 84 observations).

The k_i plots show that variability does not vary between operators and that discarding observations reduces the range of the values of k_i. No difference between skilled operators (operator 1 to operator 6) and unskilled operators (operator 7 to operator 12) is visible from these plots.

As a conclusion of this critical examination of observations, we propose to discard all the identified observations by ISO 5725-2 procedure (84 observations) and we consider that no operator shows a special pattern giving us a reason to discard him or her.

6.1.1.2 Individual relative errors

Figures : Fig. 27-Fig. 30 give the distributions of the errors (in percent). Fig. 27 and Fig. 28 give the differences between observations and reference areas, in percent of the reference areas for all data (Fig. 27) and after discarding 84 observations (Fig. 28) :

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

Fig. 29 and Fig. 30 give the differences between observations and the general mean (of all observations made on the parcel), for all the data (Fig. 29Fig. 30) and after discarding 84 observations (Fig. 30):

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

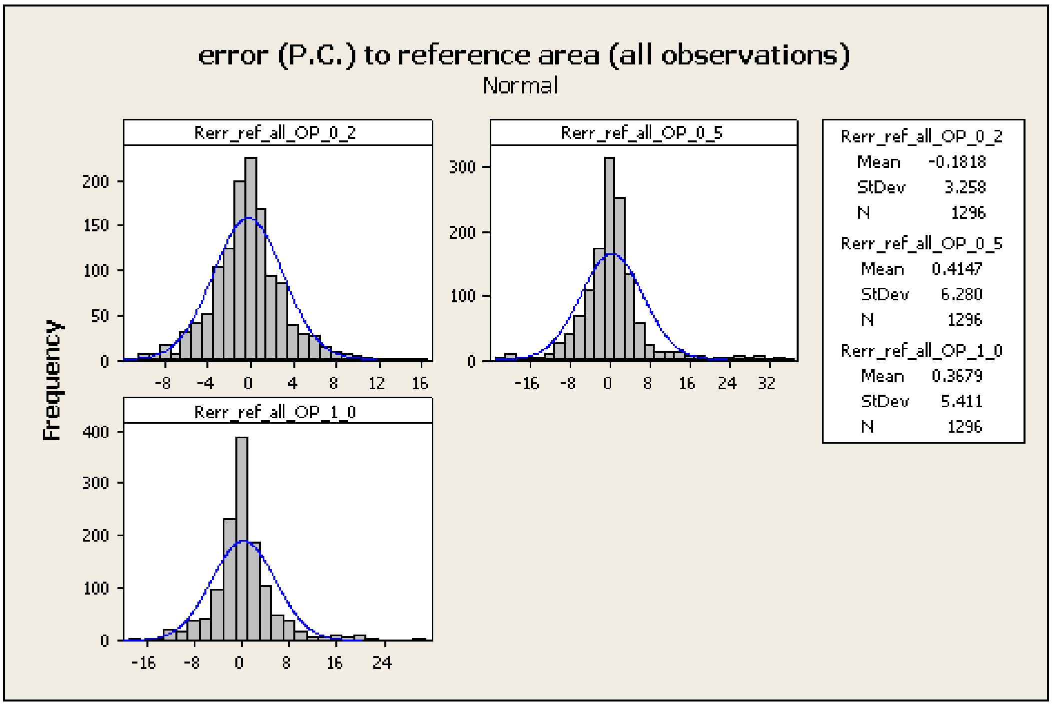


Fig. 27. Histogram of the errors (in percent) to reference area for all observations.

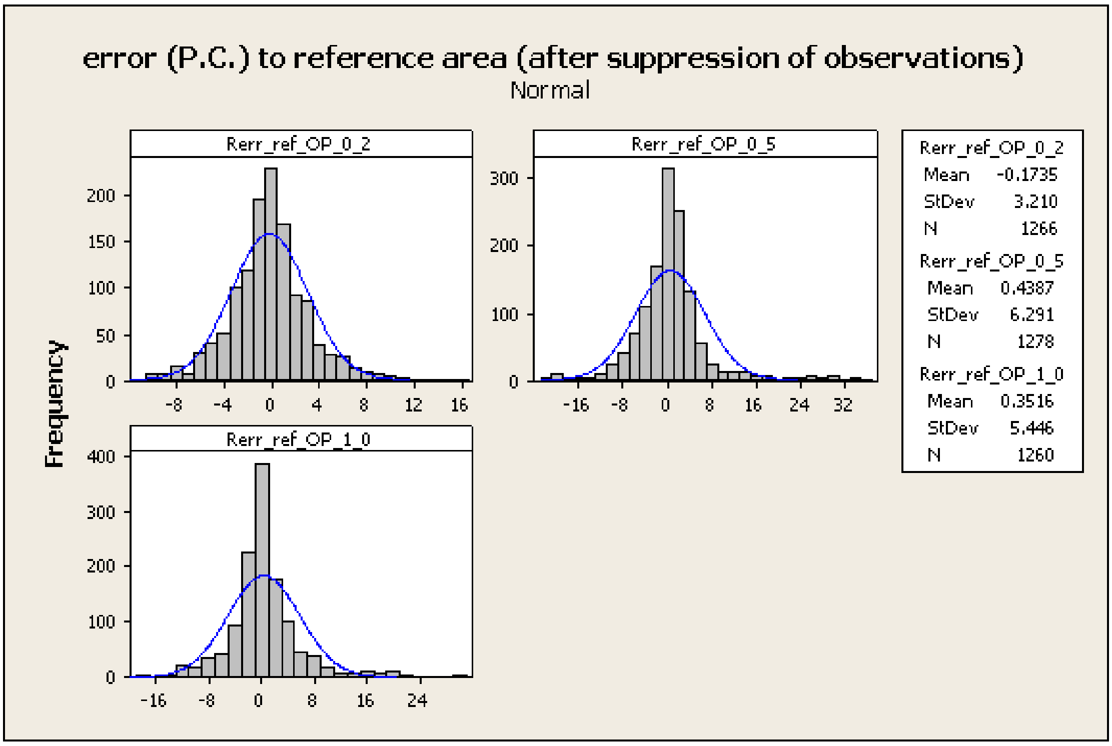


Fig. 28. Histogram of the errors (in percent) to reference area after discarding 84 observations.

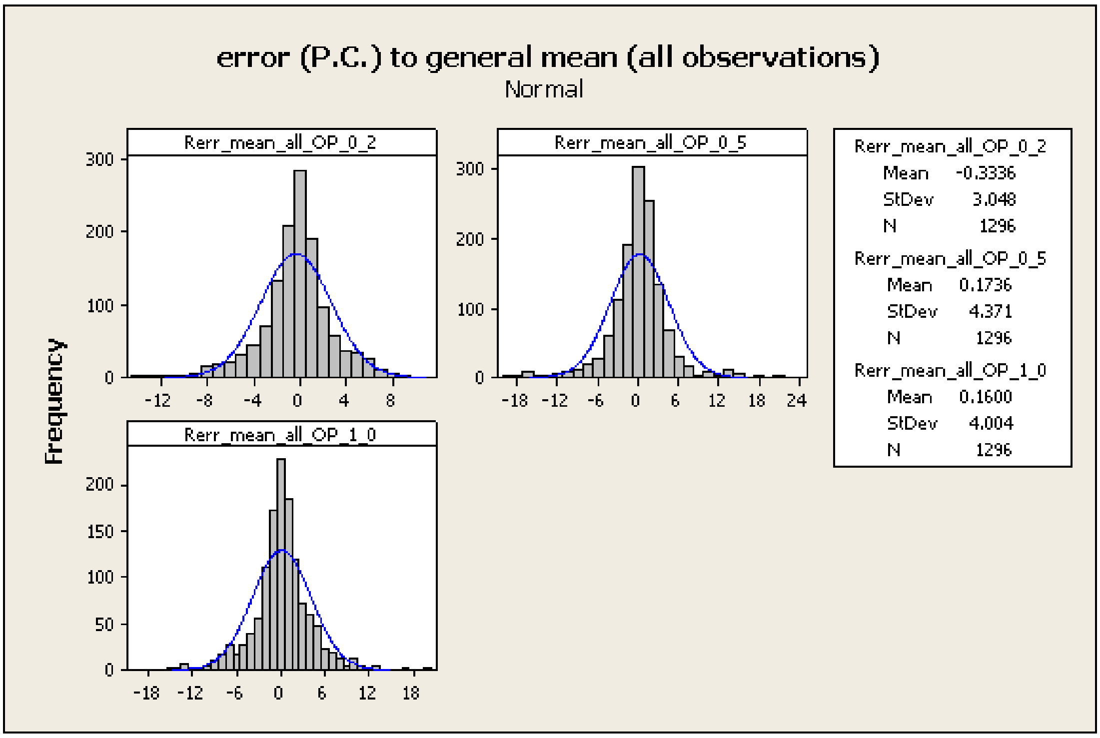


Fig. 29. Histogram of the error (in percent) to the general mean for all observations.

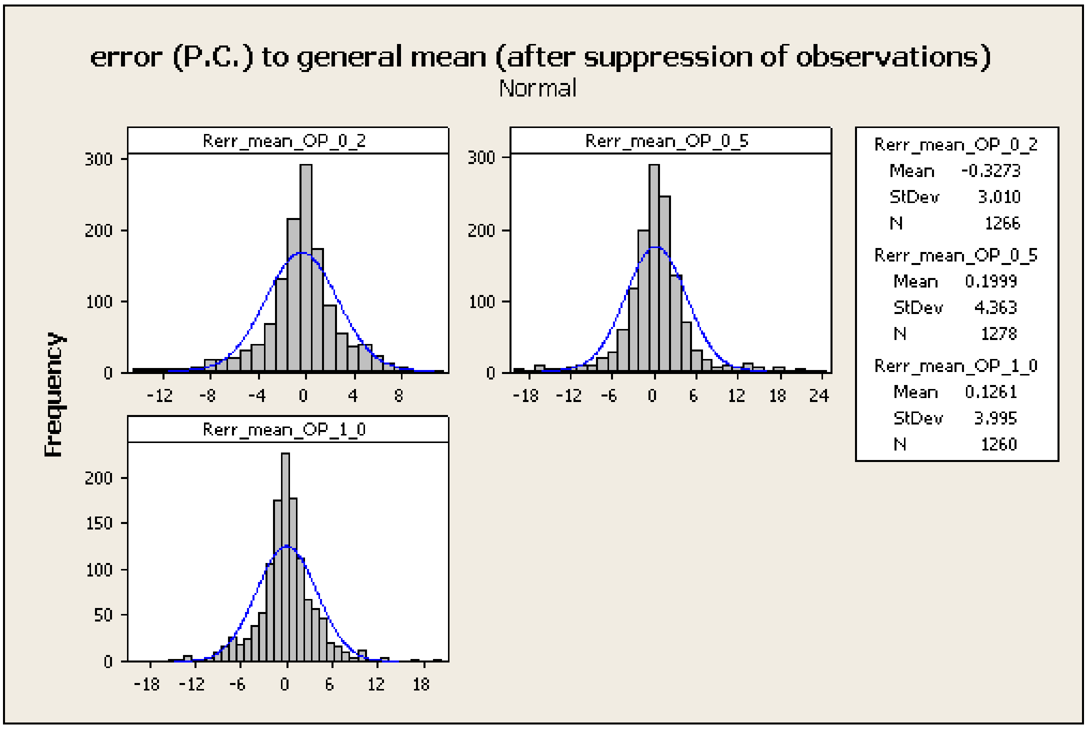


Fig. 30. Histogram of the error (in percent) to the general mean after discarding 84 observations).

Table: Tab 11 gives the percentage of observations with a (absolute) relative error less than a given value. The errors are computed as follows, after discarding 84 observations :

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

From this Tab 11, we can see, for example, that 76.3 percents of observations for photo OP_0_2 show a deviation from the mean smaller or equal to 3 percents. For photos OP_0_5 and OP_1_0, the percentages are 68.4 and 71.0.

Tab 11. .Cumulative percentages of observations as a function of the error (%).

Error (%)	OP_0_2	OP_0_5	OP_1_0
1	40.9	30.2	34.3
2	63.2	52.0	57.2
3	76.3	68.4	68.3
4	83.7	79.3	76.8
5	89.1	85.9	83.4
6	93.4	89.1	88.1
7	95.7	91.9	91.6
8	97.6	93.6	93.9
9	98.8	94.3	95.6
10	99.0	95.0	96.7

6.1.1.3 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 12. Fig. 30gives the histograms of the ratios.

The 95 % confidence intervals are :

- 0.9905 – 1.0061 for photo OP_0_2,
- 0.9860 – 1.0228 for photo OP_0_5,
- and 0.9886 – 1.0181 for photo OP_1_0.

The interval includes the value 1 for each photo. So, we can conclude that the mean value of the ratio for the 36 parcels is not significantly different from 1 and, consequently, we conclude that there is no bias.

Tab 12. Mean values of the observations and ratios mean value/reference area.

Parcels	OP_0_2	OP_0_5	OP_1_0	OP_0_2/Ref	OP_0_5/Ref	OP_1_0/Ref
1	3527	3539	3415	1.028	1.031	0.995
2	3103	3019	2877	0.976	0.949	0.905
3	3931	4046	4147	0.963	0.991	1.016
4	8373	8691	8379	0.991	1.028	0.992
5	12344	12296	12400	0.996	0.993	1.001
6	8519	8503	8740	0.994	0.993	1.020
7	23727	24113	23643	1.009	1.026	1.006
8	28167	28054	28146	1.007	1.003	1.007
9	24199	23773	24293	0.988	0.970	0.991
10	4096	4163	4161	0.988	1.004	1.004
11	3904	4042	3703	1.012	1.048	0.960
12	4896	4549	5009	1.023	0.951	1.047
13	17485	17618	17330	0.985	0.993	0.976
14	13233	13069	13532	1.036	1.024	1.060
15	10880	10934	10966	0.993	0.998	1.001
16	42018	41883	41962	1.007	1.003	1.005
17	30732	30480	30750	0.995	0.987	0.996
18	23767	24412	23519	0.984	1.011	0.974
19	3757	3420	3713	0.990	0.901	0.978
20	3231	3201	3296	0.937	0.929	0.957
21	3836	4571	3934	1.031	1.228	1.057
22	8488	8910	8722	0.964	1.012	0.990
23	9192	8828	9441	1.041	1.000	1.069
24	11263	11767	11488	0.966	1.009	0.985
25	33434	33877	33867	0.993	1.006	1.006
26	27934	28318	28503	1.017	1.031	1.038

27	25918	26097	25826	0.993	1.000	0.989
28	5493	5313	5228	0.962	0.930	0.915
29	2347	2521	2280	1.003	1.078	0.975
30	4420	4625	5023	1.025	1.072	1.165
31	12323	11877	12392	0.999	0.963	1.005
32	10592	10596	10759	1.016	1.017	1.032
33	10672	10057	10780	0.982	0.926	0.992
34	28853	28818	28803	1.011	1.010	1.009
35	44148	44609	43523	1.018	1.029	1.004
36	41643	41688	41043	1.014	1.015	0.999

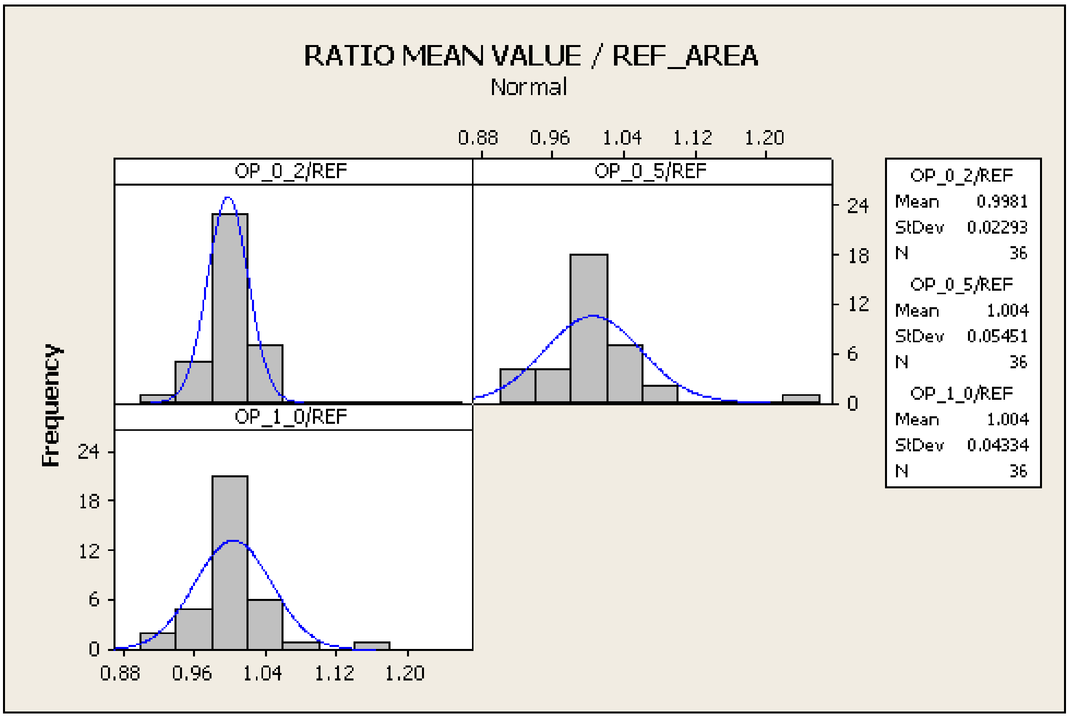


Fig. 31. Histogram of the ratios mean value/reference area.

6.1.1.4 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 13 - Tab 15 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.

Tab 13. Between operators and within operators variance components for photo OP_0_2.

Parcels	Bop	Wop	Repr	B %	W %
1	4489	1990	6479	69	31
2	1697	5434	7131	24	76
3	4128	8382	12510	33	67
4	1888	4556	6444	29	71
5	476	7459	7935	6	94
6	26815	44033	70848	38	62
7	8754	25011	33765	26	74
8	25419	39227	64646	39	61
9	0	78806	78806	0	00
10	5862	1511	7373	80	20
11	1224	3715	4939	25	75
12	347	11595	11942	3	97
13	23012	44759	67771	34	66
14	366624	19111	385735	95	5
15	13315	11356	24671	54	46
16	42552	207909	250461	17	3
17	21813	37203	59016	37	63
18	23435	35076	58511	40	60
19	2614	2940	5554	47	53
20	2158	1409	3567	60	40
21	13039	7842	20881	62	38
22	4756	3554	8310	57	43
23	8202	20663	28865	28	72
24	11100	16915	28015	40	60
25	21886	59121	81007	27	73
26	31725	137286	169011	19	81
27	0	25875	25875	0	100
28	25927	9115	35042	74	26
29	5471	8617	14088	39	61
30	6555	23439	29994	22	78
31	22619	49952	72571	31	69
32	79557	47442	126999	63	37
33	6738	26712	33450	20	80
34	4835	26681	31516	15	85
35	365159	93815	458974	80	20
36	789033	1229667	2018700	39	61

Tab 14. Between operators and within operators variance components for photo OP_0_5.

Parcels	Bop	Wop	Repr	B %	W %
1	1327	2075	3402	39	61
2	1221	5744	6965	18	82
3	8496	7292	15788	54	46
4	1432	5780	7212	20	80
5	3101	25141	28242	11	89
6	26771	48659	75430	35	65
7	14089	16965	31054	45	55
8	5080	36584	41664	12	88
9	44472	91484	135956	33	67
10	3112	2042	5154	60	40
11	7167	24079	31246	23	77
12	9972	26069	36041	28	72
13	10807	92152	102959	10	90
14	171704	86784	258488	66	34
15	0	198238	198238	0	100
16	42984	107560	150544	29	71
17	20759	24711	45470	46	54
18	83554	132507	216061	39	61
19	45112	61881	106993	42	58
20	833	15774	16607	5	95
21	8390	78472	86862	10	90
22	7756	19575	27331	28	72
23	0	36925	36925	0	100
24	29455	36732	66187	45	55
25	16033	65374	81407	20	80
26	46384	101562	147946	31	69
27	55734	48185	103919	54	46
28	4642	13286	17928	26	74
29	2984	11903	14887	20	80
30	0	34615	34615	0	100
31	5161	43056	48217	11	89
32	33614	86381	119995	28	72
33	146023	196957	342980	43	57
34	4052	23725	27777	15	85
35	390111	482784	872895	45	55
36	394015	258499	652514	60	40

Tab 15. Between operators and within operators variance components for photo OP_1_0.

Parcels	Bop	Wop	Repr	B %	W %
1	5562	10824	16386	34	66
2	11878	8470	20348	58	42
3	1737	6505	8242	21	79
4	1851	6949	8800	21	79
5	2351	24166	26517	9	91
6	0	94566	94566	0	100
7	5643	19383	25026	23	77
8	17891	21405	39296	46	54
9	31148	105430	136578	23	77
10	4675	7121	11796	40	60
11	6786	6476	13262	51	49
12	0	20199	20199	0	100
13	57717	102911	160628	36	64
14	201004	769499	970503	21	79
15	4817	24707	29524	16	84
16	37251	81219	118470	31	69
17	7835	36320	44155	18	82
18	10989	39413	50402	22	78
19	2832	1458	4290	66	34
20	0	14307	14307	0	100
21	4996	59327	64323	8	92
22	16014	19270	35284	45	55
23	10656	32730	43386	25	75
24	0	43779	43779	0	100
25	167346	77959	245305	68	32
26	4290	27800	32090	13	87
27	2769	48204	50973	5	95
28	3741	33350	37091	10	90
29	7781	24838	32619	24	76
30	44287	68772	113059	39	61
31	14539	38020	52559	28	72
32	49120	110929	160049	31	69
33	29420	42533	71953	41	59
34	19380	72390	91770	21	79
35	630789	145386	776175	81	19
36	483447	173678	657125	74	26

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

- 38 % between and 62 % within for OP_0_2,
- 29 % between and 71 % within for OP_0_5,
- 29 % between and 71 % within for OP_1_0.

Several transformations of the reproducibility have also been computed:

- the reproducibility standard deviation, $\hat{\sigma}_R$ (labeled SDev);
- the reproducibility coefficient of variation (standard deviation divided by the reference area of the parcel, labeled CoefVar);
- he buffer (standard deviation divided by the perimeter of the parcel);
- the standard deviation divided by a constant (labeled 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 16 - Tab 18.

For these four variables, the boxplots are given by types of "size", "shape" and "border". These plots, given in appendix 11, show that :

- the standard-deviation increases with size;
- the coefficient of variation decreases with size;
- the buffer and the ratio standard deviation/HB seem 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 variable.

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 19 - Tab 21 give the results of several attempts of modeling the buffer.

Tab 16. Transformations of the reproducibility variance for photo OP_0_2.

Parcels	SDev	Buffer	CoefVar	SDev/HB
1	80	0.324	0.023	1.260
2	84	0.214	0.027	0.666
3	112	0.172	0.027	0.904
4	80	0.207	0.009	0.967
5	89	0.171	0.007	0.610
6	266	0.231	0.031	1.714
7	184	0.295	0.008	1.223

8	254	0.357	0.009	2.126
9	281	0.313	0.011	1.983
10	86	0.311	0.021	1.195
11	70	0.187	0.018	0.602
12	109	0.153	0.023	0.703
13	260	0.477	0.015	2.048
14	621	1.267	0.049	5.543
15	157	0.247	0.014	0.965
16	500	0.526	0.012	2.554
17	243	0.252	0.008	1.311
18	242	0.197	0.010	1.410
19	75	0.301	0.020	1.205
20	60	0.138	0.017	0.523
21	145	0.193	0.039	1.303
22	91	0.230	0.010	0.966
23	170	0.351	0.019	1.191
24	167	0.205	0.014	0.823
25	285	0.388	0.008	1.551
26	411	0.469	0.015	2.512
27	161	0.168	0.006	0.816
28	187	0.609	0.033	2.396
29	119	0.427	0.051	2.018
30	173	0.345	0.040	1.144
31	269	0.572	0.022	2.175
32	356	0.761	0.034	2.927
33	183	0.182	0.017	1.180
34	178	0.238	0.006	1.321
35	677	0.643	0.016	4.269
36	1421	1.214	0.035	10.847

Tab 17. Transformations of the reproducibility variance for photo OP_0_5.

Parcels	SDev	Buffer	CoefVar	SDev/HB
1	58	0.235	0.017	0.913
2	83	0.212	0.026	0.658
3	126	0.193	0.031	1.015
4	85	0.219	0.010	1.023
5	168	0.323	0.014	1.151
6	275	0.239	0.032	1.769
7	176	0.283	0.007	1.173
8	204	0.287	0.007	1.707
9	369	0.411	0.015	2.604
10	72	0.260	0.017	0.999
11	177	0.471	0.046	1.515

12	190	0.266	0.040	1.221
13	321	0.588	0.018	2.524
14	508	1.037	0.040	4.538
15	445	0.701	0.041	2.735
16	388	0.408	0.009	1.980
17	213	0.221	0.007	1.151
18	465	0.378	0.019	2.710
19	327	1.323	0.086	5.288
20	129	0.297	0.037	1.129
21	295	0.393	0.079	2.658
22	165	0.417	0.019	1.751
23	192	0.397	0.022	1.347
24	257	0.316	0.022	1.265
25	285	0.389	0.008	1.555
26	385	0.439	0.014	2.350
27	322	0.336	0.012	1.635
28	134	0.435	0.023	1.714
29	122	0.439	0.052	2.075
30	186	0.371	0.043	1.229
31	220	0.466	0.018	1.773
32	346	0.740	0.033	2.845
33	586	0.583	0.054	3.778
34	167	0.223	0.006	1.241
35	934	0.886	0.022	5.888
36	808	0.690	0.020	6.167

Tab 18. Transformations of the reproducibility variance for photo OP_1_0.

Parcels	SDev	Buffer	CoefVar	SDev/HB
1	128	0.515	0.037	2.003
2	143	0.362	0.045	1.124
3	91	0.139	0.022	0.733
4	94	0.241	0.011	1.130
5	163	0.313	0.013	1.115
6	308	0.267	0.036	1.981
7	158	0.254	0.007	1.053
8	198	0.279	0.007	1.657
9	370	0.412	0.015	2.610
10	109	0.394	0.026	1.512
11	115	0.307	0.030	0.987
12	142	0.199	0.030	0.914
13	401	0.734	0.023	3.152
14	985	2.009	0.077	8.793
15	172	0.270	0.016	1.056

16	344	0.362	0.008	1.757
17	210	0.218	0.007	1.134
18	225	0.183	0.009	1.309
19	65	0.265	0.017	1.059
20	120	0.276	0.035	1.048
21	254	0.338	0.068	2.287
22	188	0.473	0.021	1.990
23	208	0.431	0.024	1.461
24	209	0.257	0.018	1.029
25	495	0.675	0.015	2.699
26	179	0.204	0.007	1.094
27	226	0.235	0.009	1.145
28	193	0.626	0.034	2.465
29	181	0.650	0.077	3.071
30	336	0.670	0.078	2.222
31	229	0.487	0.019	1.851
32	400	0.855	0.038	3.286
33	268	0.267	0.025	1.730
34	303	0.406	0.011	2.255
35	881	0.836	0.020	5.552
36	811	0.692	0.020	6.189

Tab 19. Modeling buffer for OP_0_2.

All	Buffer = 0.370 (0.263)
Good border	Buffer = 0.263 (0.091)
Bad border	Buffer = 0.478 (0.331)
All	Buffer = 0.256 + 0.000007 Ref_Area (0.250)
Good border	Buffer = 0.197 + 0.000005 Ref_Area (0.078)
Bad border	Buffer = 0.358 + 0.000007 Ref_Area (0.326)

Tab 20. Modeling buffer for OP_0_5.

All	Buffer = 0.441 (0.247)
Good border	Buffer = 0.373 (0.250)
Bad border	Buffer = 0.509 (0.230)
All	Buffer = 0.413 + 0.000002 Ref_Area (0.249)
Good border	Buffer = 0.398 + 0.000002 Ref_Area (0.257)
Bad border	Buffer = 0.465 + 0.000003 Ref_Area (0.234)

Tab 21. Modeling buffer for OP_1_0.

All	Buffer = 0.447 (0.331)
Good border	Buffer = 0.330 (0.130)
Bad border	Buffer = 0.565 (0.424)

All	Buffer = 0.418 + 0.000002 Ref_Area (0.335)
Good border	Buffer = 0.302 + 0.000002 Ref_Area (0.132)
Bad border	Buffer = 0.572 + 0.000000 Ref_Area (0.437)

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. 32 - Fig. 34. For each model the (residual) standard deviation is given in parentheses.

For all types of photo the factor "border" is important buffer is larger for parcels with bad border and, except for photo OP_0_5, the standard deviation is larger for parcels with good border.

Whether or not it is useful to take into account the size as a second factor depends on the kind of photo. For photos OP_0_5 and OP_1_0 using the reference area in addition to the factor "border" does not improve the model. For photo OP_0_2, the introduction of the reference area into the model slightly decreases the residual standard deviation (from 0,091 to 0,078 for parcels with good border and from 0,331 to 0,326 for parcels with bad border).

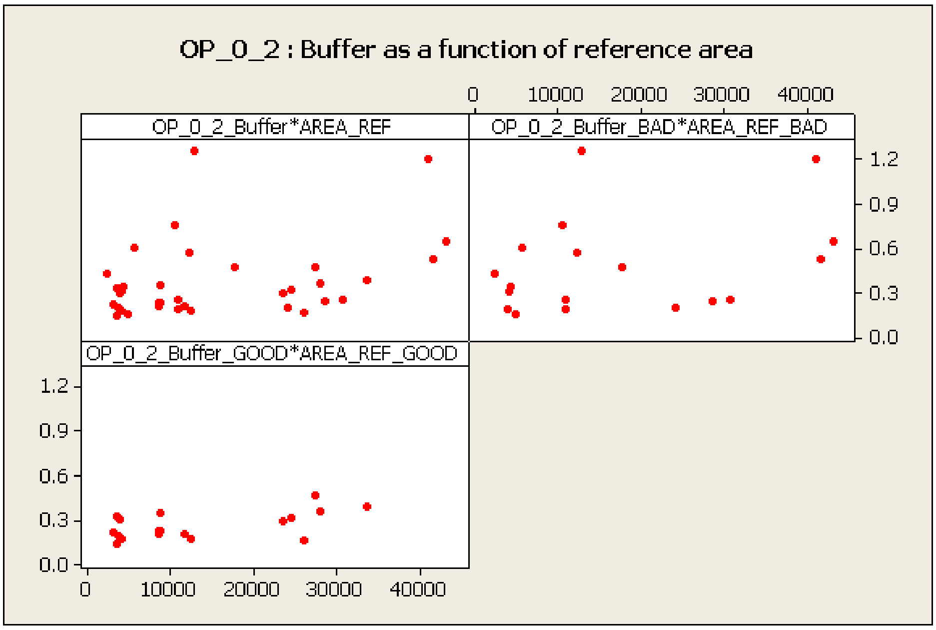


Fig. 32. Buffer as a function of reference area for photo OP_0_2.

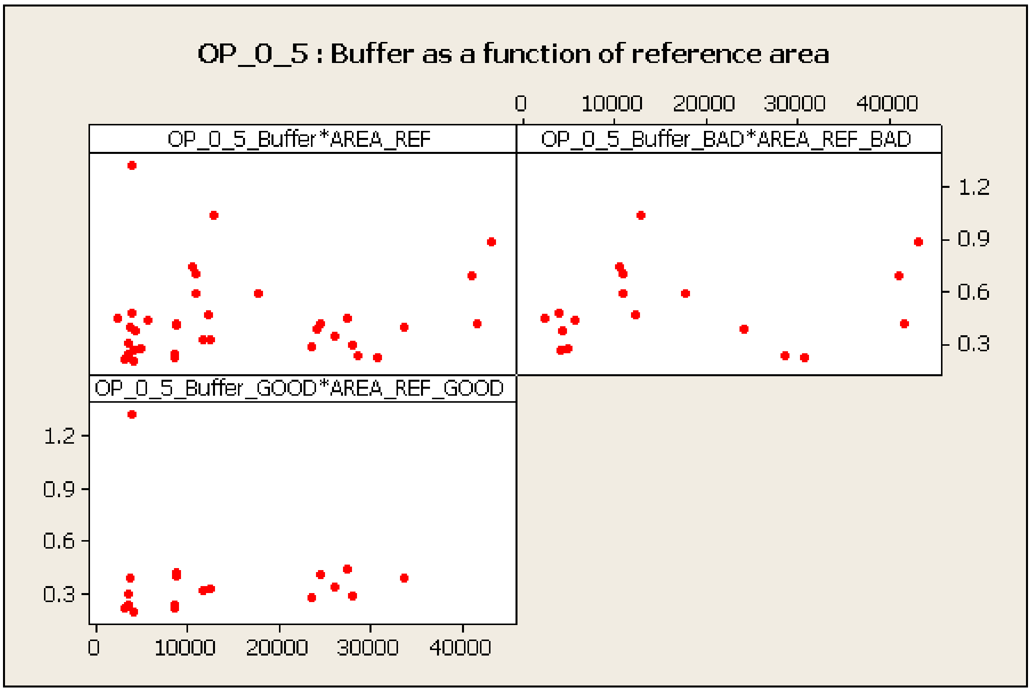


Fig. 33. Buffer as a function of reference area for photo OP_0_5.

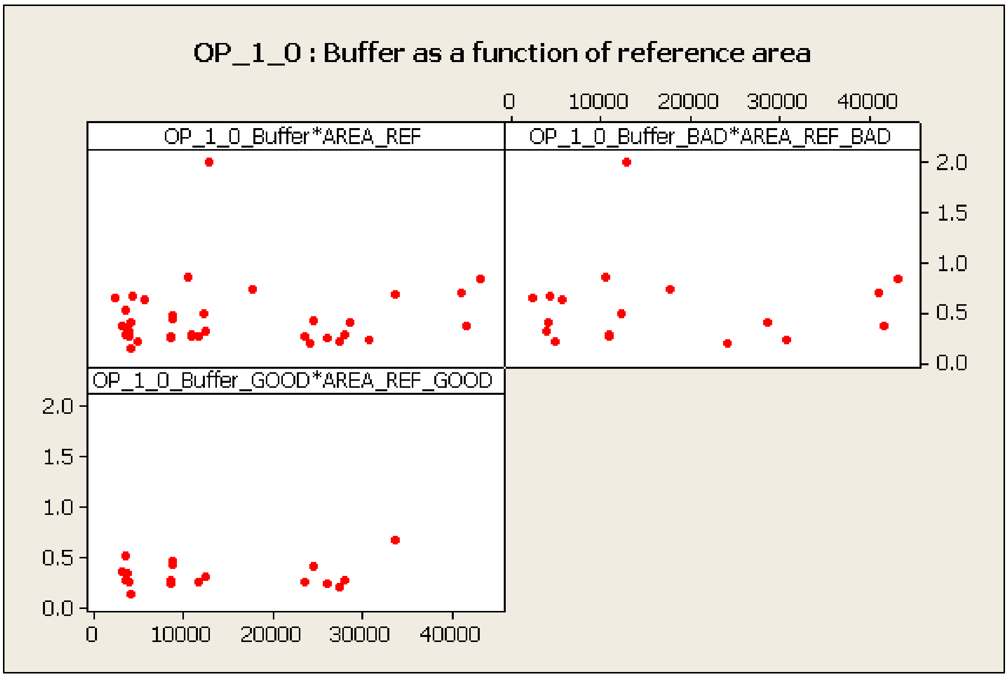


Fig. 34. Buffer as a function of reference area for photo OP_1_0.

6.2 GPS

6.2.1 Experiment A

6.2.1.1 Critical examination of the data

When using ISO 5725-2, the pooling factor is the factor day. Each parcel has been examined by six operators on six different days. The observations are allocated into 324 groups (6 days × 18 parcels × 3 instruments). The 36 observations related to a given instrument of a given parcel (6 groups × 6 operators) are analyzed separately. So the identification of outliers and other irregularities is repeated 54 times (18 parcels × 3 instruments).

Among the 1944 observations, 121 are identified as outliers (6,1 %). Most of them (90) are identified by COCHRAN's test, due to large standard deviation within repetitions for a given day, and 30 are identified by GRUBB's tests due to too extreme mean values for one or two days.

The number of observations identified for a given day vary from 8 (day 4) to 31 (day 1). Regarding the instruments, the numbers of identified observations are as follows 30 observations for GARMIN, 47 observations for SATCON and 44 observations for THALES.

For parcels 1, 4, 5, 6, 13, 14 and 16, the number of observations that are identified lies between ten and twenty. One to ten observations are discarded for parcels 3, 7, 11, 12 and 17.

The complete list of all the 121 observations that are identified is given in appendix 11.

Figures: Fig. 35 - Fig. 38 give the boxplots of the h_i and k_i values, defined by MANDEL, before and after discarding these observations. These figures do not exhibit a special pattern and we consider that no day should be discarded.

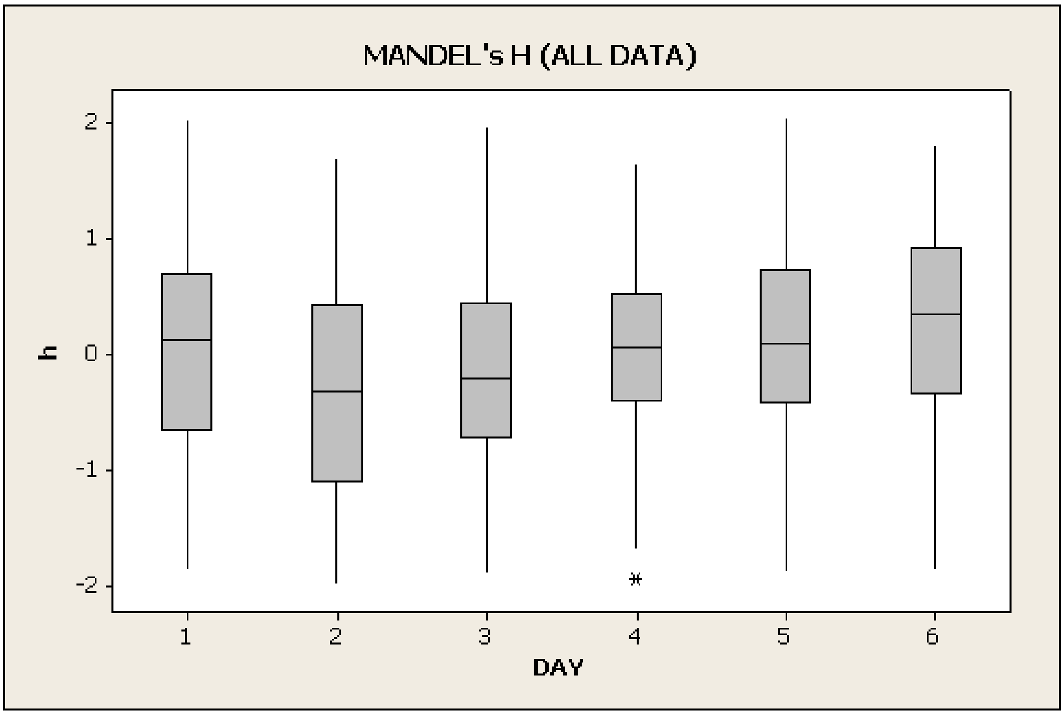


Fig. 35. Experiment A – Boxplot of MANDEL's h_i values as a function of days (before discarding observations).

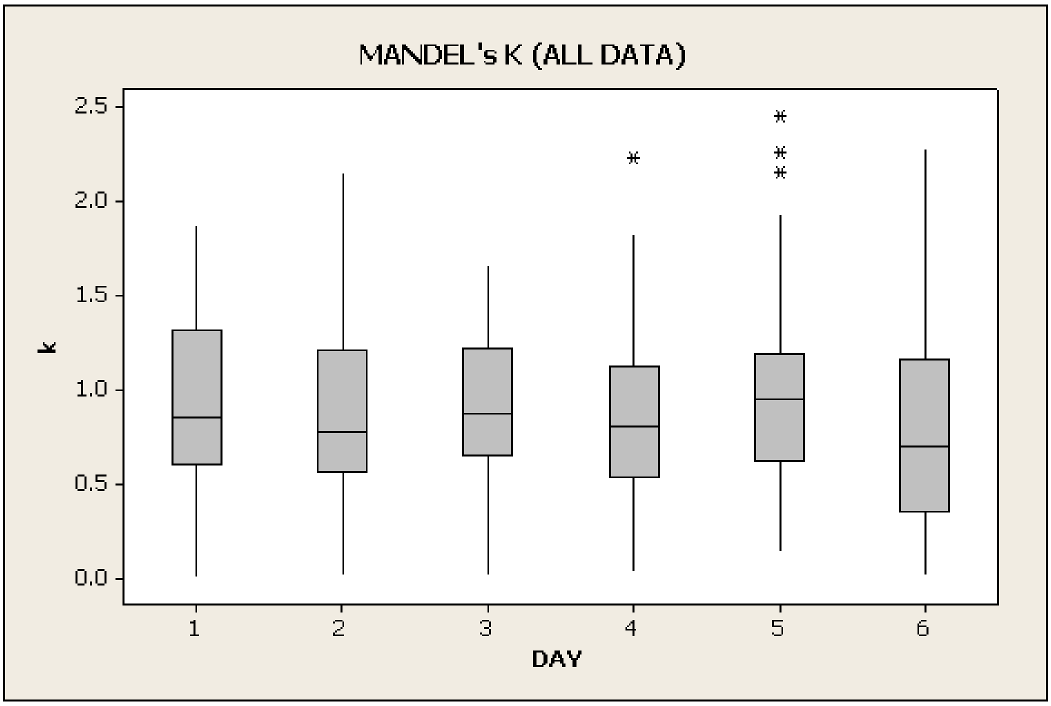


Fig. 36. Experiment A – Boxplot of MANDEL's k_i values as a function of days (before discarding observations).

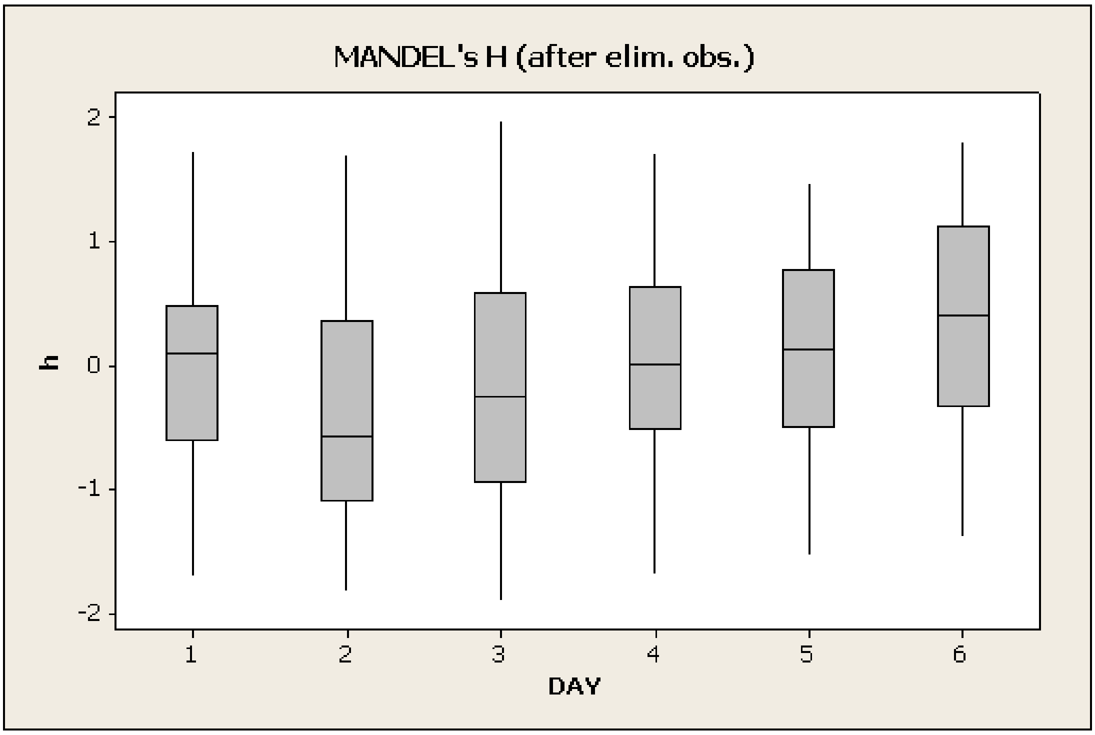


Fig. 37. Experiment A – Boxplot of MANDEL's h_i values as a function of days (after discarding 121 observations).

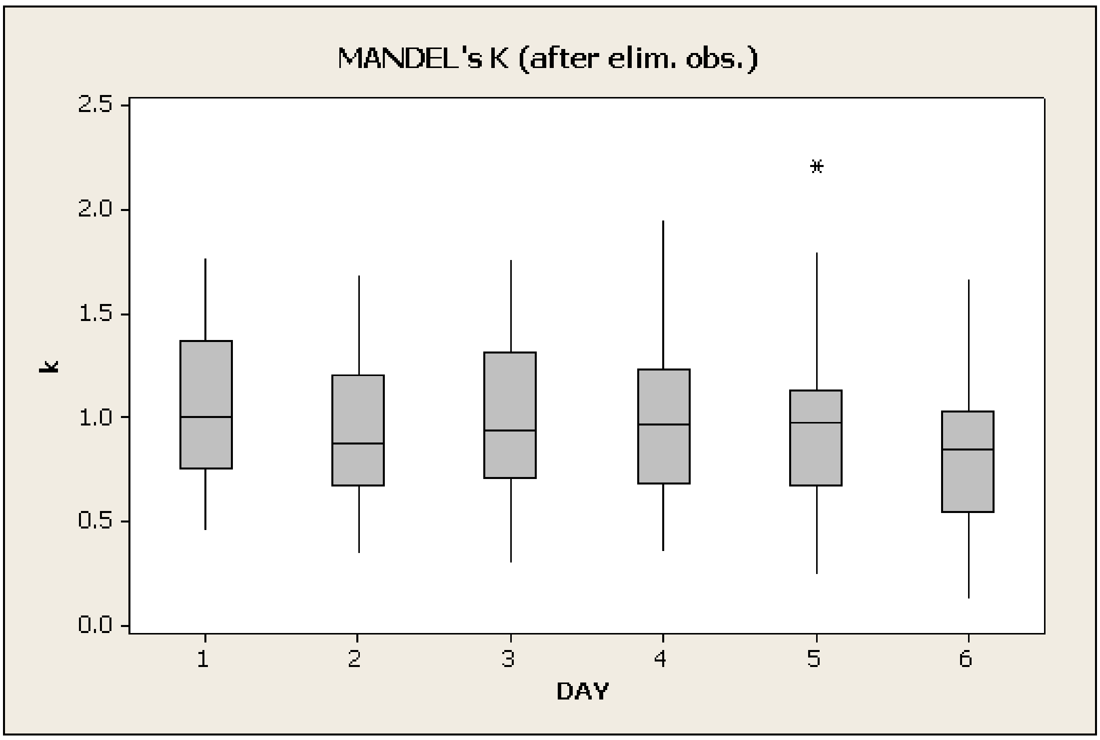


Fig. 38. Experiment A – Boxplot of MANDEL's k_i values as a function of days (after discarding 121 observations).

6.2.1.2 Individual relative errors

Figures: Fig. 39 - Fig. 42give the distributions of the errors (in percent). Figures: Fig. 39 and Fig. 40 give the differences between observations and reference areas, in percent of the reference areas for all data (Fig. 39) and after discarding 121 observations (Fig. 40):

(31) relative error = 100 (observation – general mean)/reference area.

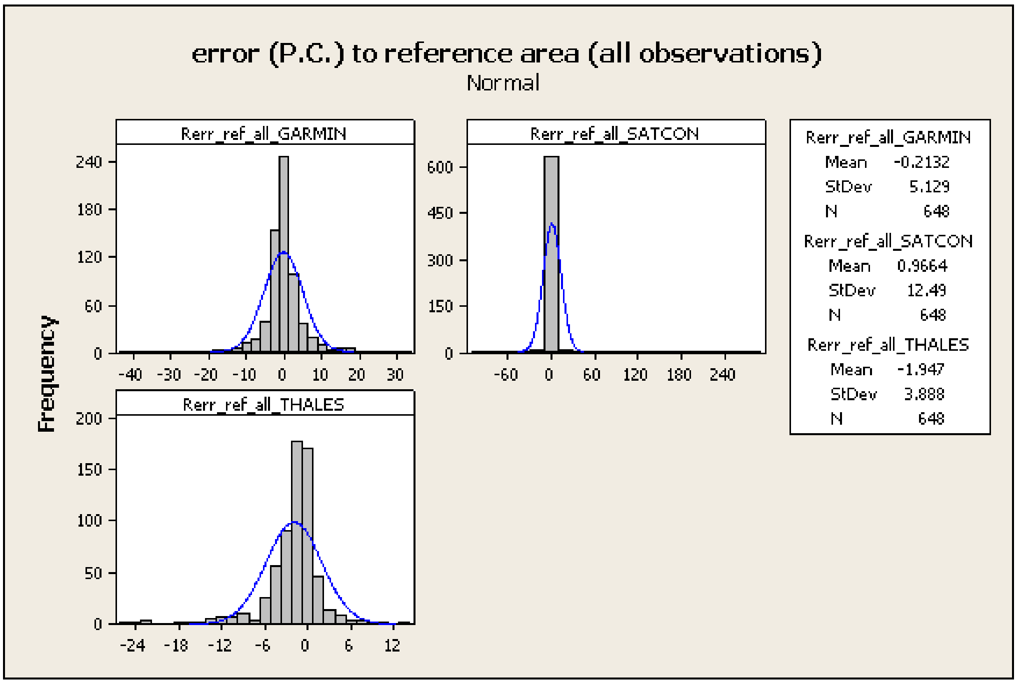


Fig. 39. Experiment A – Histogram of the errors (in percent) to reference area for all observations.

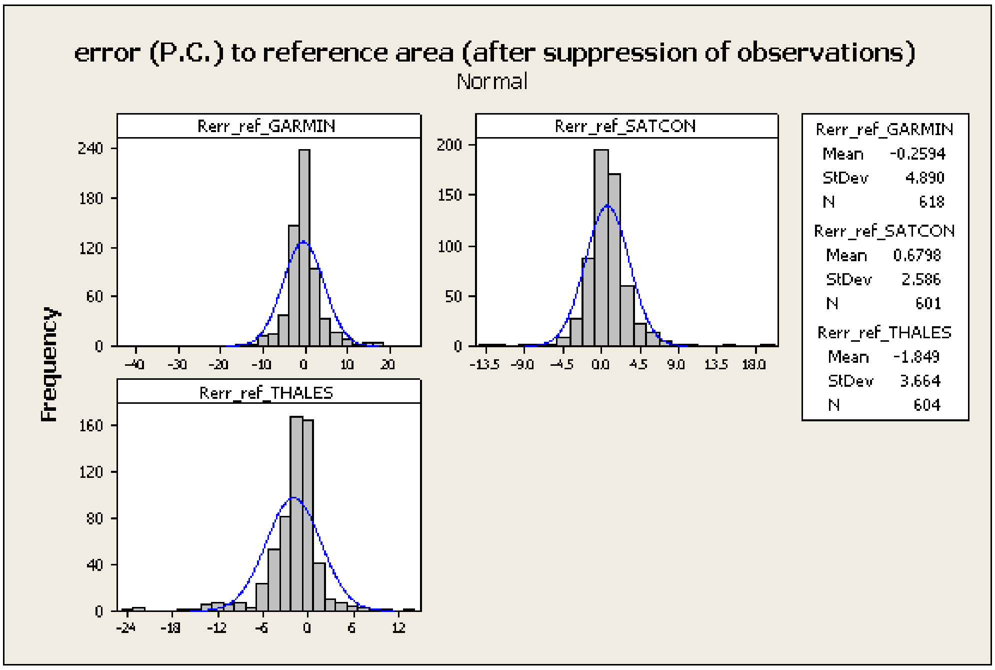


Fig. 40. Experiment A – Histogram of the errors (in percent) to reference area after discarding 121 observations.

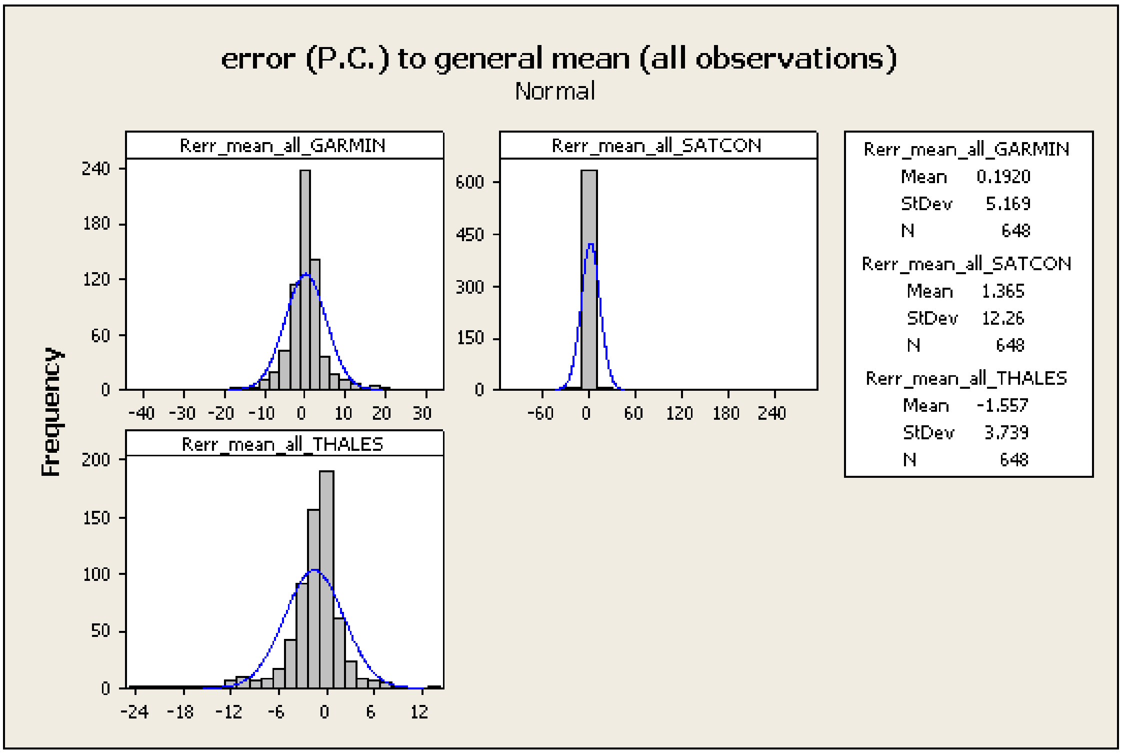


Fig. 41. Experiment A – Histogram of the errors (in percent) to the general mean for all observations.

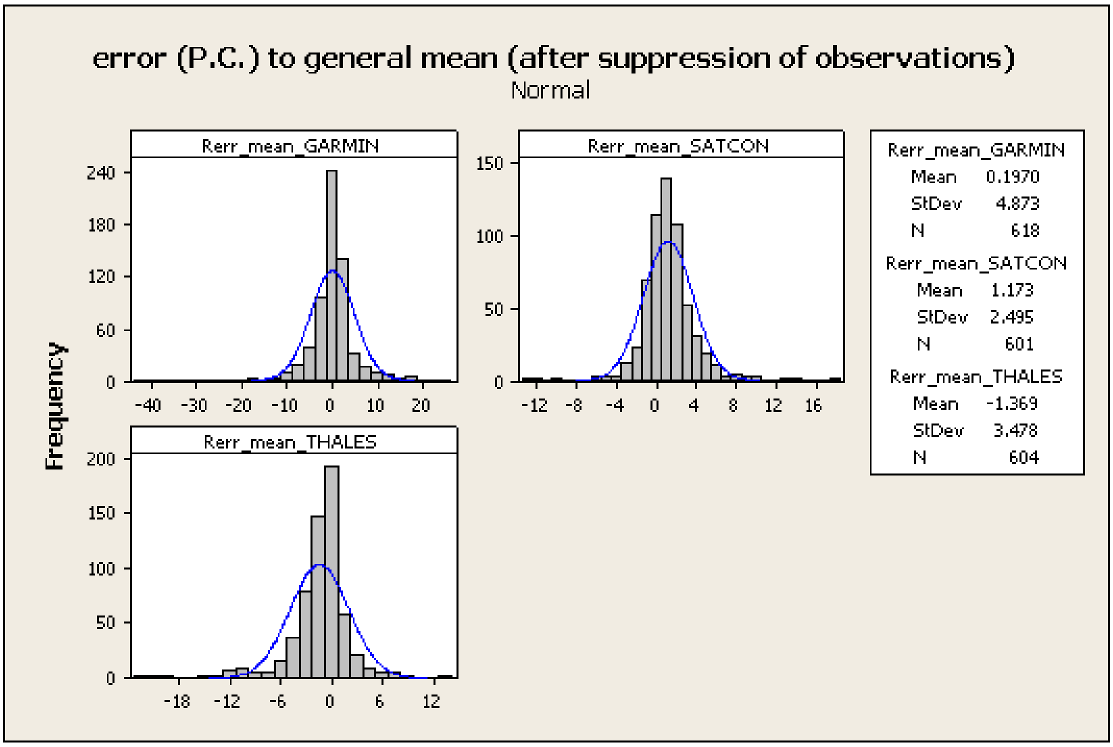


Fig. 42. Experiment A – Histogram of the errors (in percent) to the general mean after discarding 121 observations.

Figures :Fig. 41 and Fig. 42 give the differences between observations and the general mean (of all observations made on the parcel), for all the data (Fig. 41) and after discarding 121 observations (Fig. 42) :

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

Table: Tab 22 gives the percentage of observations with a (absolute) relative error less than a given value. The errors are computed as follows, after discarding 121 observations:

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

From this Tab 22, we can see, for example, that 68.8 percents of observations for GARMIN show a deviation from the mean smaller or equal to 3 percents. For SATCON and THALES, the percentages are 82.4 and 75.2.

Tab 22. Experiment A - Cumulative percentages of observations as a function of the error (%).

Error (%)	GARMIN	SATCON	THALES
1	30.1	39.4	39.6
2	54.2	66.6	63.9
3	68.8	82.4	75.2
4	79.5	89.7	84.4
5	84.3	93.7	88.7
6	87.4	96.5	92.1
7	90.3	97.3	93.9
8	92.1	98.3	95.0
9	94.0	98.7	95.5
10	95.6	99.2	96.2

6.2.1.3 Bias of the instruments

For each instrument and for each parcel, the ratio between the general mean and the reference area is computed. These ratios are given in Tab 23. Figure Fig. 43 gives the histograms of the ratios.

The 95 % confidence intervals are :

- 0.9910 – 1.0039 for GARMIN,
- 1.0014 – 1.0126 for SATCON,
- and 0.9741 – 0.9900 for THALES.

The interval includes the value 1 only for GARMIN. So, we can conclude that the mean value of the ratio for the 18 parcels is significantly different from 1 for SATCON and THALES : SATCON overestimates the reference areas and THALES underestimates the reference areas.

Tab 23. Experiment A – Means values of the observations and ratios mean value/reference area.

Parcels	GARMIN	SATCON	THALES	G/Ref	S/Ref	T/Ref
1	4912	4942	4827	1.015	1.021	0.997
2	3918	4140	4017	0.961	1.015	0.985
3	4257	4330	4198	1.002	1.019	0.988
4	11468	11277	11156	1.022	1.005	0.994
5	12463	12648	12400	0.997	1.011	0.992
6	9574	9728	9598	0.993	1.009	0.996
7	29409	29675	29380	0.991	1.000	0.990
8	28341	28434	27956	1.000	1.003	0.986
9	29047	29400	29108	0.990	1.002	0.992
10	3687	3813	3680	0.999	1.033	0.997
11	3885	3957	3801	1.001	1.019	0.979
12	4196	4219	3952	0.992	0.997	0.934
13	7090	6963	6936	1.005	0.987	0.983
14	7759	7695	7404	1.002	0.994	0.957
15	10346	10301	10002	1.007	1.003	0.974
16	33223	33904	33309	0.983	1.004	0.986
17	28223	28547	27876	0.992	1.003	0.980
18	29643	29553	28613	1.002	0.999	0.968

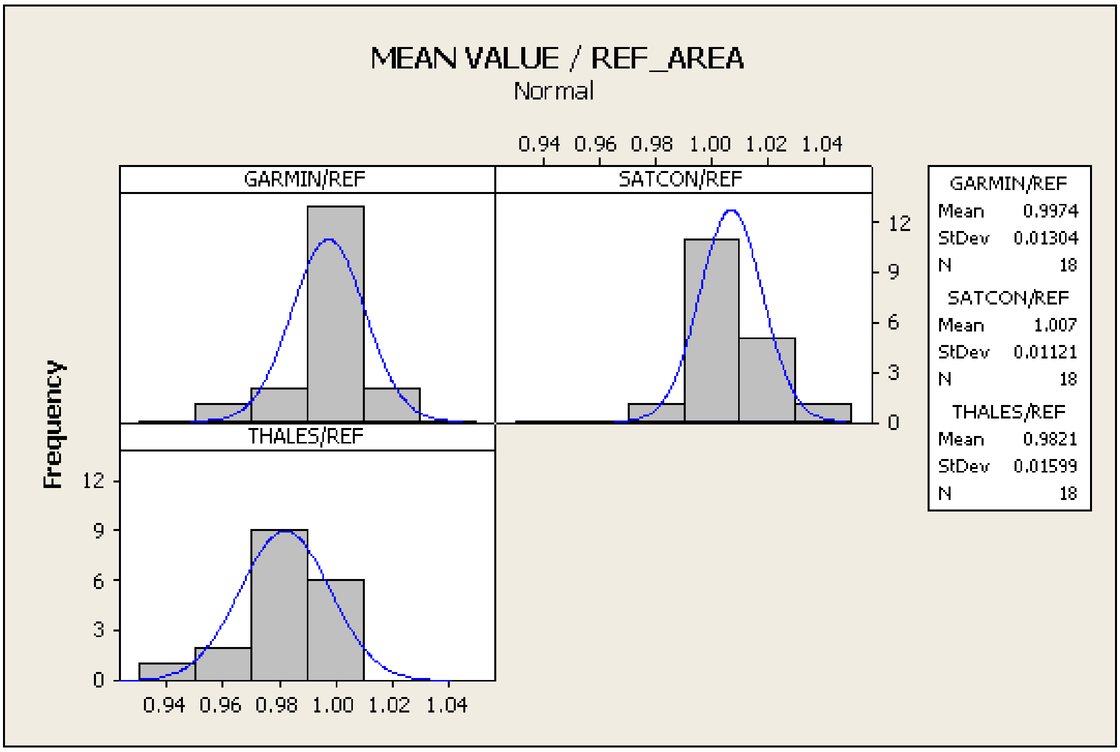


Fig. 43. Experiment A – Histogram of the ratios mean value/reference area.

6.2.1.4 Variance components and reproducibility

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

Tables: Tab 24 -Tab 26 give the variance components and the reproducibility for each parcel (labeled Bdays, Wdays and Repr). The variance components have also been expressed in percentage of the reproducibility.

Tab 24. Experiment A – Between days and within days variance components for GARMIN.

Parcels	Bdays	Wdays	Repr	B%	W%
1	48804	30776	79580	61	39
2	0	197376	197376	0	100
3	0	83796	83796	0	100
4	6374	90547	96921	7	93
5	0	235040	235040	0	100
6	17864	32320	50184	36	64
7	26276	85549	111825	23	77
8	0	1215955	1215955	0	100
9	38279	653476	691755	6	94
10	0	33659	33659	0	100
11	46724	56085	102809	45	55
12	8686	40658	49344	18	82
13	0	11104	11104	0	100
14	0	54207	54207	0	100
15	0	209965	209965	0	100
16	53260	1464739	1517999	4	96
17	0	280013	280013	0	100
18	53518	446849	500367	11	89

Tab 25. Experiment A – Between days and within days variance components for SATCON.

Parcels	Bdays	Wdays	Repr	B%	W%
1	7438	13490	20928	36	64
2	0	14222	14222	0	100
3	0	2510	2510	0	100

4	8350	18619	26969	31	69
5	0	43597	43597	0	100
6	8581	5627	14208	60	40
7	107861	83703	191564	56	44
8	0	102186	102186	0	100
9	0	54124	54124	0	100
10	6447	40317	46764	14	86
11	407	11745	12153	3	97
12	0	12239	12239	0	100
13	1936	17428	19364	10	90
14	0	79307	79307	0	100
15	6960	22811	29771	23	77
16	0	170634	170634	0	100
17	42914	54785	97699	44	56
18	7934	63213	71147	11	89

Tab 26. Experiment A – Between days and within days variance components for THALES.

Parcels	Bdays	Wdays	Repr	B%	W%
1	54	10348	10402	1	99
2	0	17451	17451	0	100
3	0	13395	13395	0	100
4	0	43191	43191	0	100
5	0	44069	44069	0	100
6	1455	2055	3510	41	59
7	100	100483	100583	0	100
8	0	176693	176693	0	100
9	13624	64603	78227	17	83
10	4510	40417	44927	10	90
11	0	18607	18607	0	100
12	0	107023	107023	0	100
13	7790	7059	14849	52	48
14	0	139054	139054	0	100
15	0	225536	225536	0	100
16	36400	226260	262660	14	86
17	26211	245473	271684	10	90
18	11507	1022631	1034138	1	99

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

- 12 % between and 88 % within for GARMIN,
- 16 % between and 84 % within for SATCON,

- 8 % between and 92 % within for THALES.

Several transformations of the reproducibility have also been computed :

- - the reproducibility standard deviation (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 (labeled 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 27 - Tab 29.

Tab 27. Experiment A – Transformations of the reproducibility variance for GARMIN.

Parcels	SDev	Buffer	CoefVar	SDev/HB
1	282	0.677	0.058	3.625
2	444	1.174	0.109	7.567
3	289	1.052	0.068	4.964
4	311	0.504	0.028	3.281
5	485	0.815	0.039	5.283
6	224	0.543	0.023	2.992
7	334	0.292	0.011	2.358
8	1103	1.103	0.039	8.176
9	832	1.129	0.028	8.388
10	183	0.444	0.050	2.367
11	321	0.895	0.083	4.759
12	222	0.773	0.053	4.536
13	105	0.185	0.015	1.331
14	233	0.404	0.030	2.750
15	458	1.045	0.045	5.759
16	1232	1.186	0.036	10.182
17	529	0.566	0.019	4.284
18	707	0.945	0.024	7.808

Tab 28. Experiment A – Transformations of the reproducibility variance for SATCON.

Parcels	SDev	Buffer	CoefVar	SDev/HB
1	145	0.347	0.030	1.859
2	119	0.315	0.029	2.031
3	50	0.182	0.012	0.859
4	164	0.266	0.015	1.731
5	209	0.351	0.017	2.275
6	119	0.289	0.012	1.592
7	438	0.382	0.015	3.087
8	320	0.320	0.011	2.370

9	233	0.316	0.008	2.346
10	216	0.523	0.059	2.790
11	110	0.308	0.028	1.636
12	111	0.385	0.026	2.259
13	139	0.245	0.020	1.758
14	282	0.488	0.036	3.326
15	173	0.394	0.017	2.169
16	413	0.398	0.012	3.414
17	313	0.334	0.011	2.531
18	267	0.356	0.009	2.944

Tab 29. Experiment A – Transformations of the reproducibility variance for THALES.

Parcels	SDev	Buffer	CoefVar	SD ev/HB
1	102	0.245	0.021	1.311
2	132	0.349	0.032	2.250
3	116	0.421	0.027	1.985
4	208	0.336	0.019	2.190
5	210	0.353	0.017	2.288
6	59	0.144	0.006	0.791
7	317	0.277	0.011	2.237
8	420	0.421	0.015	3.117
9	280	0.380	0.010	2.821
10	212	0.513	0.057	2.734
11	136	0.381	0.035	2.025
12	327	1.138	0.077	6.680
13	122	0.214	0.017	1.539
14	373	0.646	0.048	4.405
15	475	1.083	0.046	5.969
16	513	0.493	0.015	4.235
17	521	0.557	0.018	4.220
18	1017	1.358	0.034	11.224

For these four variables, the boxplots are given by types of "size", "shape" and "border" in appendix 11.These plots show that :

- the standard-deviation increases with size;
- the coefficient of variation decreases with size;
- the buffer and the ratio standard deviation/HB seem only to be slightly related to size.

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 30 - Tab 32 give the results of several attempts of modeling the buffer.

Tab 30. Experiment A – Modeling buffer for GARMIN.

All	Buffer = 0.763 (0.322)

Good border	Buffer = 0.810 (0.322)
Bad border	Buffer = 0.716 (0.334)
All	Buffer = 0.671 + 0.000006 Ref_Area (0.324)
Good border	Buffer = 0.836 + 0.000002 Ref_Area (0.344)
Bad border	Buffer = 0.538 + 0.000012 Ref_Area (0.316)

Tab 31. Experiment A – Modeling buffer for SATCON.

All	Buffer = 0.344 (0.081)
Good border	Buffer = 0.308 (0.058)
Bad border	Buffer = 0.381 (0.086)
All	Buffer = 0.338 + 0.000000 Ref_Area (0.083)
Good border	Buffer = 0.272 + 0.000002 Ref_Area (0.055)
Bad border	Buffer = 0.396 + 0.000001 Ref_Area (0.099)

Tab 32. Experiment A – Modeling buffer for THALES.

All	Buffer = 0.517 (0.338)
Good border	Buffer = 0.325 (0.090)
Bad border	Buffer = 0.709 (0.389)
All	Buffer = 0.465 + 0.000004 Ref_Area (0.346)
Good border	Buffer = 0.299 + 0.000002 Ref_Area (0.094)
Bad border	Buffer = 0.627 + 0.000006 Ref_Area (0.409)

The first three lines in these tables give the general mean and the means of 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. 44 - Fig. 46. For each model the (residual) standard deviation is given in parentheses.

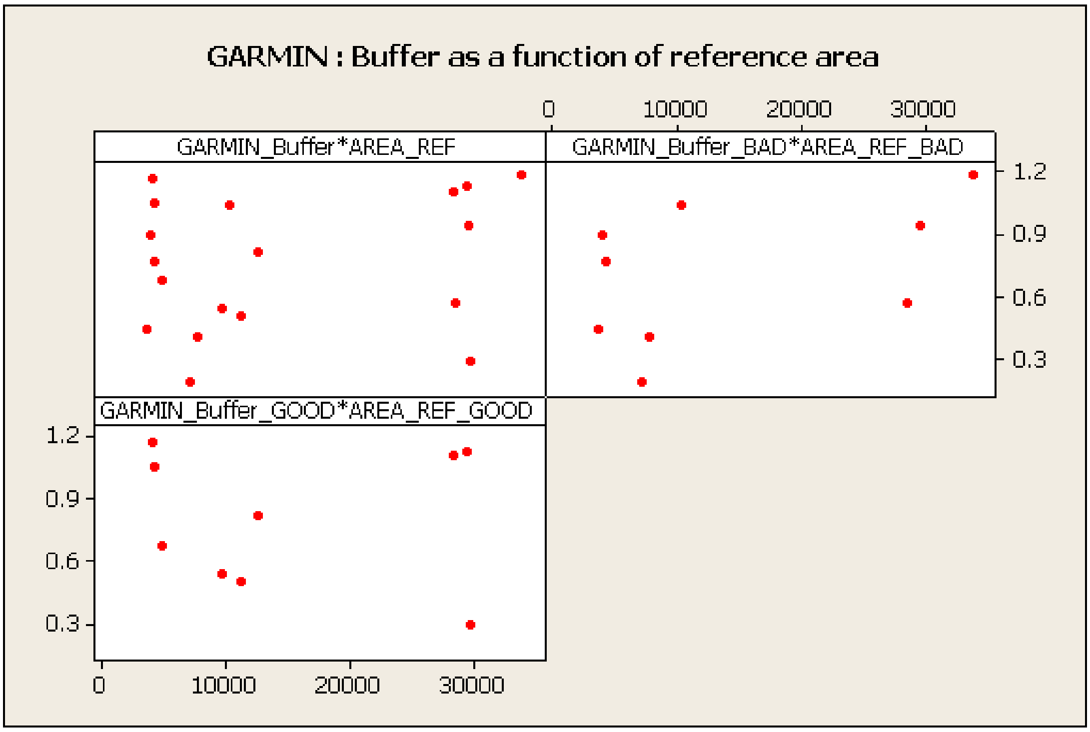


Fig. 44. Experiment A – Buffer as a function of reference area for GARMIN.

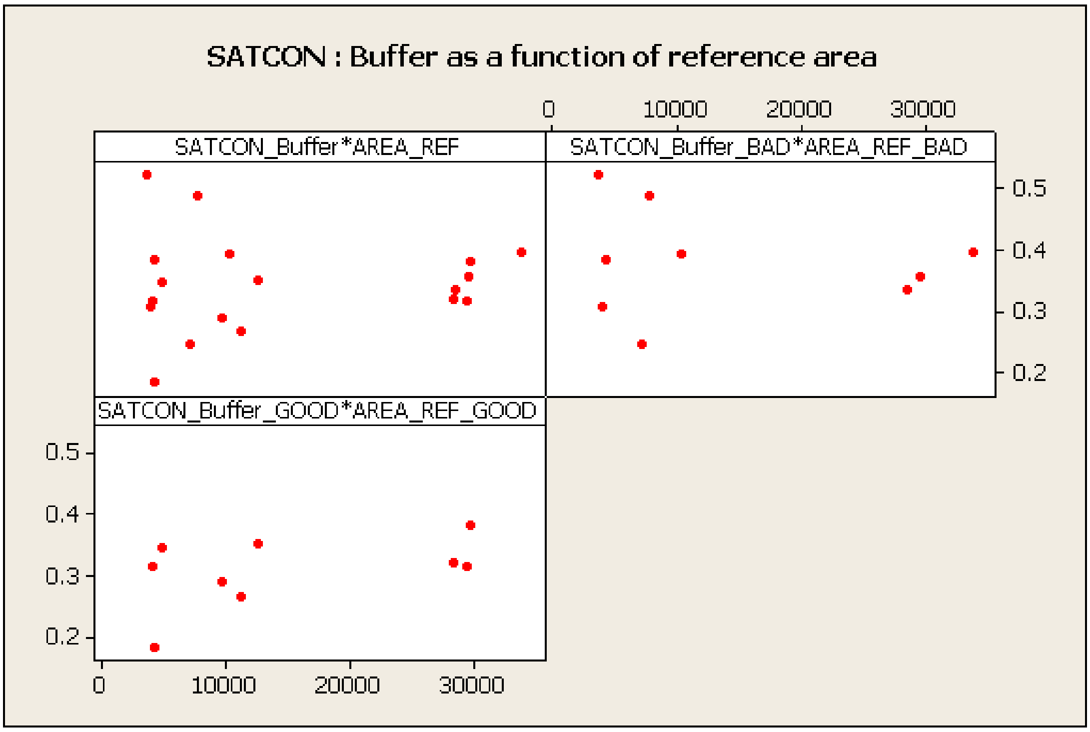


Fig. 45. Experiment A – Buffer as a function of reference area for SATCON.

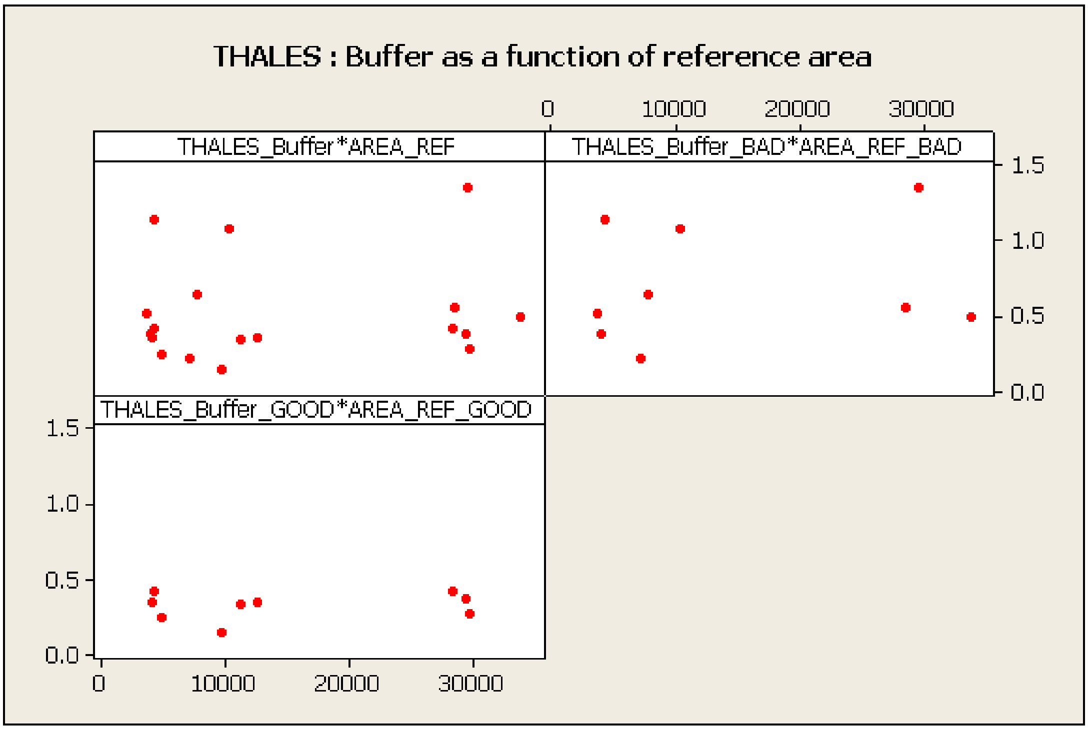


Fig. 46. Experiment A – Buffer as a function of reference area for THALES.

For GARMIN, the factor "border" and the factor "Reference area" are not significant. For SATCON and THALES, the factor "border" is significant but the factor "Reference area" is not significant.

6.2.2 Experiment B

6.2.2.1 Critical examination of the data

When using ISO 5725-2, the pooling factor is the factor day. Each parcel has been examined by four operators on six different days. The observations are allocated into 432 groups (6 days × 18 parcels × 4 instruments). The 24 observations related to a given instrument of a given parcel (6 days × 4 operators) are analyzed separately. So the identification of outliers and other irregularities is repeated 72 times (18 parcels × 4 instruments).

Among the 1728 observations, 99 are identified as outliers (5,7 %). Most of them (78) are identified by COCHRAN's test, due to large standard deviation within repetitions for a given day.

For day 2, 21 observations are identified; for days 3, 4 and 5 from 10 to 15 observations are identified and for days and 6 only 4 and 6 observations are identified.

For the two SATCON instruments, 36 and 35 observations are identified; 12 and 16 for the two THALES.

Concerning the parcels, parcels 19, 26, 28 and 33 have from 11 to 20 outliers and parcels 21, 23, 25, 27, 29, 31, 32 and 36 have from 1 to 10 outliers.

The complete list of all the 99 observations that are identified is given in appendix 11

Figures Fig. 47 to Fig. 50 give the boxplots of the h_i and k_i values, defined by MANDEL, before and after discarding these observations. Figure 27 shows that the means of the groups for day 4 are often smaller than the means for the other days. Nevertheless, we propose not to discard this day.

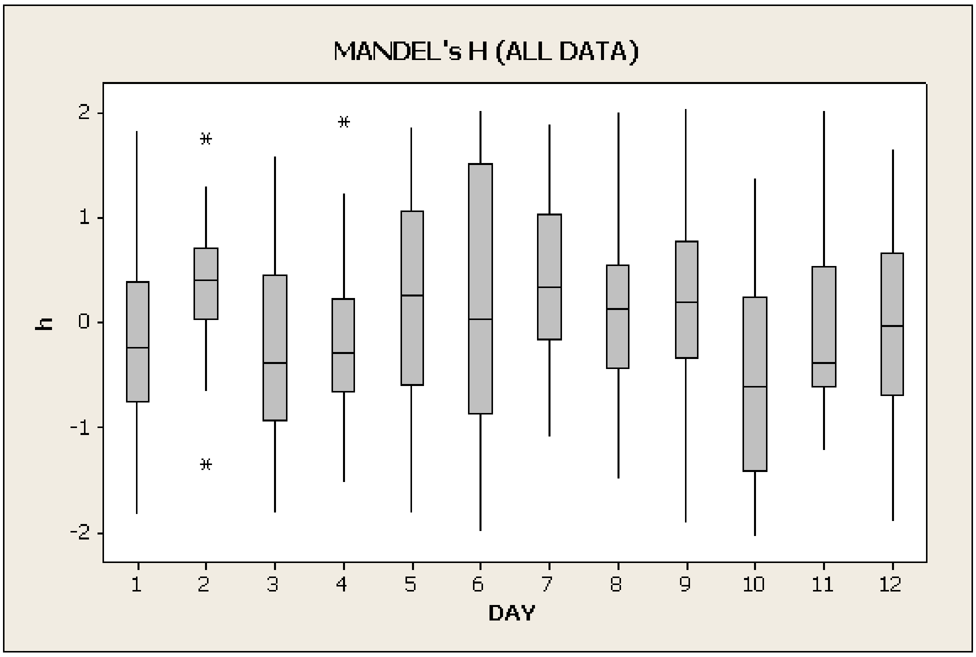


Fig. 47. Experiment B – Boxplot of MANDEL's h_i values as a function of days (before discarding observations).

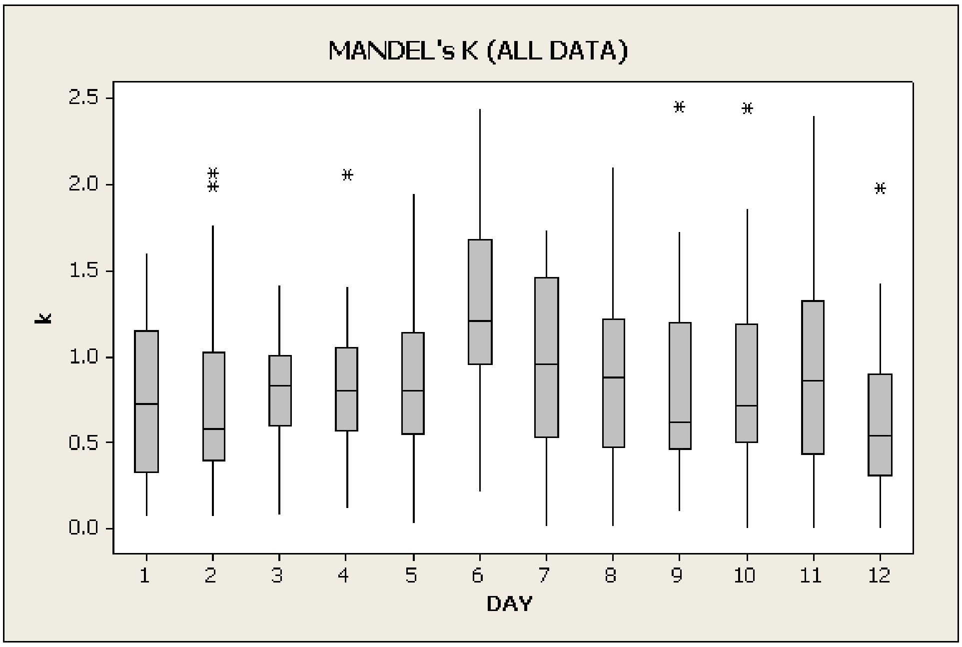


Fig. 48. Experiment B – Boxplot of MANDEL's k_i as a function of days (before discarding observations).

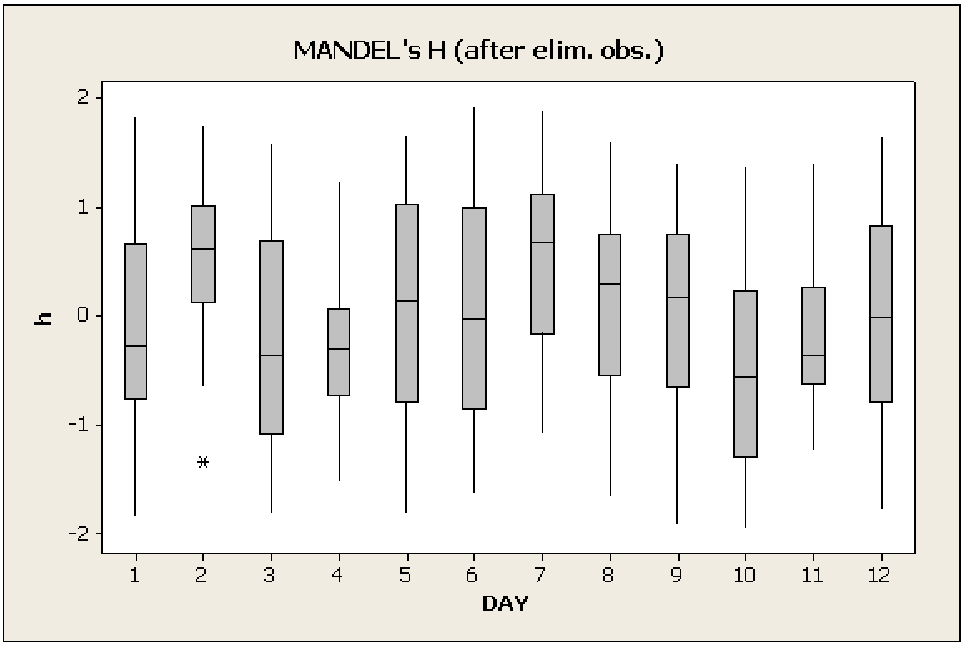


Fig. 49. Experiment B – Boxplot of MANDEL's h_i values as a function of days (after a discarding 99 observations).

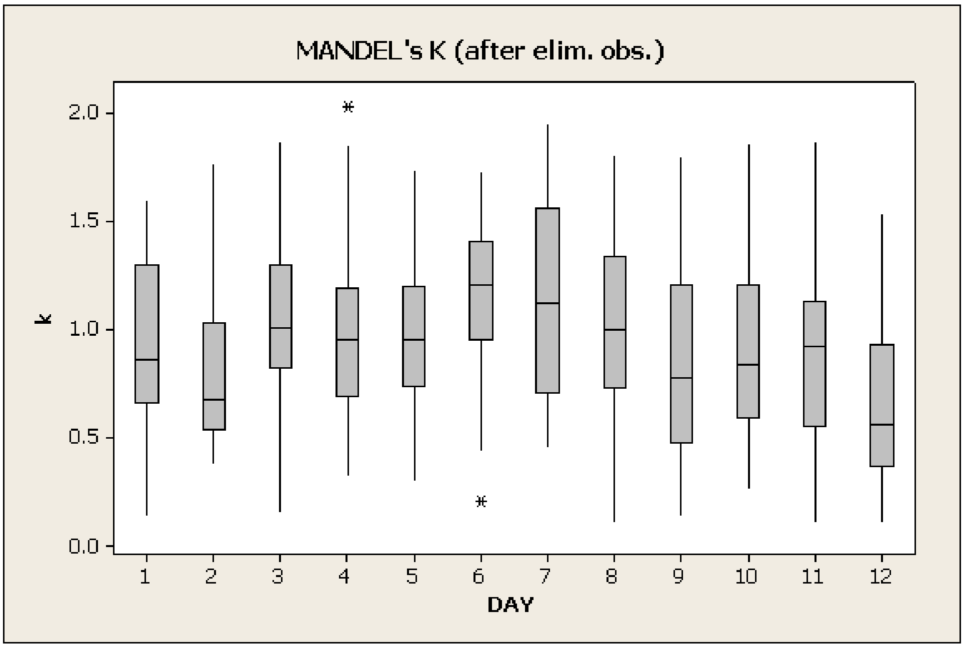


Fig. 50. Experiment B – Boxplot of MANDEL's k_i values as a function of days (after discarding 99 observations).

6.2.2.2 Individual relative errors

Figures: Fig. 51 - Fig. 54 give the distributions of the errors (in percent). Figures: Fig. 51, Fig. 52 give the differences between observations and reference areas, in percent of the reference areas for all data (Fig. 53) and after discarding 99 observations (Fig. 54) :

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

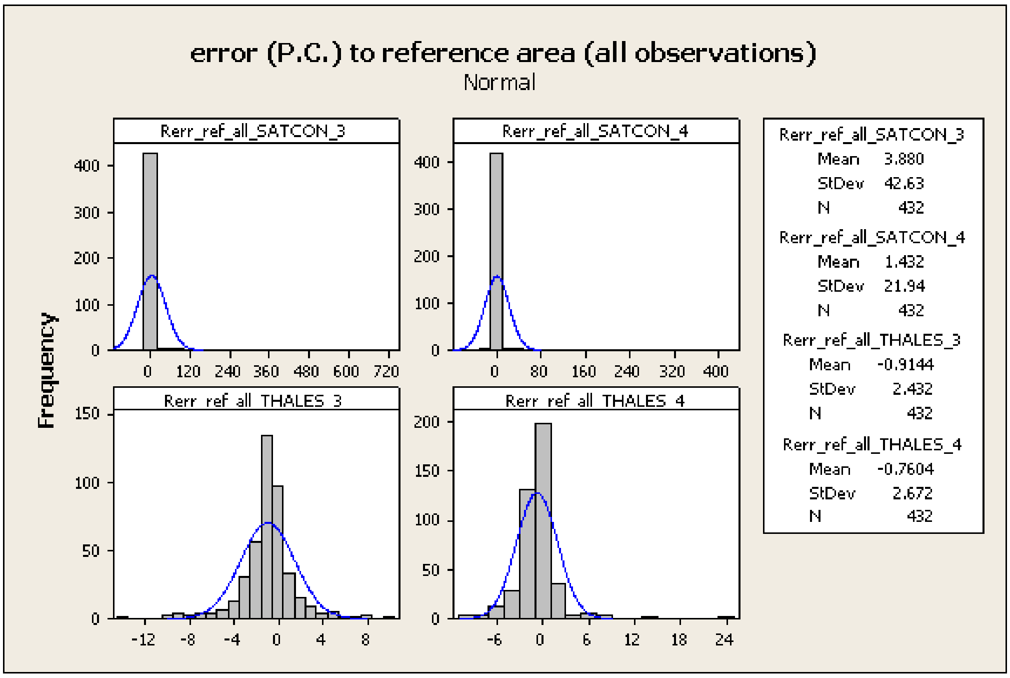


Fig. 51. Experiment B – Histogram of the errors (in percent) to reference area for all observations.

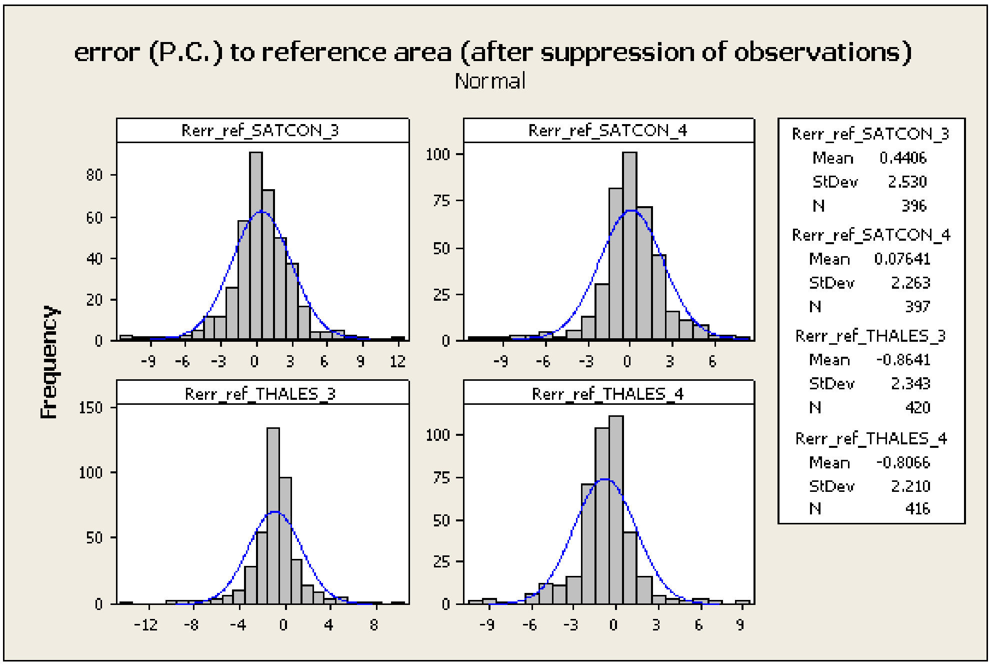


Fig. 52. Experiment B – Histogram of the errors (in percent) to reference area after discarding 99 observations.

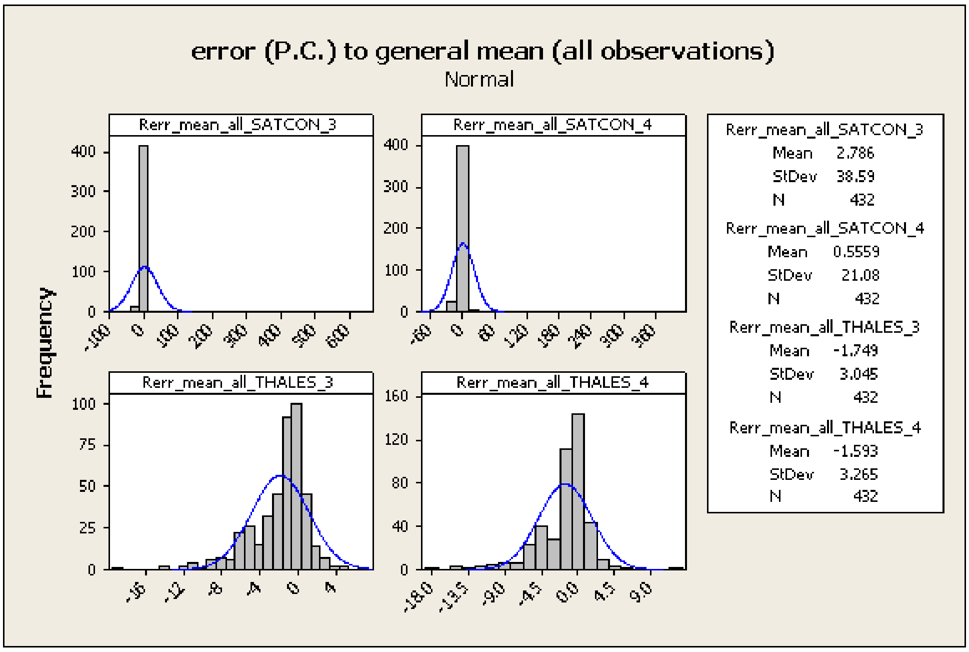


Fig. 53. Experiment B – Histogram of the error (in percent) to the general mean for all observations.

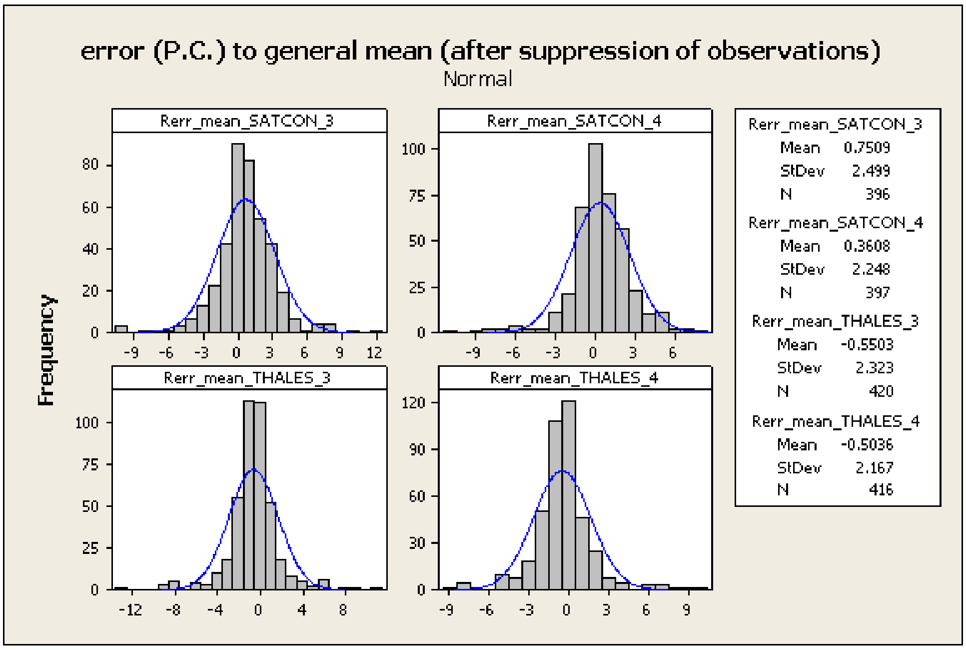


Fig. 54. Experiment B – Histogram of the error (in percent) to the general mean after discarding 46 observations).

Figures: Fig. 53, Fig. 54 give the differences between observations and the general mean (of all observations made on the parcel), for all the data (Fig. 53) and after discarding 46 observations (Fig. 54) :

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

Table: Tab 33 gives the percentage of observations with a (absolute) relative error less than a given value. The errors are computed as follows, after discarding 99 observations :

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

From this table, we can see, for example, that 80.3 percents and 87.2 percents of observations are smaller or equal to 3 percents for the two Satcon instruments. For the two Thales, the percentages are 87.4 and 88.2.

Tab 33. Experiment B – Cumulative percentages of observations as a function of the error (%).

	SATCON		THALES	
Error (%)	S3	S4	T3	T4
1	40.4	47.1	51.9	49.0
2	65.2	74.6	74.5	78.1
3	80.3	87.2	87.4	88.2
4	90.7	91.7	92.1	92.8
5	95.0	94.0	94.1	95.0
6	96.2	97.2	96.2	96.6
7	97.2	98.2	97.1	97.6
8	97.9	99.2	97.9	98.3
9	98.7	99.5	99.3	99.3
10	99.2	99.8	99.5	100.0

6.2.2.3 Bias of the instruments

For each instrument and for each parcel, the ratio between the general mean and the reference area is computed. These ratios are given in table: Tab 34. Figure Fig. 55 gives the histograms of the ratios.

The 95 % confidence intervals are :

- 0.9984 – 1.0091 for SATCON S3,
- 0.9954 – 1.0060 for SATCON S4,
- 0.9862 – 0.9967 for THALES T3,
- and 0.9880 – 0.9961 for THALES T4.

The confidence interval includes the value 1 only for Satcon. So, we can conclude that the mean value of the ratio for the 18 parcels is not significantly different from 1 for Satcon but is significantly different from 1 for Thales : there is no bias for Satcon but Thales underestimates the reference areas.

Tab 34. Experiment B – Mean values of the observations and ratios mean value/reference area.

Parcels	S3	S4	T3	T4	S3/Ref	S4/Ref	T3/Ref	T4/Ref
19	4846	4869	4884	4865	0.998	1.003	1.006	1.002
20	5006	4956	4905	4915	1.016	1.006	0.995	0.997
21	4167	4109	4054	4077	1.013	0.999	0.986	0.991
22	11318	11366	11177	11229	1.002	1.007	0.990	0.995
23	11605	11600	11404	11428	1.012	1.012	0.995	0.997
24	10074	10056	9987	10014	1.003	1.001	0.994	0.997
25	31541	31242	31156	31155	1.007	0.998	0.995	0.995
26	30100	30166	29854	29942	0.999	1.002	0.991	0.994
27	31029	30741	30685	30720	1.005	0.996	0.994	0.995
28	4113	4078	4324	4268	0.972	0.963	1.022	1.008
29	4079	4039	3927	3972	1.016	1.006	0.978	0.989
30	4670	4627	4599	4571	1.008	0.998	0.992	0.986
31	9145	9154	8794	8786	1.013	1.014	0.974	0.973
32	11226	11316	11129	11138	0.988	0.996	0.980	0.980
33	9076	9048	8869	8843	1.007	1.004	0.984	0.981
34	39485	39529	39025	39239	0.999	1.000	0.988	0.993
35	39121	39164	38785	38718	0.999	1.000	0.990	0.988
36	31274	31296	30800	30806	1.009	1.010	0.994	0.994

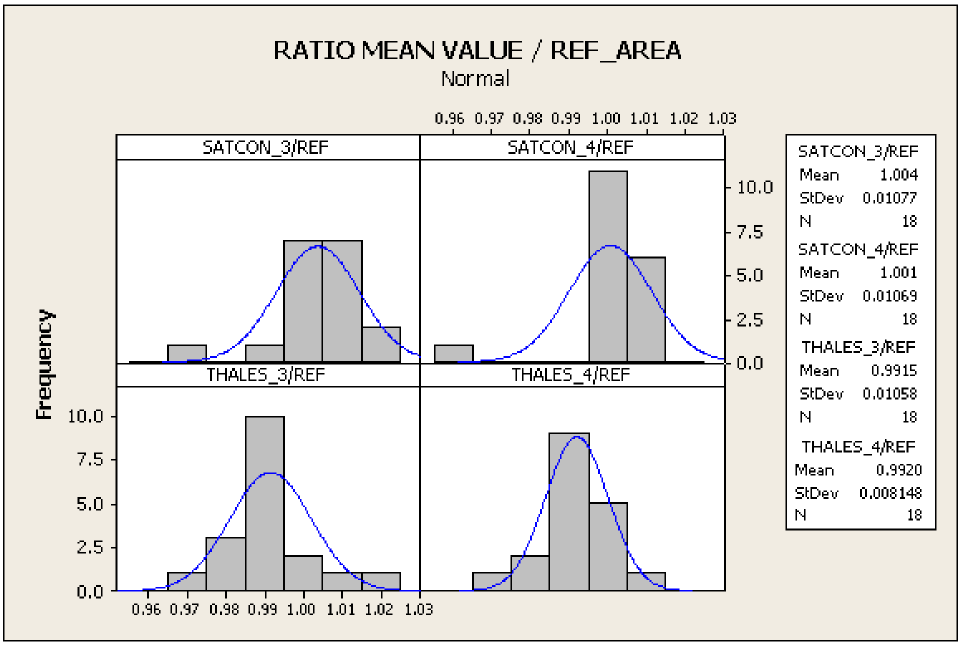


Fig. 55. Experiment B – Histogram of the ratios mean value/reference area.

6.2.2.4 Variance components and reproducibility

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

Tables: Tab 35 - Tab 37 25 give the variance components and the reproducibility for each parcel (labeled Bdays, Wdays and Repr). The variance components have also been expressed in percentage of the reproducibility.

Tab 35. Experiment B – Between days and with days variance components for SATCON S3.

Parcels	Bdays	Wdays	Repr	B%	W%
19	0	13845	13845	0	100
20	0	22049	22049	0	100
21	5418	5788	11206	48	52
22	37030	16295	53325	69	31
23	0	52109	52109	0	100
24	6868	19884	26752	26	74
25	25174	110779	135953	19	81
26	4133	64206	68339	6	94
27	23976	67531	91507	26	74
28	30881	25888	56769	54	46
29	7464	14803	22267	34	66
30	0	5475	5475	0	100
31	0	112566	112566	0	100
32	0	147559	147559	0	100
33	0	13054	13054	0	100
34	0	471700	471700	0	100
35	56153	75416	131569	43	57
36	152190	36218	188408	81	19

Experiment B – Between days and with days variance components for SATCON S4.

Parcels	Bdays	Wdays	Repr	B%	W%
19	10688	24965	35653	30	70
20	0	10493	10493	0	100
21	4	3176	3180	0	100
22	21121	41848	62969	34	66
23	17452	71156	88608	20	80
24	133	18795	18928	1	99
25	0	71196	71196	0	100
26	0	123494	123494	0	100
27	8222	16968	25190	33	67
28	5223	28134	33357	16	84
29	2428	8086	10514	23	77
30	4449	2652	7101	63	37
31	0	98173	98173	0	100
32	21254	26725	47979	44	56
33	0	10271	10271	0	100
34	104278	148502	252780	41	59
35	85227	86626	171853	50	50
36	169135	81463	250598	67	33

Tab 36. Experiment B – Between days and with days variance components for THALES T3.

Parcels	Bdays	Wdays	Repr	B%	W%
19	1216	4043	5259	23	77
20	539	2826	3366	16	84
21	0	1657	1657	0	100
22	0	80232	80232	0	100
23	0	25239	25239	0	100
24	783	8601	9385	8	92
25	3	38518	38521	0	100
26	0	76707	76707	0	100
27	0	22507	22507	0	100
28	0	35349	35349	0	100
29	0	19986	19986	0	100
30	2244	11651	13895	16	84
31	0	88757	88757	0	100
32	32097	116971	149068	22	78
33	0	19307	19307	0	100
34	112774	647387	760161	15	85
35	62052	85679	147731	42	58
36	0	43735	43735	0	100

Tab 37. Experiment B – Between days and with days variance components for THALES T4.

Parcels	Bdays	Wdays	Repr	B%	W%
19	0	12432	12432	0	100
20	1232	4885	6117	20	80
21	1989	1189	3178	63	37
22	8388	29183	37571	22	78
23	0	13700	13700	0	100
24	264	6761	7025	4	96
25	41922	92164	134086	31	69
26	1052	23983	25035	4	96
27	12998	31029	44027	30	70
28	20625	38062	58687	35	65
29	0	6211	6211	0	100
30	5830	6438	12268	48	52
31	0	87026	87026	0	100
32	69028	98924	167952	41	59
33	1262	6725	7987	16	84
34	0	119474	119474	0	100
35	82125	214796	296921	28	72
36	0	31552	31552	0	100

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

- 23 % between and 77 % within for SATCON S3,
- 23 % between and 77 % within for SATCON S4,
- 8 % between and 92 % within for THALES T3,
- 20 % between and 80 % within for Thales T4.

Several transformations of the reproducibility have also been computed:

- he reproducibility standard deviation (labelled S Dev);
- the reproducibility coefficient of variation (standard deviation divided by the reference area of the parcel, labelled CoefVar);
- he 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 38 - Tab 41.

Tab 38. Experiment B – Transformations of the reproducibility variance for SATCON S3.

Parcels	SDev	Buffer	CoefVar	SDev/HB
Parcels	SDev	Buffer	CoefVar	SDev/HB
19	118	0.293	0.024	1.400
20	148	0.413	0.030	2.064
21	106	0.380	0.026	1.668
22	231	0.355	0.020	2.033
23	228	0.385	0.020	2.223
24	164	0.381	0.016	1.827
25	369	0.343	0.012	2.821
26	261	0.267	0.009	1.775
27	303	0.410	0.010	2.812
28	238	0.456	0.056	2.305
29	149	0.487	0.037	2.184
30	74	0.252	0.016	1.362
31	336	0.501	0.037	3.048
32	384	0.593	0.034	4.230
33	114	0.288	0.013	1.683
34	687	0.617	0.017	5.125
35	363	0.344	0.009	3.107

Tab 39. Experiment B – Transformations of the reproducibility variance for SATCON S4.

Parcels	SDev	Buffer	CoefVar	SDev/HB
19	189	0.471	0.039	2.247
20	102	0.285	0.021	1.424
21	56	0.203	0.014	0.889
22	251	0.386	0.022	2.209
23	298	0.501	0.026	2.899
24	138	0.321	0.014	1.537
25	267	0.248	0.009	2.041
26	351	0.359	0.012	2.387
27	159	0.215	0.005	1.476
28	183	0.350	0.043	1.767
29	103	0.335	0.026	1.500
30	84	0.287	0.018	1.551
31	313	0.468	0.035	2.847
32	219	0.338	0.019	2.412
33	101	0.255	0.011	1.493
34	503	0.451	0.013	3.752
35	415	0.393	0.011	3.551
36	501	0.660	0.016	4.237

Tab 40. Experiment B – Transformations of the reproducibility variance for THALES T3.

Parcels	SDev	Buffer	CoefVar	SDev/HB
19	73	0.181	0.015	0.863
20	58	0.161	0.012	0.806
21	41	0.146	0.010	0.641
22	283	0.435	0.025	2.493
23	159	0.268	0.014	1.547
24	97	0.226	0.010	1.082
25	196	0.183	0.006	1.501
26	277	0.283	0.009	1.881
27	150	0.203	0.005	1.395
28	188	0.360	0.044	1.819
29	141	0.461	0.035	2.069
30	118	0.401	0.025	2.169
31	298	0.445	0.033	2.707
32	386	0.596	0.034	4.251
33	139	0.350	0.015	2.047
34	872	0.783	0.022	6.507
35	384	0.364	0.010	3.293
36	209	0.276	0.007	1.770

Tab 41. Experiment B – Transformations of the reproducibility variance for THALES T4.

Parcels	SDev	Buffer r	CoefVa	SDev/HB
19	111	0.278	0.023	1.327
20	78	0.217	0.016	1.087
21	56	0.202	0.014	0.888
22	194	0.298	0.017	1.706
23	117	0.197	0.010	1.140
24	84	0.195	0.008	0.936
25	366	0.341	0.012	2.801
26	158	0.162	0.005	1.075
27	210	0.285	0.007	1.951
28	242	0.464	0.057	2.344
29	79	0.257	0.020	1.153
30	111	0.377	0.024	2.038
31	295	0.441	0.033	2.680
32	410	0.632	0.036	4.512
33	89	0.225	0.010	1.317
34	346	0.310	0.009	2.579
35	545	0.516	0.014	4.668
36	178	0.234	0.006	1.504

For these four variables, the boxplots are given by types of "size", "shape" and "border" in appendix 11. These plots show that:

- the standard-deviation increases with size;
- the coefficient of variation decreases with size;
- the buffer and the ratio standard deviation/HB seem only to be slightly related to size.

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 42 - Tab 45 give the results of several attempts of modeling the buffer.

Tab 42. Experiment B – Modeling buffer for SATCON S3.

All	Buffer = 0.408 (0.110)
Good border	Buffer = 0.359 (0.050)
Bad border	Buffer = 0.457 (0.134)
All	Buffer = 0.383 + 0.000002 Ref_Area (0,112)
Good border	Buffer = 0.374 + 0.000001 Ref_Area (0.052)
Bad border	Buffer = 0.410 + 0.000003 Ref_Area (0.136)

Tab 43. Experiment B – Modeling buffer for SATCON S4.

All	Buffer = 0.363 (0.116)
Good border	Buffer = 0.332 (0.107)
Bad border	Buffer = 0.393 (0.122)
All	Buffer = 0.331 + 0.000002 Ref_Area (0.116)
Good border	Buffer = 0.375 + 0.000003 Ref_Area (0.109)
Bad border	Buffer = 0.315 + 0.000005 Ref_Area (0.107)

Tab 44. Experiment B – Modeling buffer for THALES T3.

All	Buffer = 0.340 (0.165)
Good border	Buffer = 0.232 (0.089)
Bad border	Buffer = 0.448 (0.154)
All	Buffer = 0.302 + 0.000002 Ref_Area (0.167)
Good border	Buffer = 0.220 + 0.000001 Ref_Area (0.095)
Bad border	Buffer = 0.405 + 0.000003 Ref_Area (0.159)

Tab 45. Experiment B – Modeling buffer for THALES T4.

All	Buffer = 0.313 (0.128)
Good border	Buffer = 0.242 (0.060)
Bad border	Buffer = 0.384 (0.141)
All	Buffer = 0.303 + 0.000001 Ref_Area (0.132)
Good border	Buffer = 0.220 + 0.000001 Ref_Area (0.062)
Bad border	Buffer = 0.391 + 0.000000 Ref_Area (0.150)

The first three lines in these tables give the general mean and the means of parcels with good and bad border. The next lines show regression equations giving the buffer as a function of reference area. The related scatterplots are given in figures: Fig. 56 - Fig. 59. For each model the (residual) standard deviation is given in parentheses.

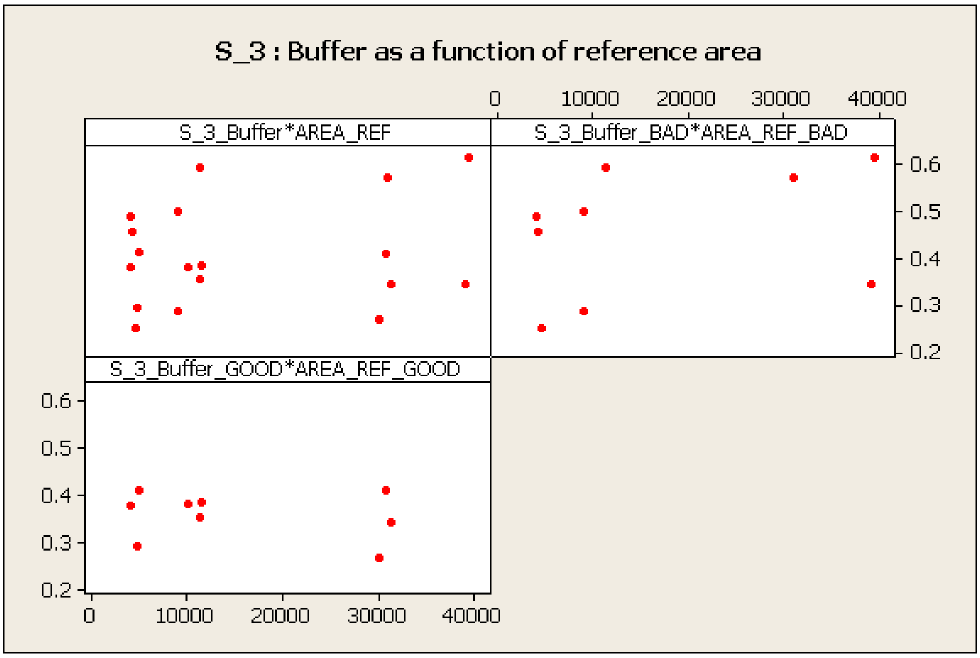


Fig. 56. Experiment B – Buffer as a function of reference area for SATCON S3.

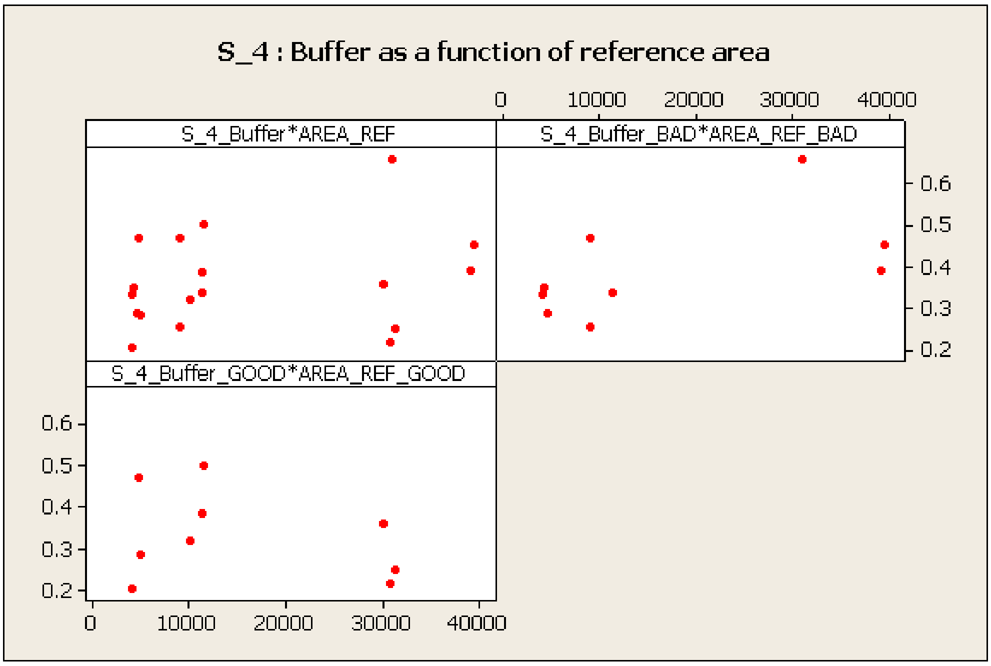


Fig. 57. Experiment B – Buffer as a function of reference area for SATCON S4.

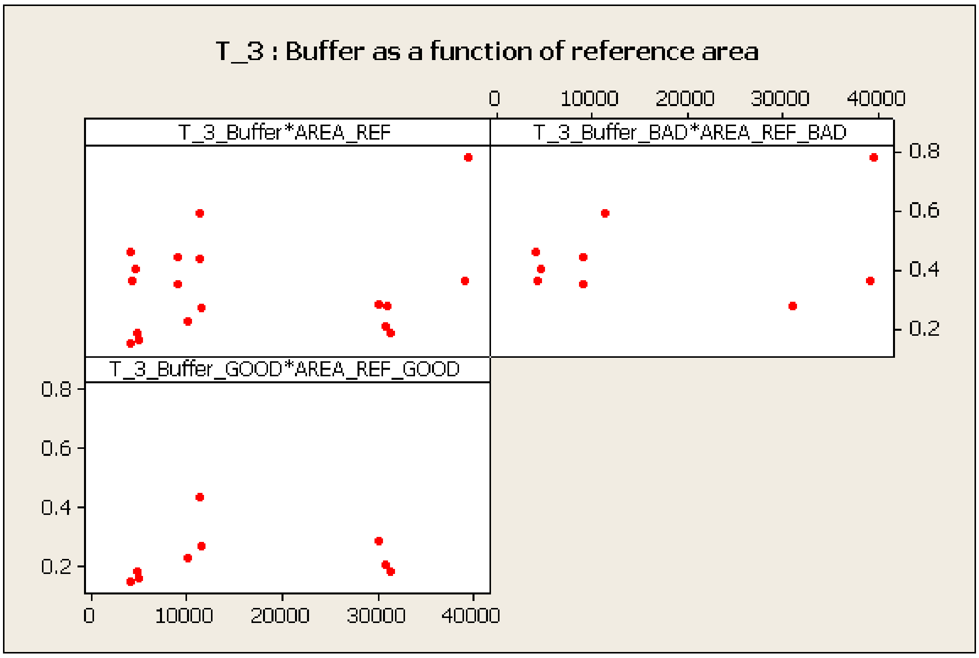


Fig. 58. Experiment B – Buffer as a function of reference area for THALES T3.

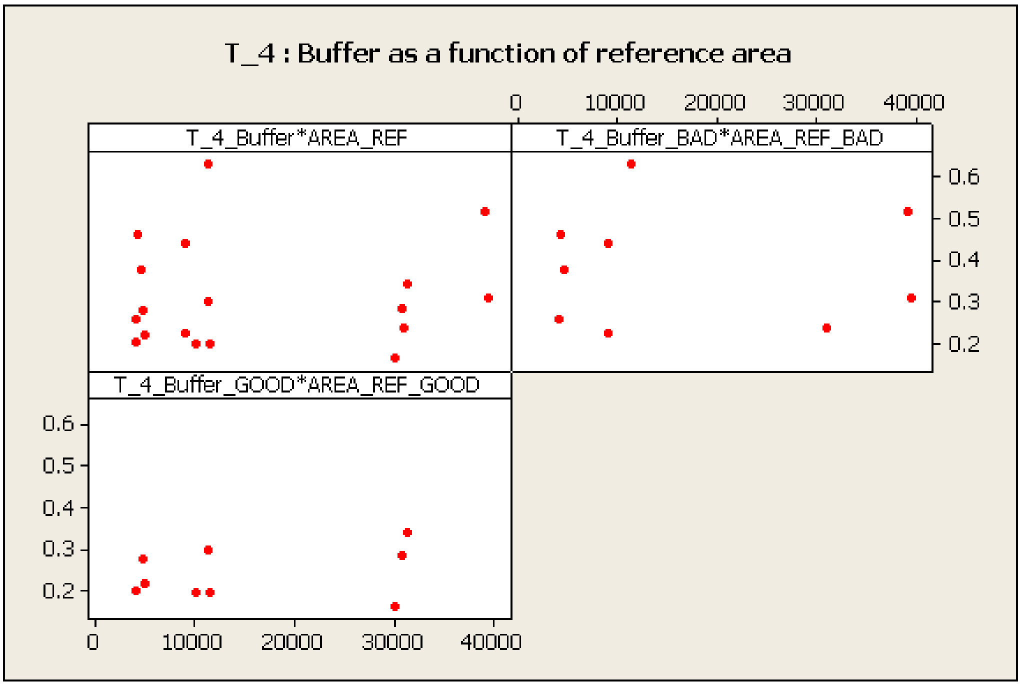


Fig. 59. Experiment B – Buffer as a function of reference area for THALES T4.

For SATCON S3 and S4, the factor "border" and the factor "Reference area" are not significant. For SATCON and THALES T3 and T4, the factor "border" is significant but the factor "Reference area" is not significant.

7. Results of RS and GPS experiment

7.1 RS measurements.

On the basis of RS measurements one can state as follows:

- 84 outliers were found (for 3888 measurements)
  - for parcels number: 24, 17 and 5 the most outliers were observed,
  - sources of this kind of errors are (see Appendix 11.1.1.1):
    - BI - bad border identification as outlier (55%),
    - RE (BI) – random error mainly caused bad border identification (23%),
    - GE – gross error, this kind of error should be avoided (17%).
  - Only the most experienced operator (OP1) has no outliers.
  - Robustness of the ortho defined as number of outliers:
    - OP_0_5 – 18 outliers
    - OP_0_2 - 29 outliers
    - OP_1_1 – 36 outliers
- Factor: “skilled” not “skilled” not influence the measurements
  - but two operators from “unskilled” group made bias (one overestimated and second underestimated the parcel area
- Standard deviation of relative area error in relation to reference parcels:
  - OP_0_2 – 3.2%
  - OP_0_5 – 6.3%
  - OP_1_0 – 5.4%
- Standard deviation of relative area error in relation to mean area value:
  - OP_0_2 – 3.0%
  - OP_0_5 – 4.4%
  - OP_1_0 – 4.0%
- For photos OP_0_5 and OP_1_0 using the reference area in addition to the factor "border" does not improve the model.
- There is no bias in RS measurements.
- Standard-deviation increases with size.
- Coefficient of variation decreases with size.
- Buffer and the ratio standard deviation/HB seem only to be slightly related to size.
- Shape has not an important influence.

- Border is an important factor.
- Value of buffer:
  - OP_0_2 – 0.37m +/- 0.26m
  - OP_0_5 – 0.44 m +/- 0.25m
  - OP_1_0 – 0.44 m +/- 0.33m
- Value of point position error:
  - OP_0_2 – 1.86m +/- 1.85m
  - OP_0_5 – 2.14 m +/- 1.39m
  - OP_1_0 – 2.12 m +/- 1.65m

Histograms of point position error for OP_0_2, OP_0_5 and OP_1_0 are presented on the following figures: Fig. 60, Fig. 61 and Fig. 62.

Relative area error for 36 measured parcels can be examined on the diagram: Fig. 63. Three parcels are characterized by enormous big error: 29, 14, 36. Borders of the parcels are especially bad, difficult to defined (Fig. 64, Fig. 65 and Fig. 66)

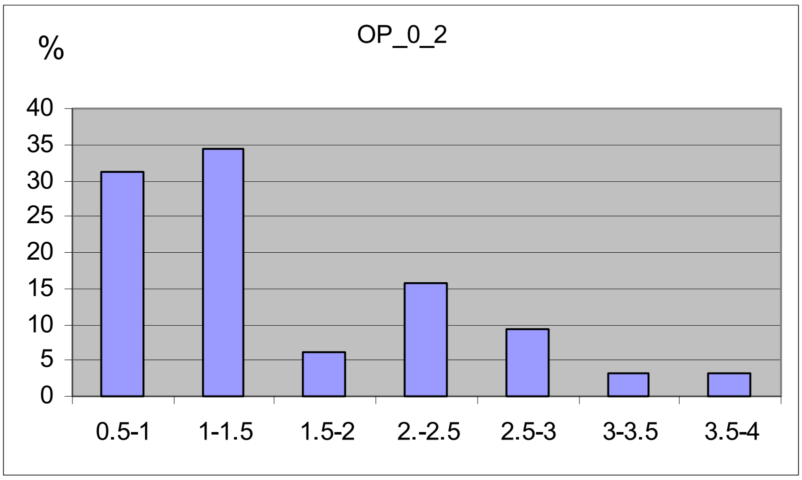


Fig. 60. Histogram of point position error for OP_2_0

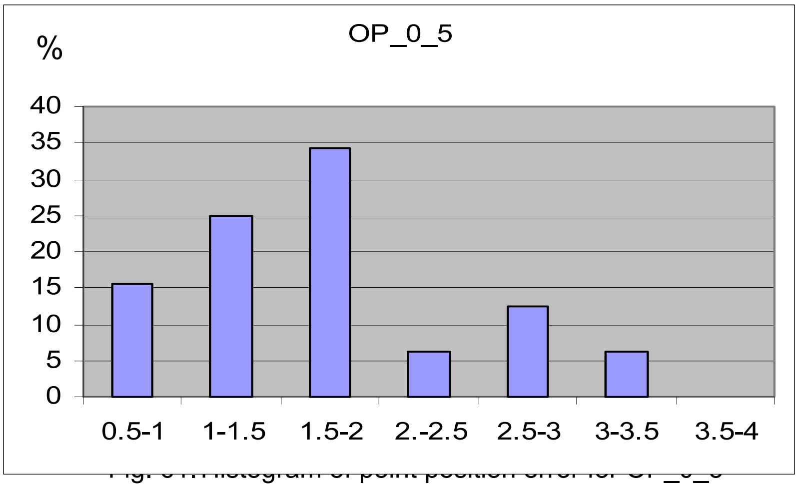


Fig. 61. Histogram of point position error for OP_0_5

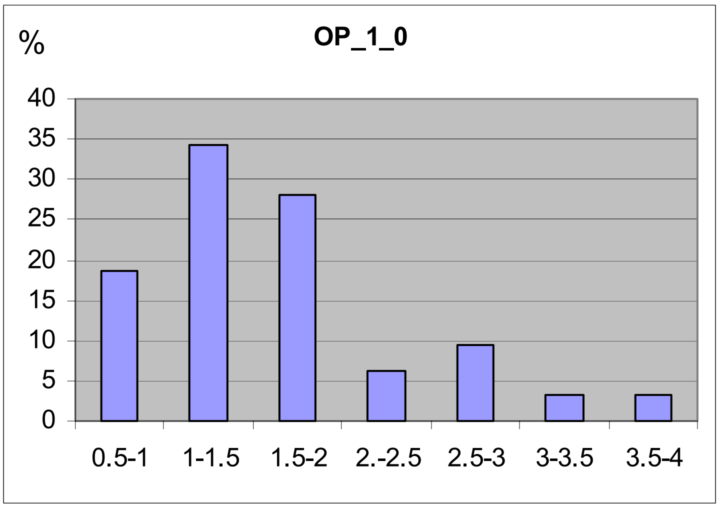


Fig. 62. Histogram of point position error for OP_1_0

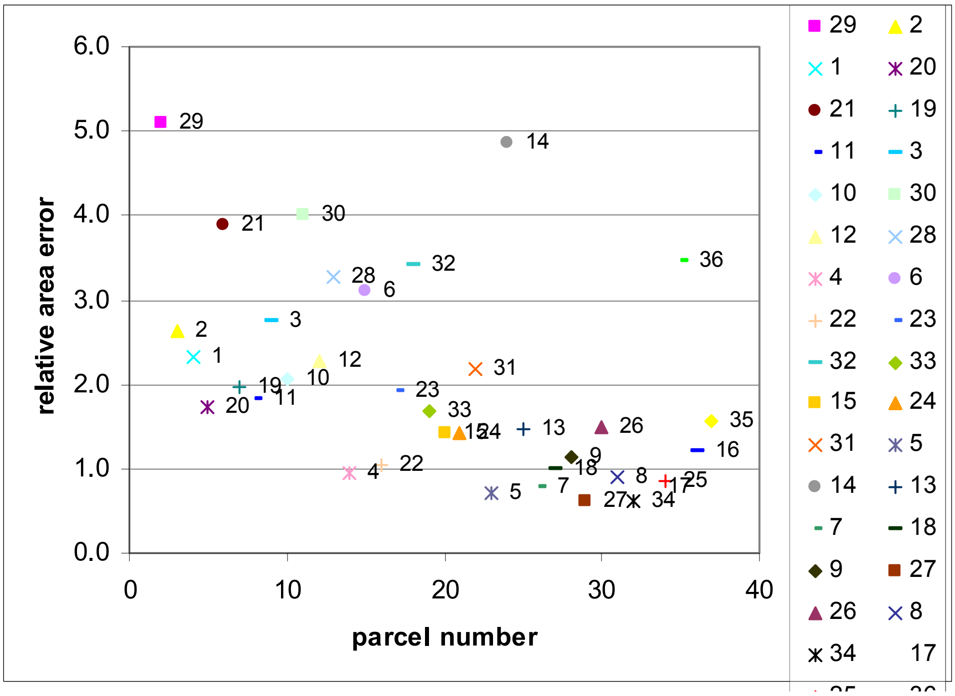


Fig. 63. Relative area error and parcel number (29, 14, 36)

Fig. 64. Parcel number 36

Fig. 65. Parcel number 14

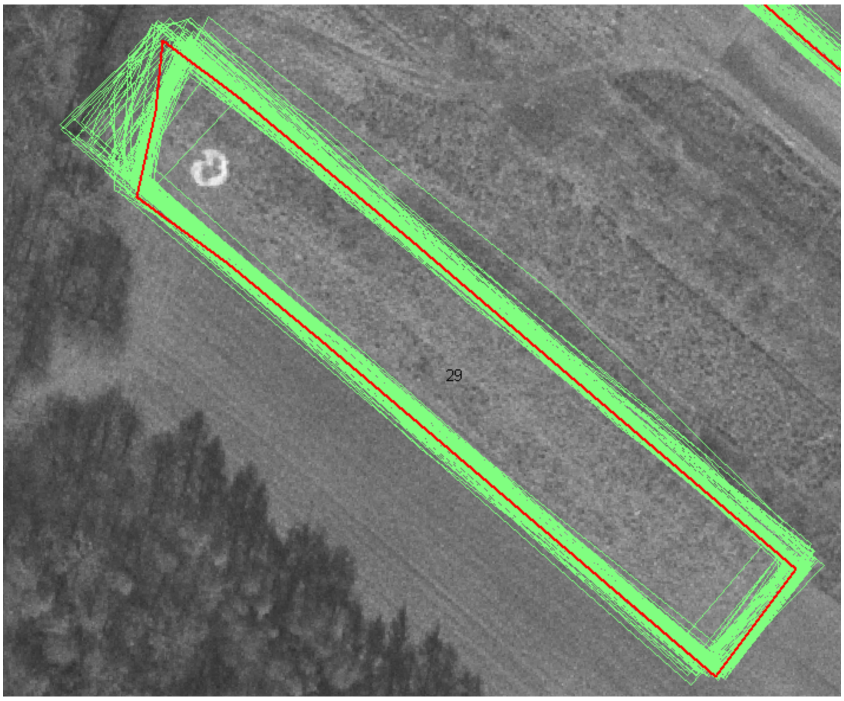


Fig. 66. Parcel number 29

7.2 GPS measurements:

On the basis of GPS measurements (experiment A) the following can be stated:

- 99 outliers were found (for 1944 measurements)
  - 30 observations for GARMIN, 47 observations for SATCON and 44 observations for THALES
  - numbers of outliers that should be notice in the field:
    - Garmin couldn't be analyzed,
    - 1 for Thales,
    - 9 for Satcon.
  - Assuming as robustness number of outlier: Gramin, Satcon, Thales
- Standard deviation of relative are error in relation to reference parcels:
  - Garmin -4.9%
  - Satcon – 2.6 %
  - Thales – 3.7%
- Standard deviation of relative are error in relation to mean area value (in parenthesis value of SDev of relative error before suppressing observations concerning outliers):
  - Garmin -4.8%
  - Satcon – (12%) 2.5 %
  - Thales – 3.5%
- Bias
  - There was no bias for Garmin
  - Satcon overestimated the reference areas and Thales underestimates the reference areas
- Standard-deviation increases with size;
- Coefficient of variation decreases with size;
- Buffer and the ratio standard deviation/HB seem only to be slightly related to size.
- For GARMIN, the factor "border" and the factor "Reference area" are not significant. For SATCON and THALES, the factor "border" is significant but the factor "Reference area" is not significant.
- Value of buffer:
  - Garmin: 0.76m +/- 0.32 m
  - Satcon: 0.34m +/- 0.08m
  - Thales: 0.52m +/- 0.34m
- Value of point position error:
  - Garmin: 21m +/- 11 m
  - Satcon: 9 m +/- 3 m
  - Thales: 14 m +/- 10m

On the basis of GPS measurements (experiment B) the following can be stated:

- 121 outliers were found (for 1728 measurements)

- For the two SATCON instruments, 36 and 35 observations are identified; 12 and 16 for the two THALES.
- numbers of outliers that should be notice in the field:
  - 0 for Thales,
  - 14 for Satcon.
- Assuming as robustness number of outlier: Satcon, Thales

- Standard deviation of relative are error in relation to reference parcels(in parenthesis value of SDev of relative error before suppressing observations concerning outliers):
  - Santcon S3 –(42%) 2.5%
  - Satcon S4 – (21%) 2.3 %
  - Thales T3– (2.4%) 2.3%
  - Thales T4 – (2.7%) 2.2%
- Standard deviation of relative are error in relation to mean area value (in parenthesis value of SDev of relative error before suppressing observations concerning outliers):
  - Santcon S3 –(38%) 2.5%
  - Satcon S4 – (21%) 2.2 %
  - Thales T3– (3%) 2.3%
  - Thales T4 – (3.2%) 2.2%
- Bias
  - there is no bias for Satcon
  - Thales underestimates the reference areas the standard-deviation increases with size;
- Standard-deviation increases with size;
- Coefficient of variation decreases with size;
- Buffer and the ratio standard deviation/HB seem only to be slightly related to size.
- Value of buffer:
  - Santcon S3: 0.41m +/- 0.11m
  - Satcon S4: 0.36m +/- 0.12m
  - Thales T3: 0.34m +/- 0.16m
  - Thales T4: 0.31m +/- 0.13m
- Value of point position error:
  - Santcon S3: 11m +/- 5m
  - Satcon S4: 10 m +/- 4 m
  - Thales T3: 10 m +/- 6 m
  - Thales T4: 9 m +/- 5 m

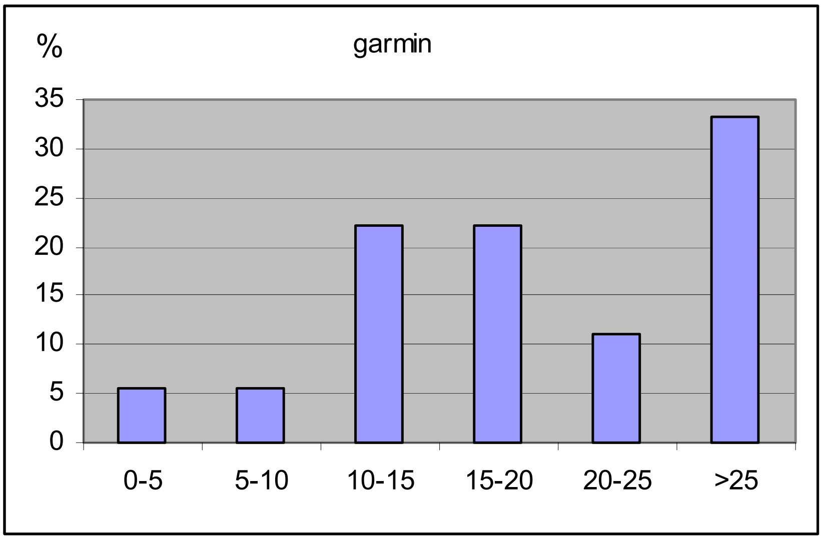


Fig. 67. Histogram of point position error for Garmin

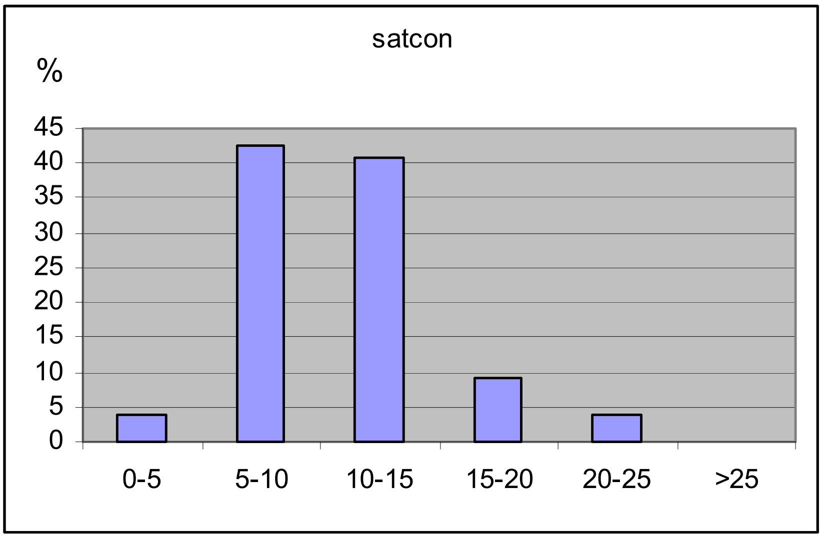


Fig. 68. Histogram of point position error for Satcon

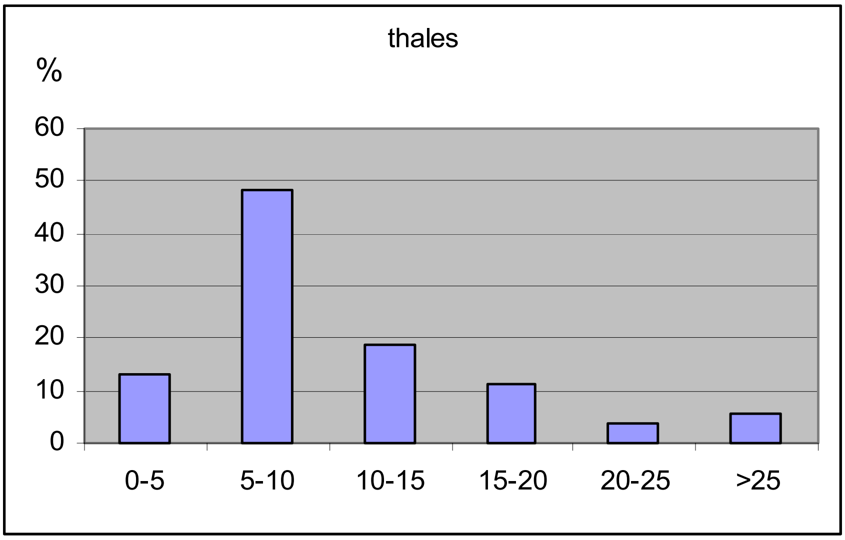


Fig. 69. Histogram of point position error for Thales

7.3 Results of area measurements – summary

Generally, according statistical analysis can be stated:

- Error of parcel area (m^2) increases with size;
- Coefficient of variation decreases with size;
- Buffer and point position error (m_{pkt}) seem only to be slightly related to size.
- Buffer less then m_{pkt} depends on parcel area.

In the table Tab 46 buffer and its standard deviation for all measurements, RS and GPS are presented. Average value of buffer for all measurements is equal about 0.4 m +/- 0.2m.

In the tables: Tab 47 and Tab 48 point position error (m_{pkt}) and its standard deviation for RS and GPS measurements area shown. Average of m_{pkt} for RS measurements was: 2.0m +/- 1.6m, and for GPS: 12m +/-6m.

Tab 46. Buffer for all measurements

	Buffer [m]	standard deviation [m]
OP_0_2	0.37	0.26
OP_0_5	0.44	0.25
OP_1_0	0.44	0.33
Garmin	0.76	0.32
Satcon	0.34	0.08
Thales	0.52	0.34
Satcon S3	0.41	0.11
Satcon S4	0.36	0.12
Thales T3	0.34	0.16

Thales T4	0.31	0.13
average	0.429	0.21

Tab 47. Point position error for all RS measurements

	mpkt [m]	**standard deviation [m]**
OP_0_2	1.86	1.85
OP_0_5	2.14	1.39
OP_1_0	1.89	1.78
average	**2.04**	**1.63**

Tab 48. Point position error for all GPS measurements

	mpkt [m]	standard deviation [m]
Garmin	21	11
Satcon	9	3
Thales	14	10
Satcon S3	11	5
Satcon S4	10	4
Thales T3	10	6
Thales T4	9	5
average	**12**	**6**

8. Point position error – discussion

Buffer width and point position error are compared in this chapter. RS analyses are performed on the base of data from chapter 6.1.1. Relationships between point position error and parcel area are presented for good and bad conditions on the diagrams: Fig. 70 - Fig. 75.

Tab 49. Average point position error

	Average m_{pkt}	σ of m_{pkt}
OP_0_2	1.24	0.55
OP_0_5	1.78	1.08
OP_1_0	1.52	0.60

Tab 50. Average buffer width

	Average buffer width	σ of buffer width
OP_0_2	0.26	0.09
OP_0_5	0.38	0.25
OP_1_0	0.33	0.40

Let us analyze diagrams: Fig. 70 - Fig. 75 and put the offset from formula on diagram to the table.

Tab 51. Offset from diagrams: Fig. 70 - Fig. 75

	offset (good)	offset (bad)
OP_0_2	0.83	0.95
OP_0_5	1.68	1.58
OP_1_0	1.28	1.95

Assuming accuracy of parcel edge recognition of 0.5m we can calculate point position error for measured ortho, assuming nominal RMS for each ortho.

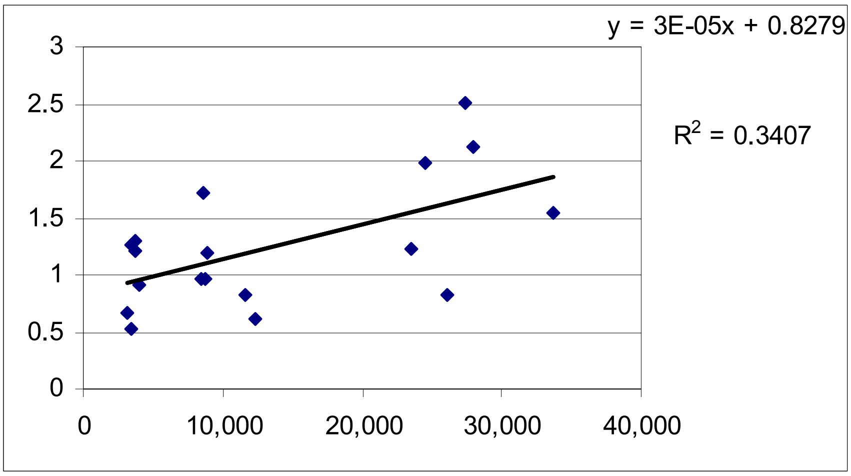
Tab 52. A'priori point position error

	Ortho RMS	Resultant RMS)
OP_0_2	0.75	0.90
OP_0_5	1.5	1.58
OP_1_0	2.5	2.55

It follows from the table: Tab 52 that having assumed a'priori ortho RMS and accuracy of parcel edge recognition, we can estimate minimum RMS in the case of OP_0_2 and OP_0_5 and overestimate of OP_1_0. This other option is that nominal RMS of OP_1_0 was badly estimated.

8.1 Remote Sensing – good border

8.1.1 OP_0_2 - good



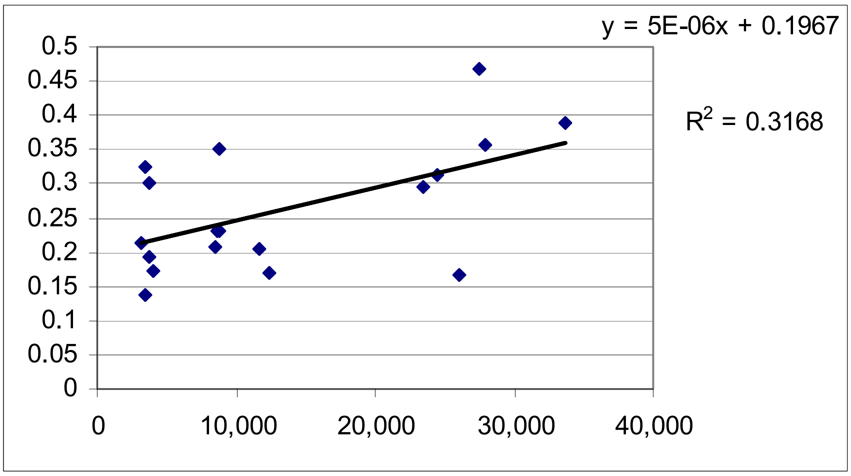
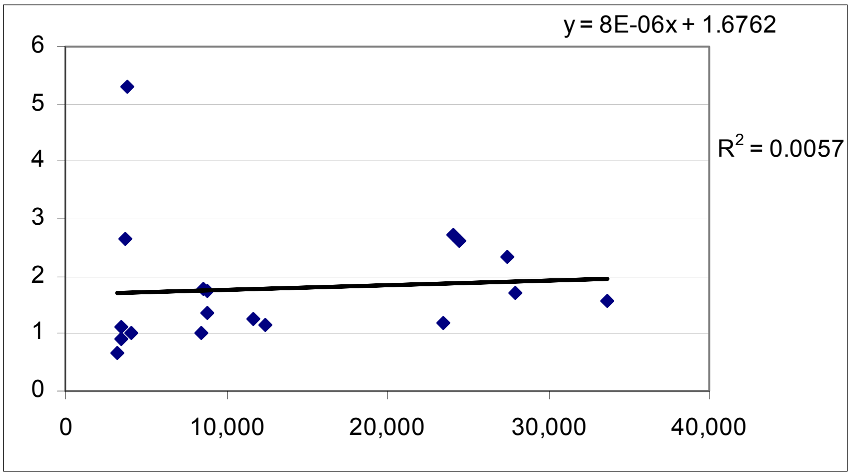


Fig. 70. OP_0_2 – good (error of point position -above, buffer width – below)

8.1.2 OP_0_5 - good



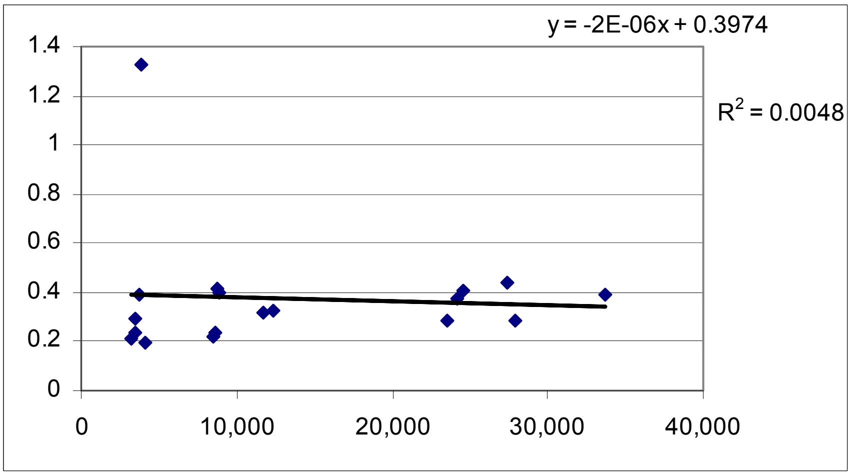


Fig. 71. OP_0_5 – good (error of point position -above, buffer width – below)

8.1.3 OP_1_0 - good

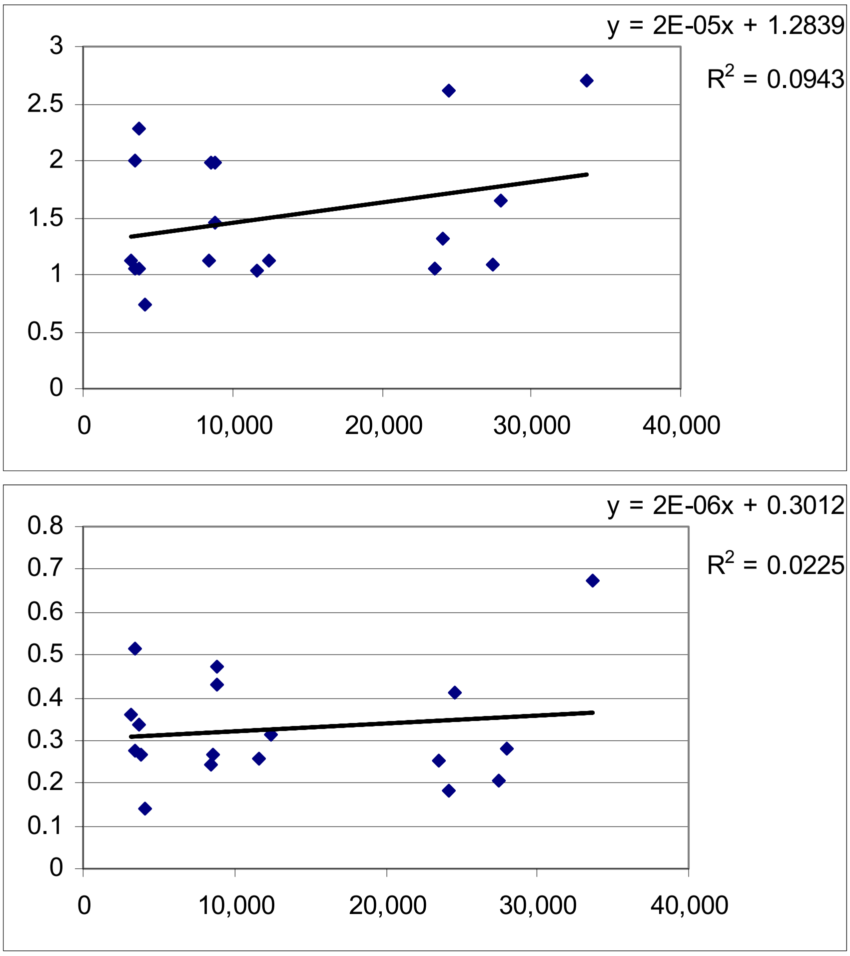
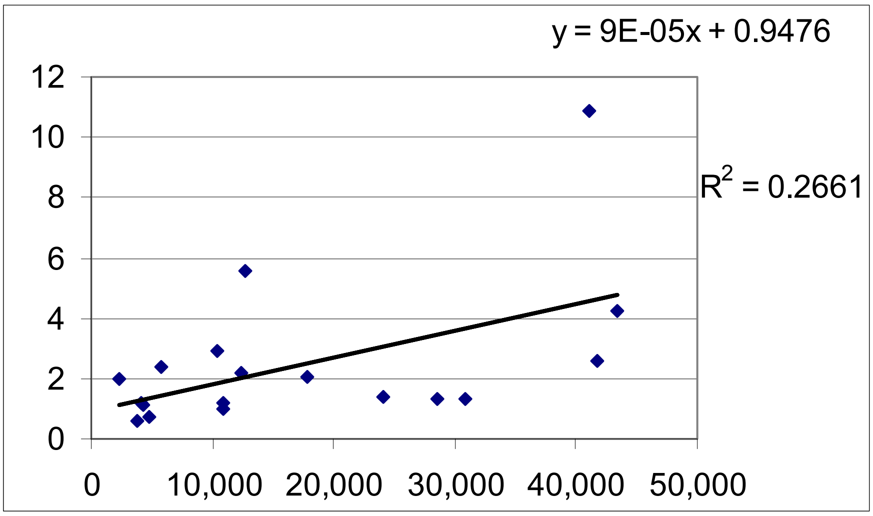


Fig. 72. OP_1_0 – good (error of point position -above, buffer width – below)

8.2 Remote sensing – bad border

8.2.1 OP_0_2 - bad



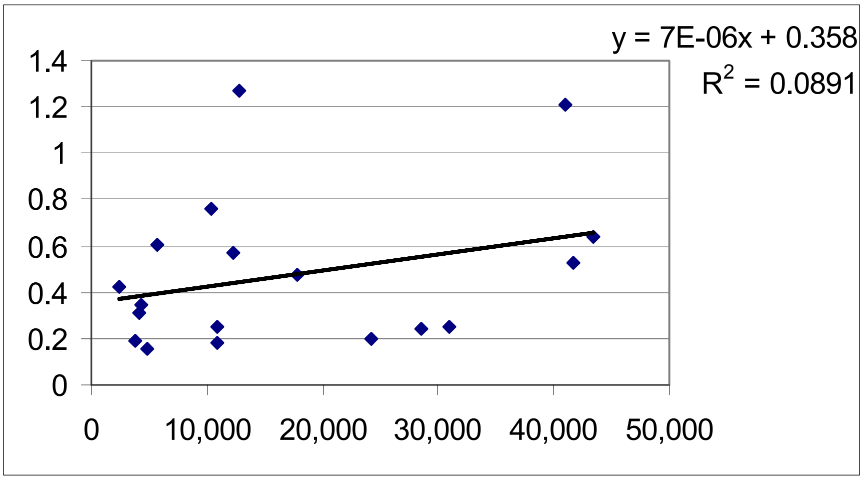
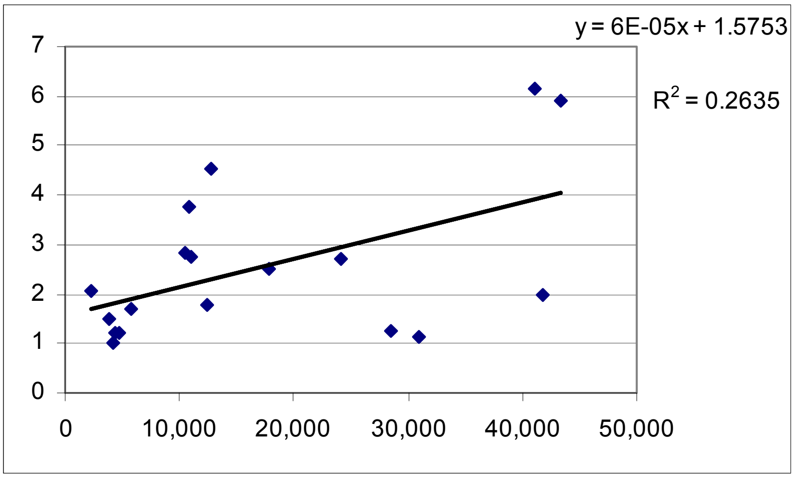


Fig. 73. OP_0_2 – bad (error of point position -above, buffer width – below)

8.2.2 OP_0_5 - bad



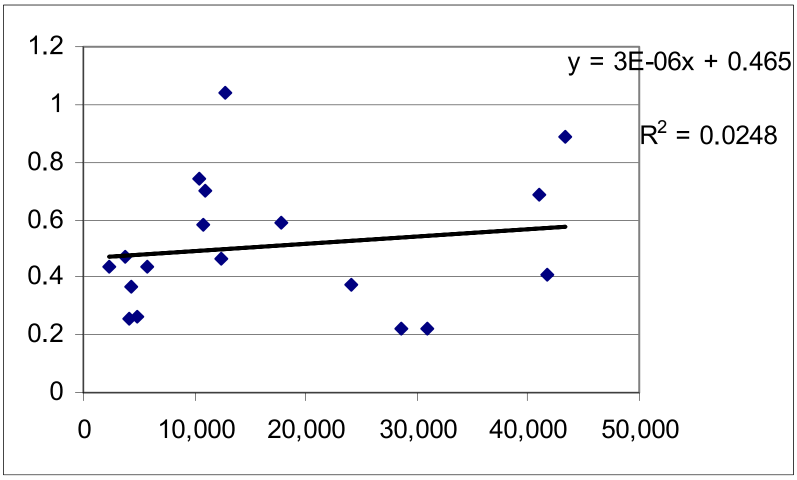


Fig. 74. OP_0_5 – bad (error of point position -above, buffer width – below)

8.2.3 OP_1_0 - bad

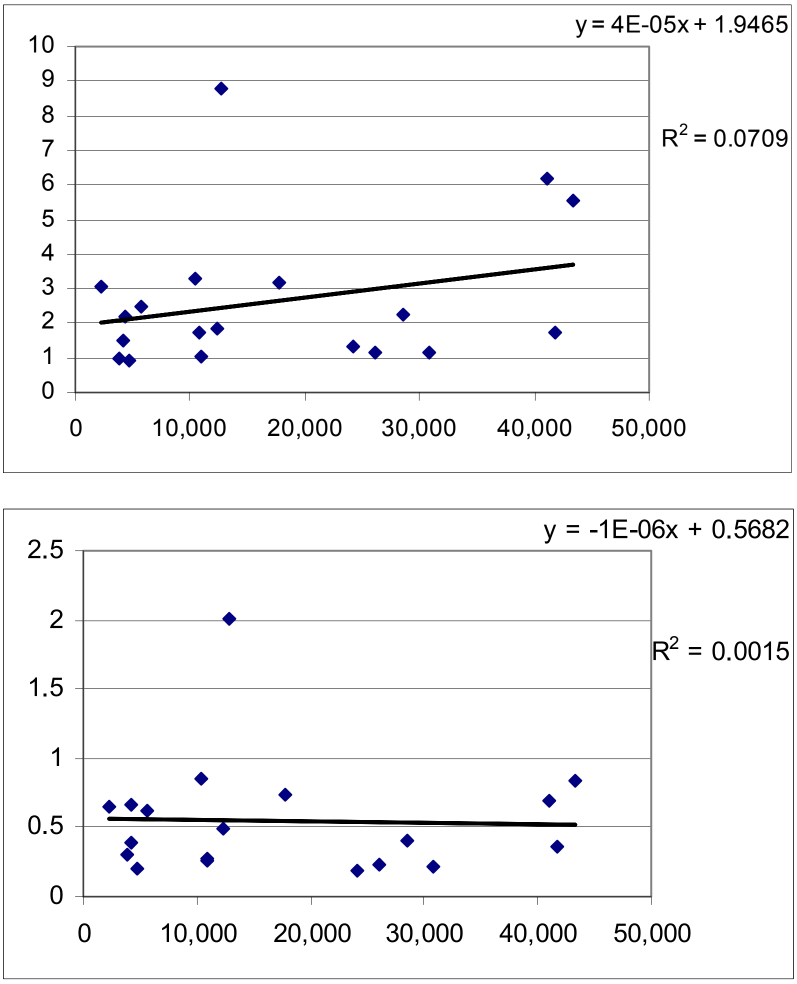
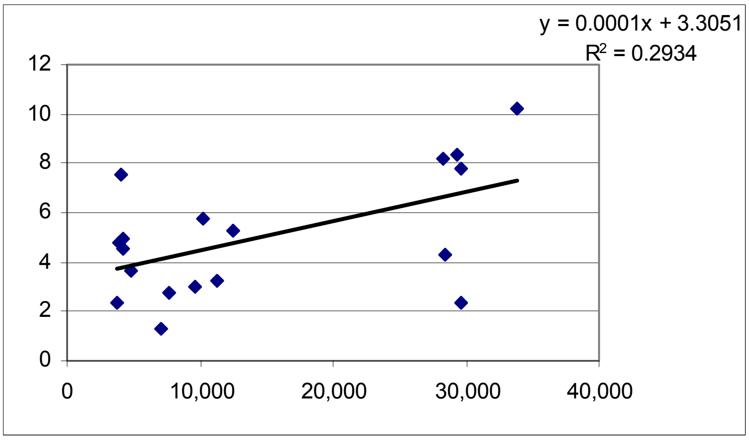


Fig. 75. OP_1_0 – bad (error of point position -above, buffer width – below)

8.3 GPS – example

Relationships between buffer width and point position error and parcel area are compared for chosen data in this chapter (experiment A, Garmin and Satcon), (Fig. 76,Fig. 77). Point position error strongly depends on amount of vertex of parcel border. All analysis performed for GPS data based on reference parcel defined by stakes (each 20m). In real GPS measurements we have more points than stakes therefore point position error calculated on the basis of the reference parcel doesn't represent real point position for GPS measurement.



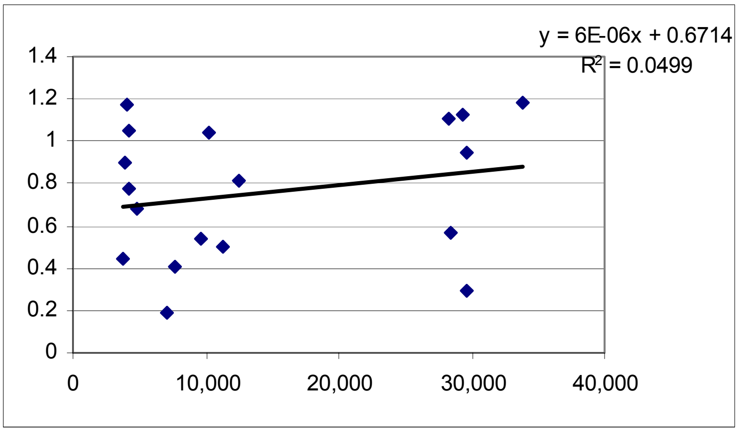
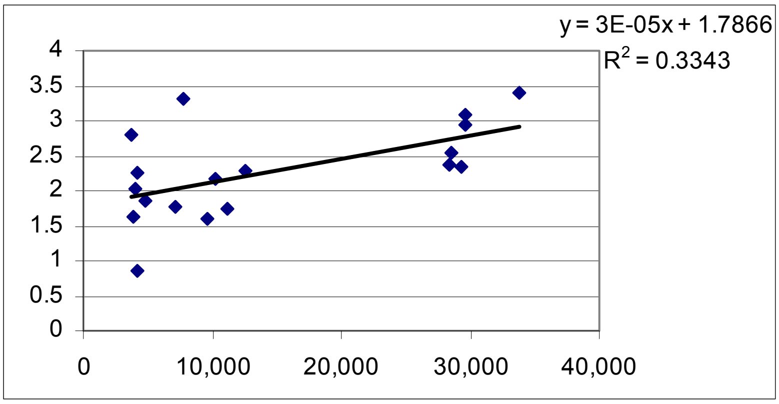


Fig. 76. Experiment A – Garmin (error of point position -above, buffer width – below)



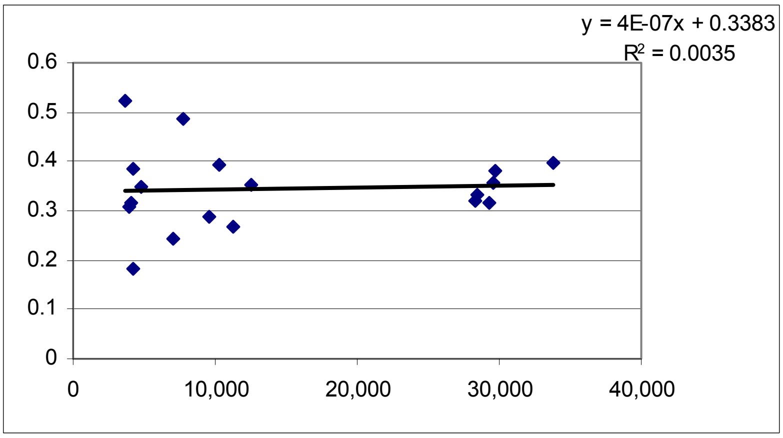


Fig. 77. Experiment A - Satcon (error of point position -above, buffer width – below)

8.3.1 Analysis of results of GPS measurements basing on point position error calculated for real measurements

Reference parcels were assumed for point position error calculation for GPS experiment. The parcels were composed of stabilized points on the border (each 20 m). Calculations performed above concern coordinates of these points. However in real GPS measurement distance between neighborhood points varied between dozen cm and few meters (Fig. 78, Fig. 79). Difference between measurements of reference parcels and measurements of the parcel area by GPS disclose by different value of point position error (HB coefficient). It was inspiration for analysis presented in this chapter performed for real measurements.

Comparison of point position error calculated from reference parcel and real GPS measurements are presented in tables: Tab 53 - Tab 59. The differences between HB coefficient calculated for reference parcel (HB reference parcel) and for real measurement (HB GPS real measurements) are presented in the tables.

Relationship between point position error m_{pkt} [m] and parcel area [m^2] for experiment A is presented on Fig. 80 and for experiment B on Fig. 81.

Relationships between point position error m_{pkt} [m] and parcel area [m^2] for SATCON, Thales and Garmin for all GPS experiment (A and B) are presented on the figures: Fig. 82, Fig. 83Fig. 84.

Generally 126 variances (point position errors) have been taken into account (7 GPS instruments * 18 parcels). Analyzing point position errors on the figure Fig. 82, Fig. 83 and Fig. 84 can be stated that only 6 values of error (5%) are bigger than 30 m (1 for Thales and 5 for Garmin, for Satcon all vales are below of 25 m). Analyzing only Satcon and Thales, point position error was bigger than 20 m in only 6 cases (5.5% of Satcon and Thales values of error). The point position error for only Satcon was bigger than 15m in 5 cases (9% of Satcon values of error). Therefore analysis of area error was performed assuming: 30m, 20m and 15m of point position error (Fig. 85, Fig. 86, Fig. 87)

Area error calculation basing of formula:(25) was performed for all 36 parcels assuming point position error of 30m, 20m and 15 m. Relationships between relative area error m_p [%[and parcel area [m^2] assuming different point position error are presented on figures: Fig. 85, Fig. 86 and Fig. 87.

The following can stated:

1) For m_{pkt}=30 m:

   - Relative error of 39% of all parcels is less then 5%,
   - Relative error of parcels of area exceeding 3 ha is below 4%.
   - Relative error of parcels of area of about 1 ha is about 5%.
   - Maximum error is 17%.

2) For m_{pkt}=20 m:

   - Relative error of 56% of all parcels is less then 5%,
   - Relative error of parcels of area exceeding 3 ha is below 3% (even less then 2.5%).
   - Relative error of parcels of area exceeding 1ha is below 5%.
   - Maximum error is 12%.

3) For m_{pkt}=15 m:

   - Relative error of 61% of all parcels is less then 5%,
   - Maximum error is 8.5%.

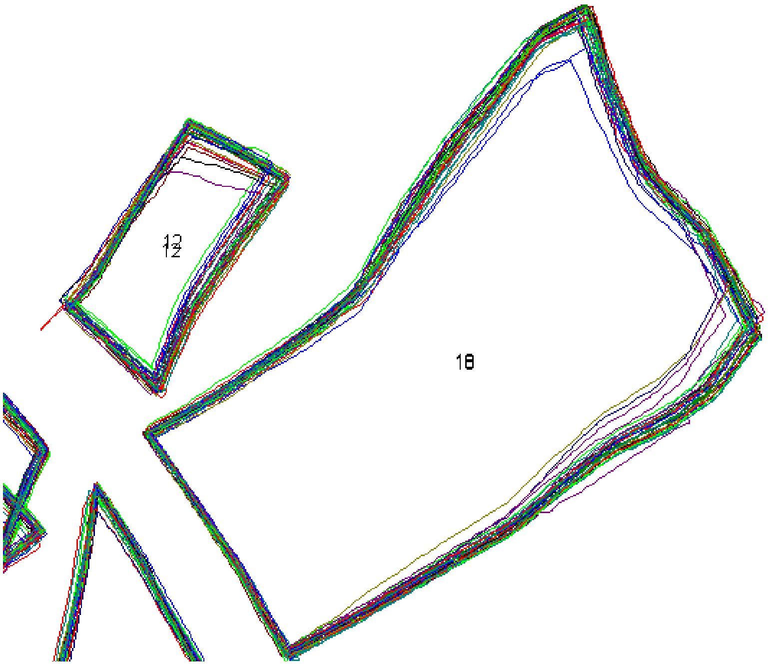


Fig. 78. An example of real GPS measurements

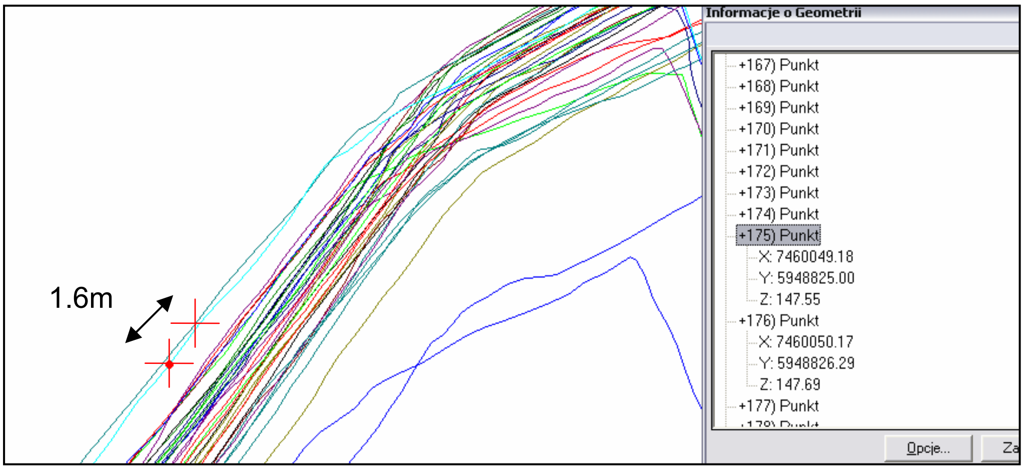


Fig. 79. An example of neighborhood points in real GPS measurements

Tab 53. Experiment A – Garmin - Comparison of point position error (m_{pkt}) calculated from reference parcel and real GPS measurements

Number of parcel	SDev $m_p[m^2]$	HB reference parcels [m]	SDev/HB $m_{pkt}[m]$	HB GPS real measurements [m]	Sdev/HB GPS $m_{pkt}[m]$
1	282	77.62	3.6	18.15	15.5

2	444	58.42	7.6	16.71	26.6
3	289	58.17	5.0	15.67	18.4
4	311	95.3	3.3	25.15	12.4
5	485	91.8	5.3	20.73	23.4
6	224	74.53	3.0	22.39	10.0
7	334	141.76	2.4	37.89	8.8
8	1103	135.38	8.2	27.95	39.5
9	832	98.96	8.4	22.51	37.0
10	183	77.63	2.4	17.54	10.4
11	321	67.56	4.8	17.16	18.7
12	222	48.81	4.5	14.94	14.9
13	105	79.22	1.3	28.54	3.7
14	233	83.94	2.8	22.12	10.5
15	458	79.47	5.8	16.65	27.5
16	1232	120.98	10.2	28.12	43.8
17	529	123.05	4.3	25.00	21.2
18	707	90.53	7.8	23.00	30.7

Tab 54. Experiment A – Satcon - Comparison of point position error m_{pkt}) calculated from reference parcel and real GPS measurements

Number of parcel	SDev $m_p[m^2]$	HB reference parcels [m]	SDev/HB m_{pkt}[m]	HB GPS real measurements [m]	Sdev/HB GPS m_{pkt}[m]
1	145	77.62	1.9	18.15	8.0
2	119	58.42	2.0	16.71	7.1
3	50	58.17	0.9	15.67	3.2
4	164	95.3	1.7	25.15	6.5
5	209	91.8	2.3	20.73	10.1
6	119	74.53	1.6	22.39	5.3
7	438	141.76	3.1	37.89	11.6
8	320	135.38	2.4	27.95	11.4
9	233	98.96	2.4	22.51	10.4
10	216	77.63	2.8	17.54	12.3
11	110	67.56	1.6	17.16	6.4
12	111	48.81	2.3	14.94	7.4
13	139	79.22	1.8	28.54	4.9
14	282	83.94	3.4	22.12	12.7
15	173	79.47	2.2	16.65	10.4
16	413	120.98	3.4	28.12	14.7
17	313	123.05	2.5	25.00	12.5

18	267	90.53	2.9	23.00	11.6

Tab 55. Experiment A – Thales - Comparison of point position error (m_{pkt}) calculated from reference parcel and real GPS measurements

Number of parcel	SDev $m_p[m^2]$	HB reference parcels [m]	SDev/HB $m_{pkt}[m]$	HB GPS real measurements [m]	Sdev/HB GPS $m_{pkt}[m]$
1	102	77.62	1.311	18.15	5.6
2	132	58.42	2.25	16.71	7.9
3	116	58.17	1.985	15.67	7.4
4	208	95.3	2.19	25.15	8.3
5	210	91.8	2.288	20.73	10.1
6	59	74.53	0.791	22.39	2.6
7	317	141.76	2.237	37.89	8.4
8	420	135.38	3.117	27.95	15.0
9	80	98.96	2.821	22.51	3.6
10	212	77.63	2.734	17.54	12.1
11	136	67.56	2.025	17.16	7.9
12	327	48.81	6.68	14.94	21.9
13	122	79.22	1.539	28.54	4.3
14	373	83.94	4.405	22.12	16.9
15	475	79.47	5.969	16.65	28.5
16	513	120.98	4.235	28.12	18.2
17	521	123.05	4.22	25	20.8
18	1017	90.53	11.224	23	44.2

Tab 56. Experiment B – Satcon S3 - Comparison of point position error (m_{pkt}) calculated from reference parcel and real GPS measurements

Number of parcel	SDev $m_p[m^2]$	HB reference parcels [m]	SDev/HB $m_{pkt}[m]$	HB GPS real measurements [m]	Sdev/HB GPS $m_{pkt}[m]$
19	118	83.8	1.4	18	6.6
20	148	71.73	2.064	17	8.7
21	106	63.46	1.668	15	7.1
22	231	113.72	2.033	24	9.6
23	228	102.57	2.223	22	10.4
24	164	89	1.827	18	9.1
25	369	130.69	2.821	30	12.3
26	261	147.26	1.775	29	9.0
27	303	107.72	2.812	25	12.1
28	238	104.72	2.305	21	11.3

29	149	67.83	2.184	16	9.3
30	74	54.45	1.362	15	4.9
31	336	109.93	3.048	24	14.0
32	384	91.12	4.23	22	17.5
33	114	67.55	1.683	18	6.3
34	687	135.04	5.125	30	22.9
35	363	116.85	3.107	28	13.0
36	434	117.82	3.674	25	17.4

Tab 57. Experiment B – Satcon S4 - Comparison of point position error (m_{pkt}) calculated from reference parcel and real GPS measurements

Number of parcel	SDev $m_p[m^2]$	HB reference parcels [m]	SDev/HB $m_{pkt}[m]$	HB GPS real measurements [m]	Sdev/HB GPS $m_{pkt}[m]$
19	189	83.8	2.247	18	10.5
20	102	71.73	1.424	17	6.0
21	56	63.46	0.889	15	3.7
22	251	113.72	2.209	24	10.5
23	298	102.57	2.899	22	13.5
24	138	89	1.537	18	7.7
25	267	130.69	2.041	30	8.9
26	351	147.26	2.387	29	12.1
27	159	107.72	1.476	25	6.4
28	183	104.72	1.767	21	8.7
29	103	67.83	1.5	16	6.4
30	84	54.45	1.551	15	5.6
31	313	109.93	2.847	24	13.0
32	219	91.12	2.412	22	10.0
33	101	67.55	1.493	18	5.6
34	503	135.04	3.752	30	16.8
35	415	116.85	3.551	28	14.8
36	501	117.82	4.237	25	20.0

Tab 58. Experiment B – Thales T3 - Comparison of point position error (m_{pkt}) calculated from reference parcel and real GPS measurements

Number of parcel	SDev $m_p[m^2]$	HB reference parcels [m]	SDev/HB $m_{pkt}[m]$	HB GPS real measurements [m]	Sdev/HB GPS $m_{pkt}[m]$
19	73	83.8	0.863	18	4.1
20	58	71.73	0.806	17	3.4
21	41	63.46	0.641	15	2.7

22	283	113.72	2.493	24	11.8
23	159	102.57	1.547	22	7.2
24	97	89	1.082	18	5.4
25	196	130.69	1.501	30	6.5
26	277	147.26	1.881	29	9.6
27	150	107.72	1.395	25	6.0
28	188	104.72	1.819	21	9.0
29	141	67.83	2.069	16	8.8
30	118	54.45	2.169	15	7.9
31	298	109.93	2.707	24	12.4
32	386	91.12	4.251	22	17.5
33	139	67.55	2.047	18	7.7
34	872	135.04	6.507	30	29.1
35	384	116.85	3.293	28	13.7
36	209	117.82	1.77	25	8.4

Tab 59. Experiment B – Thales T4 - Comparison of point position error (m_{pkt}) calculated from reference parcel and real GPS measurements

Number of parcel	SDev $m_p[m^2]$	HB reference parcels [m]	SDev/HB $m_{pkt}[m]$	HB GPS real measurements [m]	Sdev/HB GPS $m_{pkt}[m]$
19	111	83.8	1.327	18	6.2
20	78	71.73	1.087	17	4.6
21	56	63.46	0.888	15	3.7
22	194	113.72	1.706	24	8.1
23	117	102.57	1.14	22	5.3
24	84	89	0.936	18	4.7
25	366	130.69	2.801	30	12.2
26	158	147.26	1.075	29	5.4
27	210	107.72	1.951	25	8.4
28	242	104.72	2.344	21	11.5
29	79	67.83	1.153	16	4.9
30	111	54.45	2.038	15	7.4
31	295	109.93	2.68	24	12.3
32	410	91.12	4.512	22	18.6
33	89	67.55	1.317	18	4.9
34	346	135.04	2.579	30	11.5
35	545	116.85	4.668	28	19.5
36	178	117.82	1.504	25	7.1

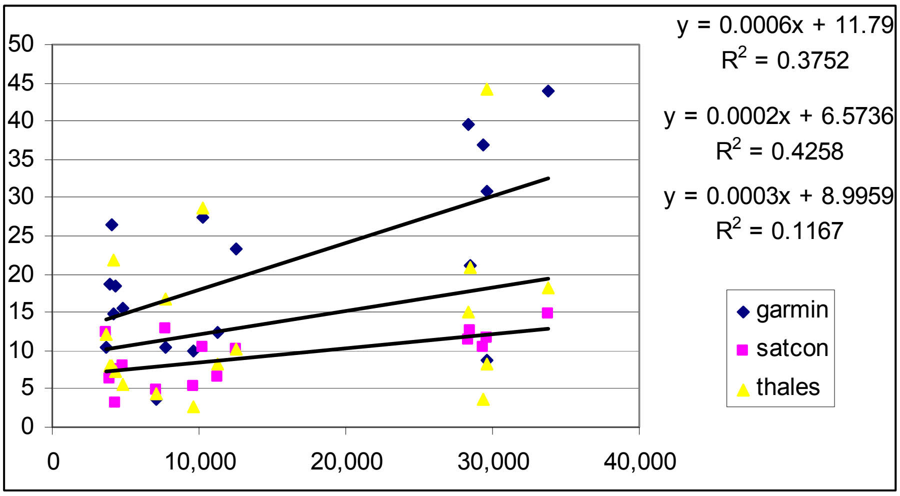


Fig. 80. Relationship between point position error m_{pkt} [m] and parcel area [m^2] – experiment A

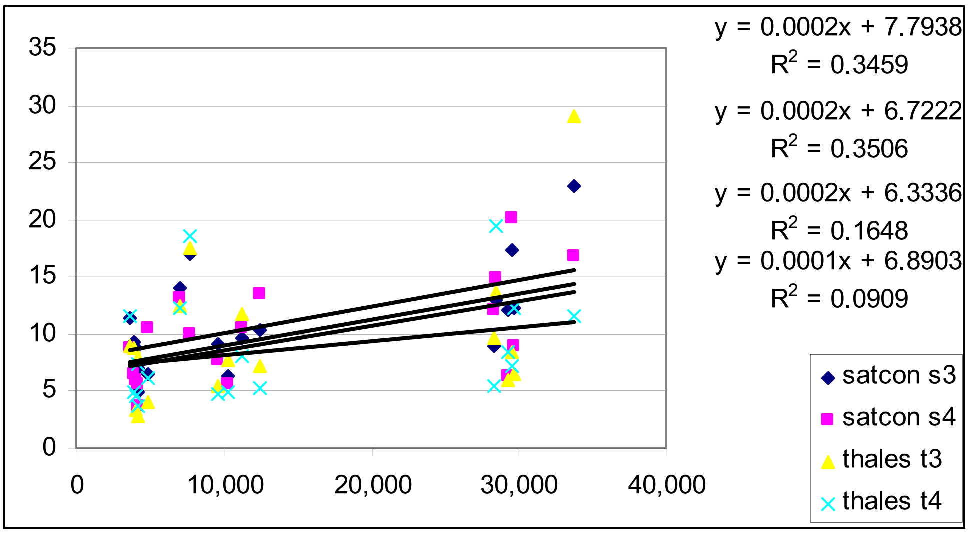


Fig. 81. Relationship between point position error m_{pkt} [m] and parcel area [m^2] – experiment B

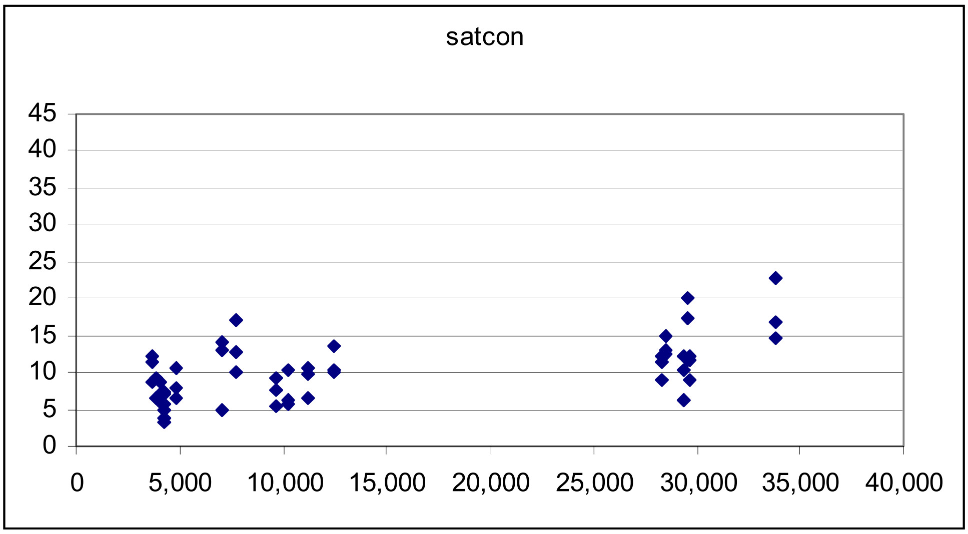


Fig. 82. Relationship between point position error m_{pkt} [m] and parcel area [m^2] – SATCON, experiment A and B

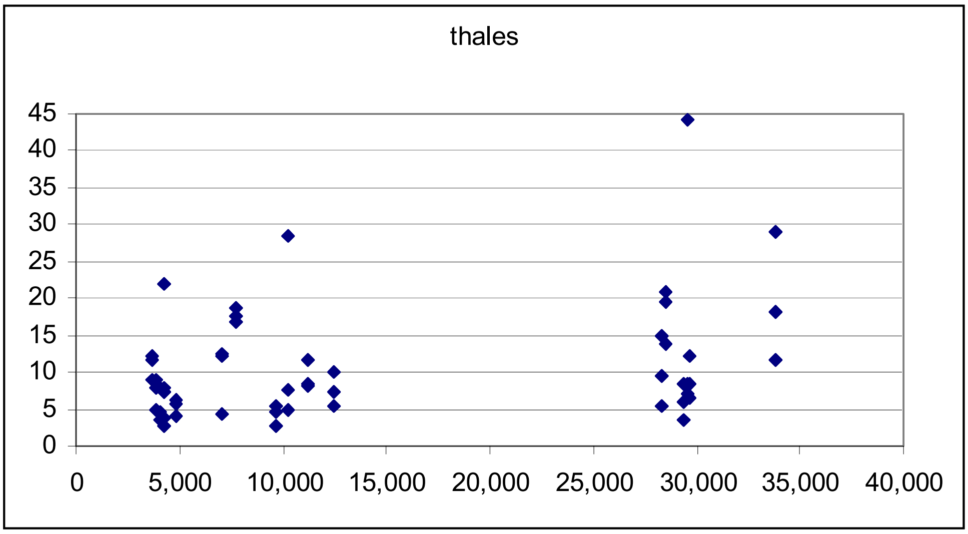


Fig. 83. Relationship between point position error m_{pkt} [m] and parcel area [m^2] – THALES, experiment A and B

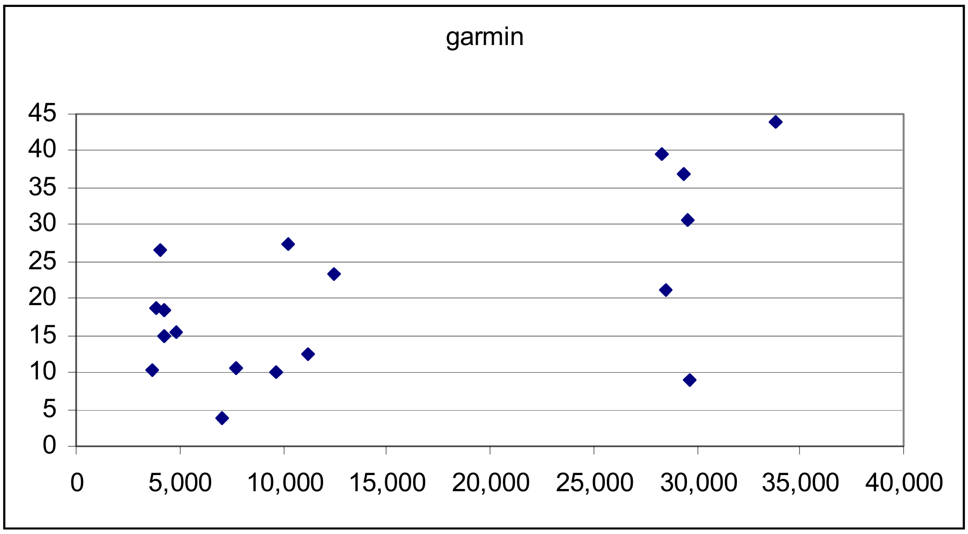


Fig. 84. Relationship between point position error m_{pkt} [m] and parcel area [m^2] – GARMIN, experiment A and B

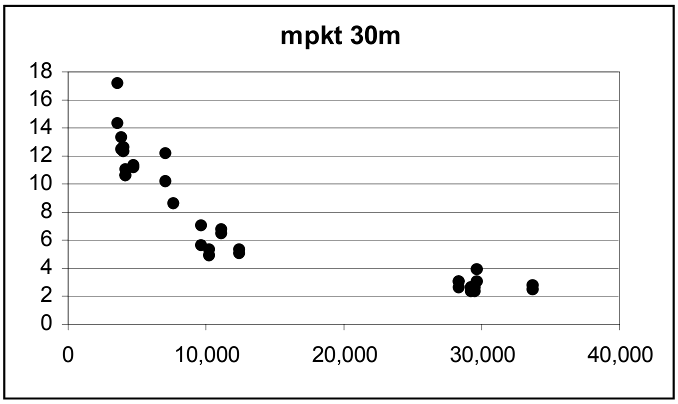


Fig. 85. Relationship between relative area error m_p [%[and parcel area [m^2] – assuming point position error m_{pkt} = 30m

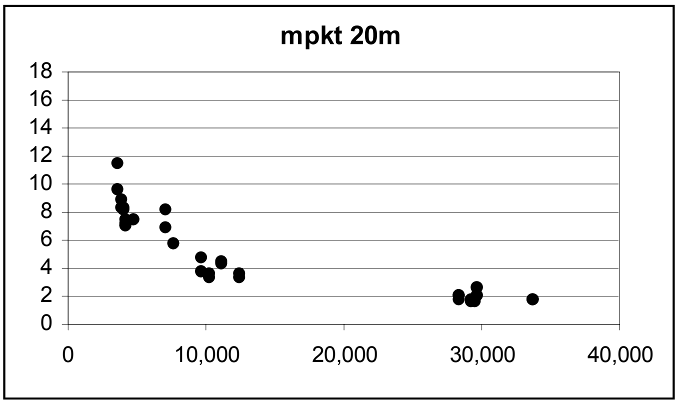


Fig. 86. Relationship between relative area error m_p [%[and parcel area [m^2] – assuming point position error m_{pkt} = 20m

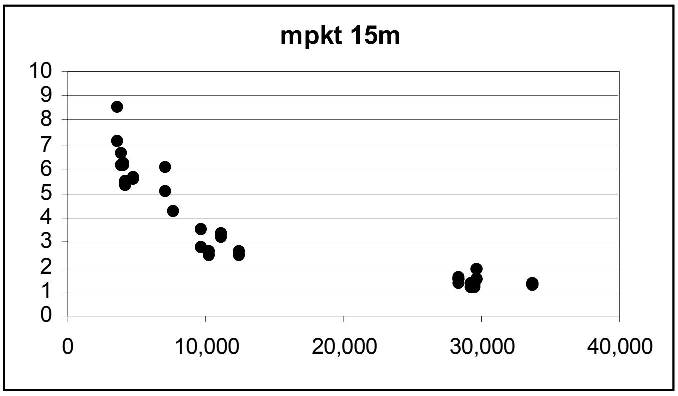


Fig. 87. Relationship between relative area error m_p [%] and parcel area [m^2] – assuming point position error m_{pkt} = 15m

8.4 Prediction of parcel area error basing on point position error

Prediction of parcel area error is possible basing on the point position error. Point is understood as a point where measurement is done (GPS positioning, or point digitized on ortophotomap).

8.4.1 RS

In RS modeling different point position error was assumed: 2.55m (max.), 0.9m (min.), 1.7m (average value of error), (see Tab 52) and 2.0m as a general average (see Tab 47). Value of 2.55m overestimate the area error, 0.9m underestimate it, value of 1.7m and 2.0m seems to be more adequate.

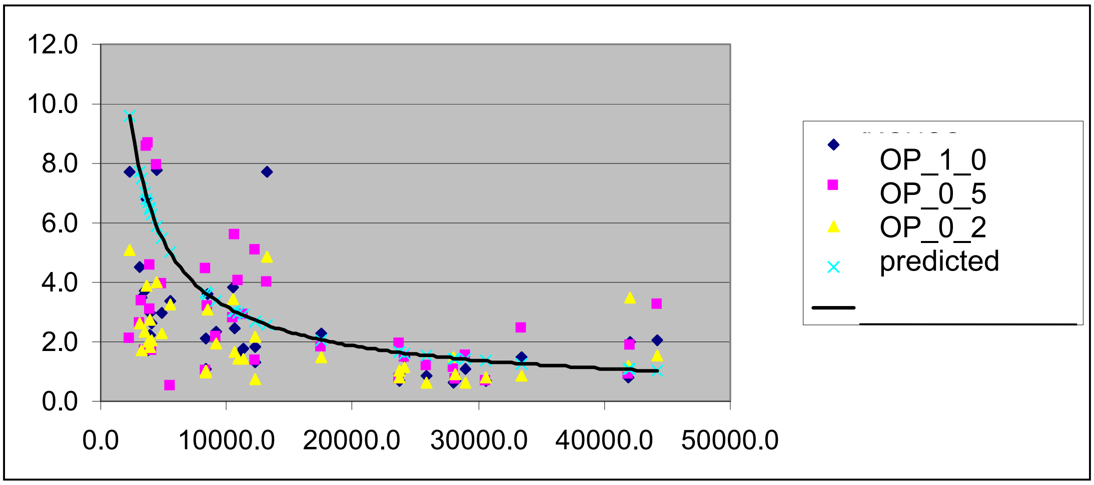


Fig. 88. Relationship between relative area error [%] and area [m^2] assuming m_{pkt}= 2.55m

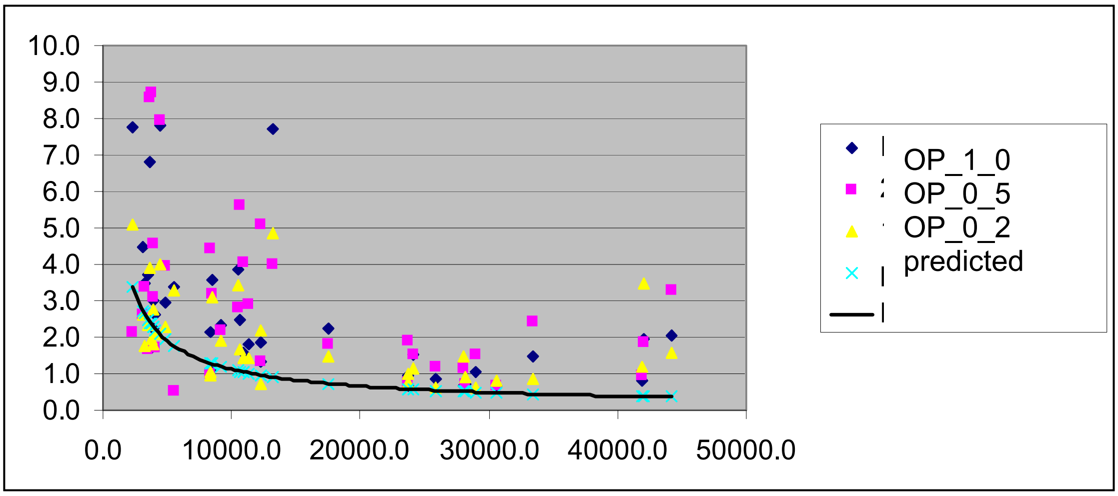


Fig. 89. Relationship between relative area error [%] and area [m^2] assuming m_{pkt}= 0.9 m

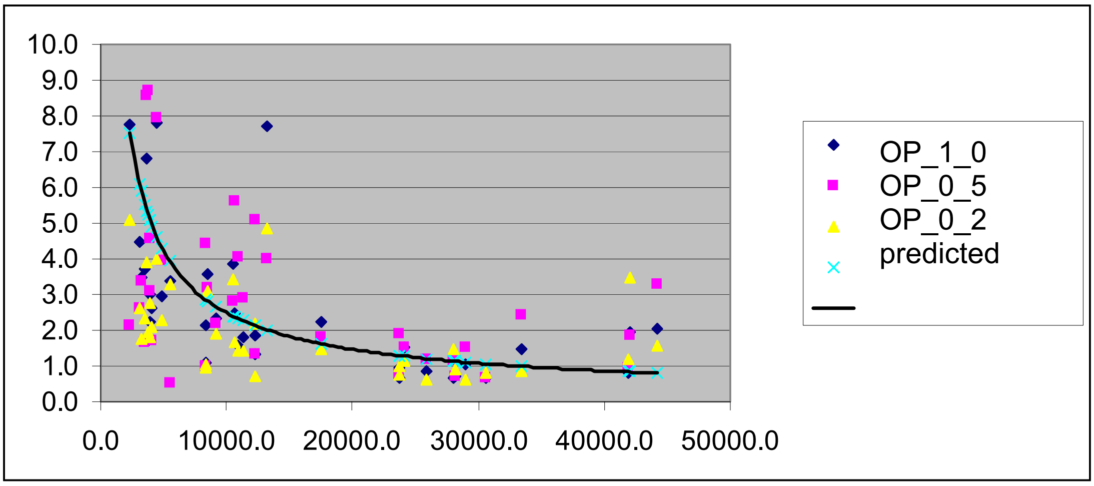


Fig. 90. Relationship between relative area error [%] and area [m^2] assuming m_{pkt}= 2.0 m

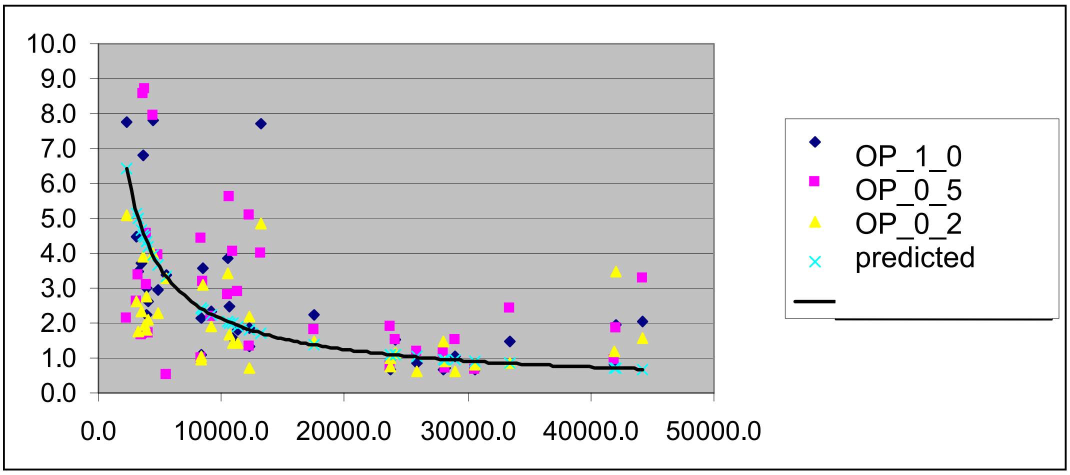


Fig. 91. Relationship between relative area error [%] and area [m^2] assuming m_{pkt}= 1.7 m

8.4.2 GPS

In GPS modeling different point position error was assumed: 15m and 10m. Value of 15m for experiment A and of 10m for experiment B seems to be adequate. Point position error of 15m overestimates the area error in experiment B.

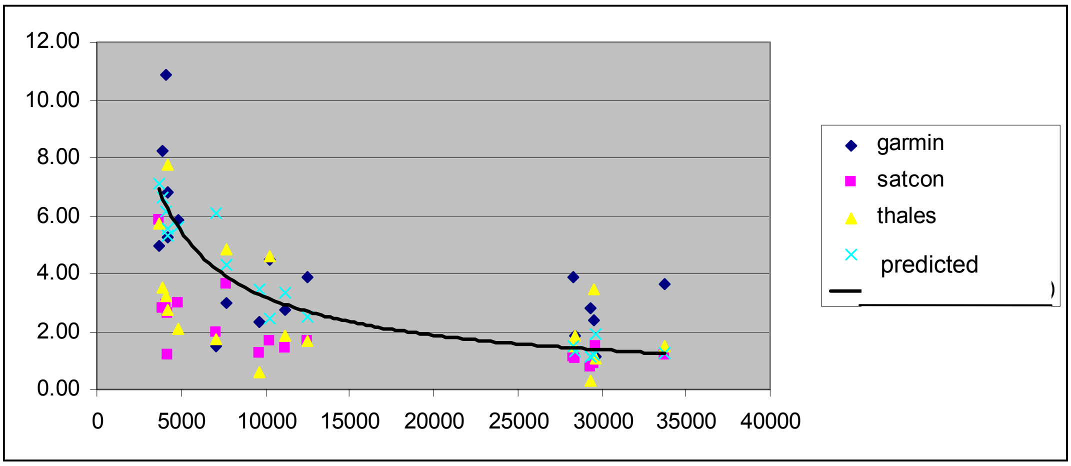


Fig. 92. Relationship between relative area error [%] and area [m^2] assuming m_{pkt}= 15 m – Experiment A

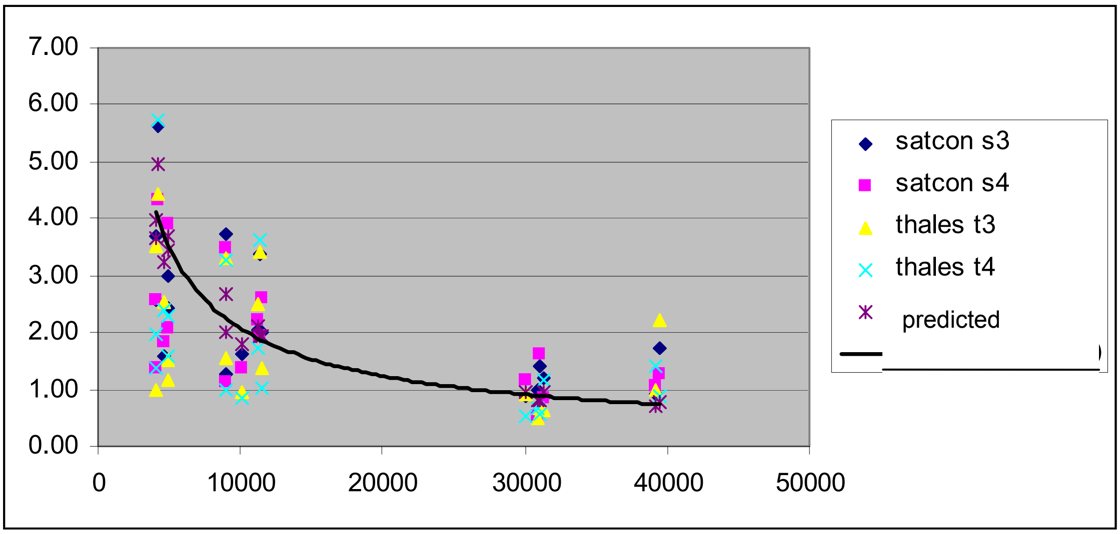


Fig. 93. Relationship between relative area error [%] and area [m^2] assuming m_{pkt}= 10 m – Experiment B

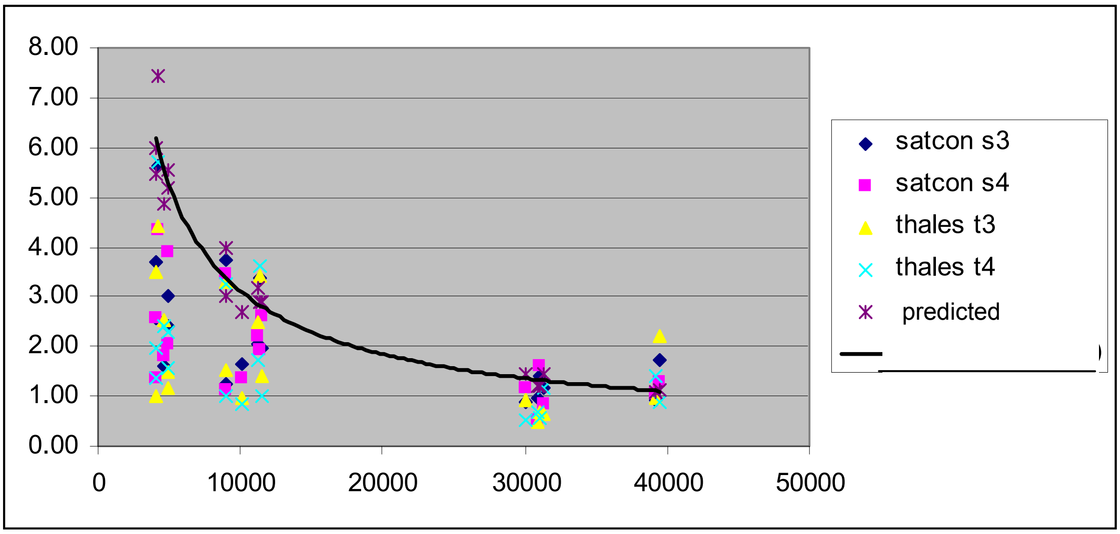


Fig. 94. Relationship between relative area error [%] and area [m^2] assuming m_{pkt}= 15 m – Experiment B

9. Proposal for validation of measurement of land parcel area

Design of experiment must be defined in methodology of validation of land parcel area measurement: how many parcels should be measured, how many times should be measured one parcel and how many operators should take part in the experiment. Because of rather big variability of results of parcel area measurements recommendation of experiment design is not common taking into account practical point of view. Therefore some statistical tests are planned in extension of the project. Theoretical backgrounds of the variants' recalculations are presented below.

9.1 Validation method: statistical aspect

The results of the three experiments show that the mean value of the buffer and the standard deviation of buffer between parcels vary with the measurement method. For the following discussion we consider the example of Satcon receiver in experiment A.

For this example, the mean value of buffer is 0.344 and the standard deviation for the 18 parcels is 0.081 (Tab 31). The values for each parcel are given in Tab 28and in Fig. 45.

If we consider the parcels as a random sample, the confidence limits (at level .95) for the mean are:

(37) $$0.344 \pm 2(0.081)\big/\sqrt{18}$$

or 0.306 and 0.382 and the precision (half of the length of the 0.95 confidence interval) is of about 11 % of the estimated value.

If we want a precision of 10 %, the number of parcels should be increased to

(38) $$p = (4)(0.081^2)\big/\left[(0.10)(0.344)\right]^2 = 22,$$

each parcel being measured 36 times.

The observed variability (0.081) is due to the differences between each (unknown) buffer of the parcels, but also to the error on each estimated buffer (from 36 observations).

If we propose to reduce the number of observations in each parcel, the between parcels observed standard deviation will increase. The between parcels observed variance is the sum of two components: the pure variance between parcels and the variance of the estimated buffer, which depends on the number of observations made in the parcel.

For a given parcel, the buffer is proportional to the standard deviation of the observations. The variance of a standard deviation estimator for a random sample of n observations taken from a normal distribution with variance σ^2 is approximately equal to:

(39) $$V(\mathrm{stdev}) = \sigma^2 / (2\ n).$$

Thus, the standard deviation of the buffer is:

(40) $$\mathrm{stdev}(\mathrm{buffer}) = \mathrm{buffer} / \left(\sqrt{2\ n}\right).$$

This standard deviation depends on the parcel, because parcels have different buffers, but, hereafter we consider the mean value of the buffer (0.344).

An estimation of the between parcels variance of the buffer is given by:

(41) $$0.081^2 - \frac{0.344^2}{(2)(36)} = 0{,}0050.$$

This variance is an estimated variance between parcels, after correction for the error of the estimation of the buffer in a given parcel. The observed standard deviation between parcels when the buffer is estimated from n measurements is given by:

(42) $$stdev = \sqrt{\frac{(0.344)^2}{2n} + 0{,}0050}.$$

For example

- if n = 10 stdev = 0.104
- if n = 4 stdev = 0.140
- if n = 1 stdev = 0.253.

The numbers of parcels needed to reach a precision (half of the length of the 0.95 confidence interval) of 10 % of the mean values of the buffer are:

- n = 10 p = 37 (370 observations)
- n = 4 p = 67 (268 observations)
- n = 1 p = 217 (217 observations).

Several approximations have been made to obtain these results and it could be useful to check them by using MC simulation.

Table Tab 60 shows some results for the other methods. This table gives the number of parcels necessary to get a precision (half of the length of the 0.95 confidence interval) of 10 % for the actual number of observations (36 observations for experiment A and remote sensing experiment and 24 observations for experiment B) and for numbers of observations equal to 10, 4 and 1.

The conclusion is that of we want a mean buffer value with a precision (half of the length of the 0.95 confidence interval) of 10 %, we need a large number of observations and thus an expensive experiment.

Another way of validation could be to check a given method in 15-20 parcels related to given conditions. The objective would not be to estimate the mean buffer with a fixed precision but to estimate the buffer of the given parcels. Twelve observations on each parcel would give a buffer of the parcel with a standard error of about:

(43) $$buffer \big/ \sqrt{(2)(12)} \approx 0{,}2 \ \ buffer,$$

and an estimation of variability in buffer between parcels would also be available through this experiment. Once again, it could be useful to reanalyse the results of several methods after splitting a given experiment into several smaller datasets and to examine the variability of the results in parcels and between parcels.

Tab 60. Number of parcels needed to get a precision of 10 % for the actual number of observations (N), for 10 observations, for 4 observations and for 1 observation per parcel.

	Method	N	N = 10	N = 4	N = 1
1	OP_0_2_ALL	202	217	247	397
2	OP_0_2_GOOD	48	62	92	242
3	OP_0_2_BAD	192	206	236	386
4	OP_0_5_ALL	125	140	170	320
5	OP_0_5_GOOD	180	194	224	374
6	OP_0_5_BAD	82	96	126	276
7	OP_1_0_ALL	219	234	264	414
8	OP_1_0_GOOD	62	77	107	257
9	OP_1_0_BAD	225	240	270	420
10	G_ALL/A	71	86	116	266
11	G_GOOD/A	63	78	108	258
12	G_BAD/A	87	101	131	281
13	S_ALL/A	22	37	67	217
14	S_GOOD/A	14	29	59	209
15	S_BAD/A	20	35	65	215
16	T_ALL/A	171	185	215	365
17	T_GOOD/A	31	45	75	225
18	T_BAD/A	120	135	165	315
19	S3_ALL/B	29	41	71	221
20	S3_GOOD/B	8	20	50	200
21	S3_BAD/B	34	46	76	226
22	S4_ALL/B	41	53	83	233
23	S4_GOOD/B	42	53	83	233
24	S4_BAD/B	39	50	80	230
25	T3_ALL/B	94	106	136	286

26	T3_GOOD/B	59	71	101	251
27	T3_BAD/B	47	59	89	239
28	T4_ALL/B	67	79	109	259
29	T4_GOOD/B	25	36	66	216
30	T4_BAD/B	54	66	96	246

9.2 Design of experiment

Design of the validation experiment is not detailed described in the final report because of the problems shown in chapter above (9.1). In extension of the project some variants of statistical analysis are planned for optimizing validation procedure. However some assumption can be presented:

- It is not necessary to test skilled and unskilled operators (the obtained results are similar for both, but unskilled operator must be more detailed trained in compare to the unskilled).
- Parcels of different area should be measured.
- Parcels sets should composed by parcels with: good and bad borders.
  - In RS measurements bad border can be understood as borders with trees, or bad brightness and contrast of the image.
  - In GPS measurements trees are also obstruction because of availability satellites.
- Two kind of parcel size seems to be enough (instead of three kinds: S1, S2, S3 in the project).
- Reference parcels should be measured using geodetic instruments, for example Total Station, cadastre parcel can be used with especially caution.
- Storing all data in GIS data base is suggested.

9.3 Work flow of measurements

- Selection of reference parcels and measurements of:
  - Area and perimeter of the parcels.
  - Coordinates of all parcels' vertexes.
- Statistical planning of experiments to avoid correlations between measurements. The sequences of measurements of each parcel should be planned according statistical assumptions.
- Training of the operators.
- Area and perimeter measurement by operators in a few series according defined sequences.
  - Storage, if possible, coordinates of parcel vertexes for all measurements.
- Controlling results of all measurements to avoid gross errors.

9.4 Data preparation

- Automatic transformation of the results of all measurements by all operators to the statistical analysis.
- Area_error_coefficient calculation (BH or BDK)

9.5 Statistical outlier identification basing on workflow in chapter 3

- Mandel's h and k statistics.
- Corchan's test
- Grubb's test
- Identifying of outliers.

9.6 Parcel area error calculation

Workflow of parcel area calculation is described on the basis of all experiment performed in the project (ex. Chapter 6).

- Relative area error analyze before and after suppression of observations.
- Bias of the method assessment.
- Variance components and reproducibility.
- Calculation of standard deviation for all parcels.
- Calculation of buffer and point position error (SDev/BH or SDev/BDK).
- Analysis of relationship between buffer and/or point position error and area of the parcels.
- Modeling of buffer or/and point position error of the method.

9.7 Parcel area error prediction.

Errors of area measurements can be also predicted basing of the point position error obtained from other measurements: GPS accuracy measurements, RMS of ortofotomaps. Besides "instruments" accuracy, ex. GPS or ortho quality of parcel borders should be take into account. It is very important when recognition of the parcel border is comparable with "instrument" accuracy. Resultant point position error can be used for parcel area error prediction on the basis of formula (25) or (26).

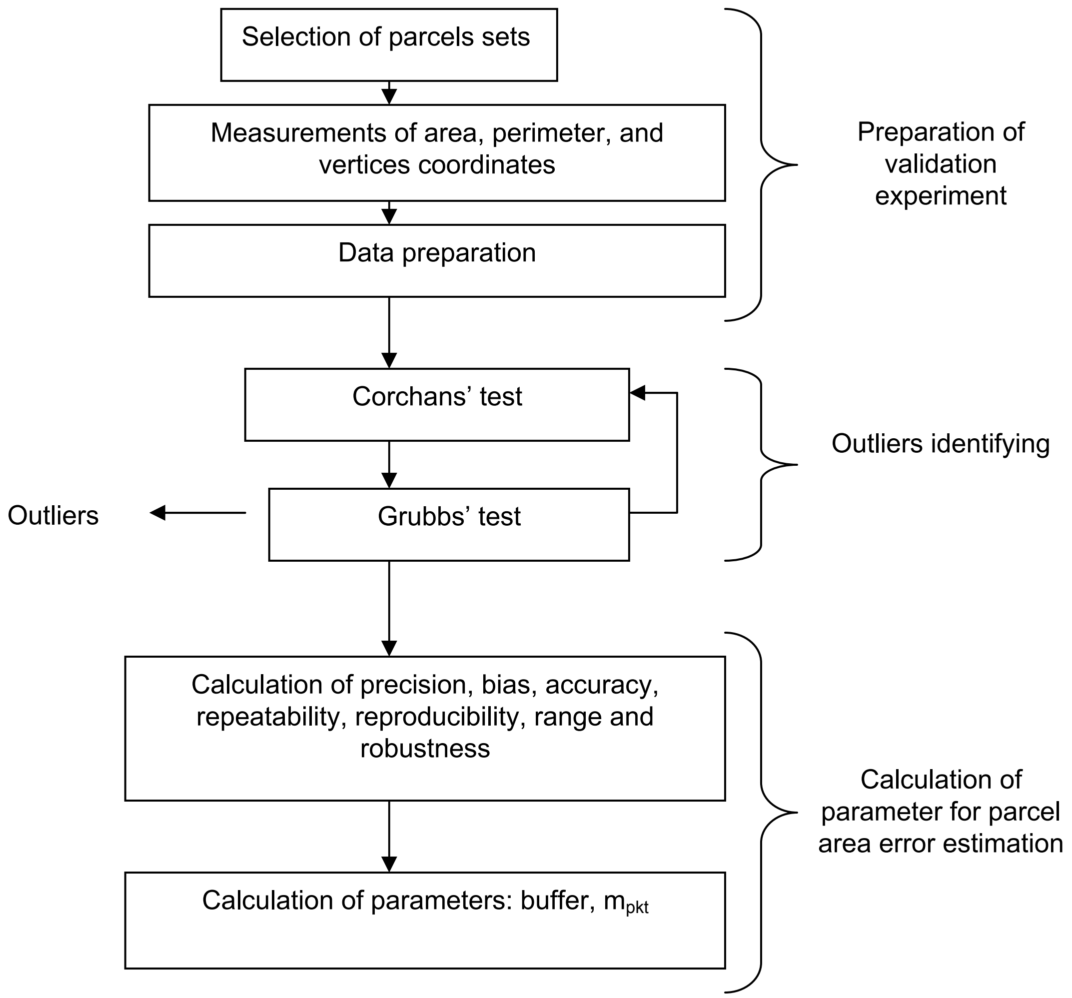


Fig. 95. Validation method schema

10. Bibliography

1) Bogaert P., Delinc´e J., Kay S. 2005 – “Assessing the error of polygonal area measurements: a general formulation with applications to agriculture” – Institute of Physics Publishing, Measurements Science Technology, 16 (2005), 1170-1178

2) Hejmanowska B., 2003 – „Data inaccuracy in geographic system – propagation of DTM and ortophotomaps in the spatial analysis”, – Geodesy 40, Publishing of Geodesy and Environmental Engineering, Polish Academy of Science, Kraków

3) Kay S., Spruyt P. 2002 - JRC GPS validation scheme (ref. JRC IPSC/G03/P/SKA/ska D(2002)(1092))

4) Kay S., 2003 - JRC Technical Information Document: Technical tolerances for On the Spot checks (ref. JRC IPSC/G03/P/SKA/ska D(2003)(1576))

5) Oszczak. S - "Assessment and development of selection criteria for GPS measurement methods and equipment to ensure required accuracy and reliability of area-bases subsidies control in IACS system" - a collective study, developed under direction of Prof Dr Eng Stanislaw Oszczak, February 2004

6) Oszczak. S - "Examination of accuracy and usefulness of Thales Mobile Mapper GPS receiver for area-bases subsidies control in IACS system" - a collective study, developed under direction of Prof Dr Eng Stanislaw Oszczak, April 2004

7) Oszczak. S – “Final report of "on the spot control" in Kujawsko-Pomorskie region commissioned by ARMA”. All together over 70 000 hectares controlled in the 2004 campaign.

8) Rodolphe Palm - Echantillonnage avec probabilités inégales et sans remise : comparaison de l'estimateur de Horvitz et Thompson à des alternatives plus simples (in collaboration with F. Bertrand). Rev. Stat. Appl., 38, 5-21, 1990.

9) Rodolphe Palm - Tendance générale et effets du climat dans la prévision des rendements agricoles des différents pays de la Communauté européenne (in collaboration with P. Dagnelie). Luxembourg, Office des Publications officielles des Communautés européennes, 128 p., 1993.

10) Rodolphe Palm - Regression methods including the EUROSTAT AGROMET model and time trends. In : DALLEMAND J.F., VOSSEN P. Workshop for Central and Eastern Europe

on Agrometeorological models : theory and applications in the MARS project. Luxembourg, Office for Official Publications of the European Communities, 61-72, 1996.

11) Rodolphe Palm - Conditions d'application et transformations de variables en régression linéaire (in collaboration with A.F. Iemma). Notes Stat. Inform. (Gembloux) 2002/1, 34 p., 2002.

12) Rodolphe Palm - Comparaison empirique des estimateurs des taux d'erreur en analyse discriminante (in collaboration with R.L. Glèlé Kakaï, F. Piraux and N.H. Fonton). Rev. Stat. Appl. 51, 3, 61-74, 2003.

13) Spruyt P., 2004 - JRC Protocol for reference field-measurement (ref. JRC IPSC/G03/P/PSP/psp D(2002)(1108))

14) Note on the use of stand-alone GPS for parcel measurement (ref. JRC IPSC/G03/SKA/OLE D(2002)(1087))

15) DG-AGRI Guidance for on-the-spot checks of area and area measurement (ref. AGRI-2254-2003), Working Document No. AGRI/2254/2003 replacing working document VI/8388/94 rev. 6 of 17/12/1999, on-the-spot checks of area according to articles 15-23 of commission regulation (ec) no 2419/2001

16) **ISO standards**:

- ISO 5725 “Accuracy (trueness and precision) of measurement methods and results”
    - º Part 1 „General principles and definitions”
    - º Part 2 “Basic method for the determination of repeatability and reproducibility of a standard measurement method”
    - º Part 3 “Intermediate measures of the precision of a standard measurements method”

17) **Polish regulations concerning to surveying**

- º “General regulations concerning the background of surveying O-1, 1988” -
- º “Technical specification G-5 – Cadastre of grounds and buildings, 2003”

11. Appendix - Statistical analysis.

11.1.1 Remote sensing

11.1.1.1 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 3.4.3.

In the table results of GIS analysis are presented in last column. The following notations are used for source of errors:

- BI - bad border identification (55%),
- RE (BI) – random error mainly caused bad border identification (23%),
- GE – gross error, only this kind of error could be avoided (17%).

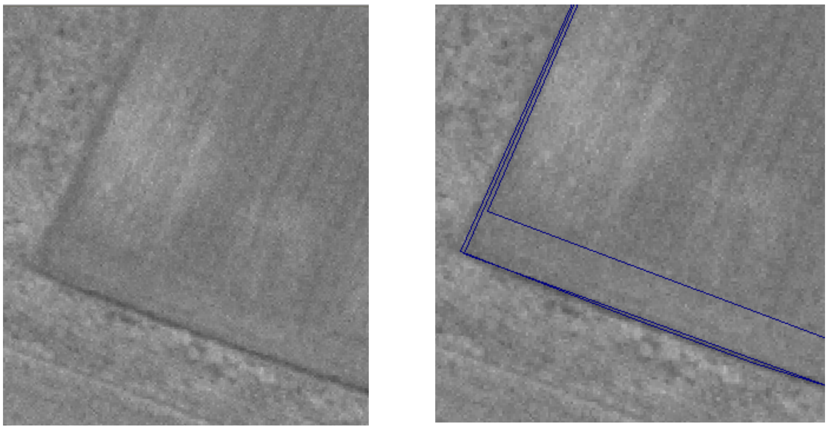


Fig. 96. BI – operator 2, parcel 5, OP_0_2

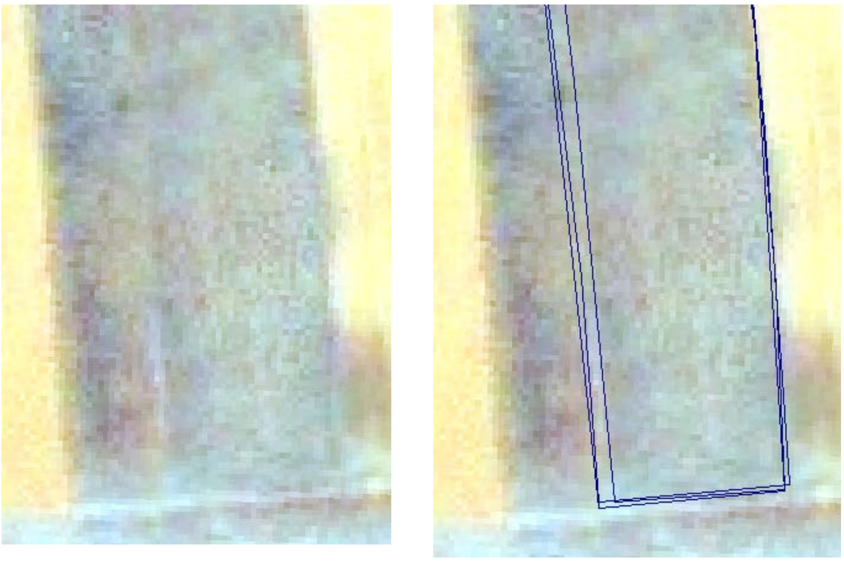


Fig. 97. RE (BI) – operator 8, parcel 24, OP_1_0

Fig. 98. GE – operator 1, parcel 14, OP_0_2

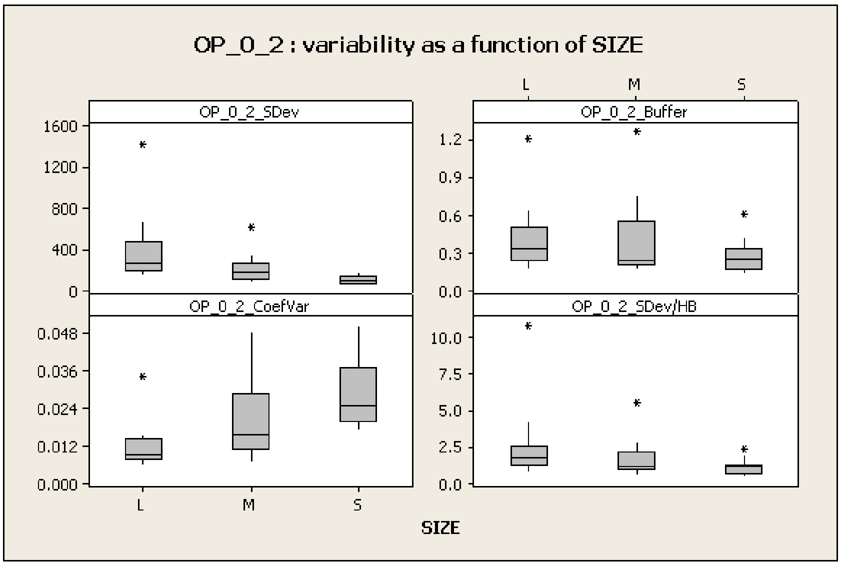
Row	Parcel	Photo	Operator	Data	Cochran	Grubbs/1	Grubbs/2	GIS analysis
1	1	OP_0_2	3	3587.3	2	0	0	BI
2	1	OP_0_2	3	3592.7	2	0	0	BI
3	1	OP_0_2	3	3320.5	2	0	0	BI
4	1	OP_0_5	3	3127.1	2	0	0	BI
5	1	OP_0_5	3	3626.5	2	0	0	BI
6	1	OP_0_5	3	3540.1	2	0	0	BI
7	5	OP_0_2	2	11791.6	0	0	10	BI
8	5	OP_0_2	2	12148	0	0	10	BI
9	5	OP_0_2	2	12139	0	0	10	BI
10	5	OP_0_2	12	11969.9	0	0	10	RE (BI)

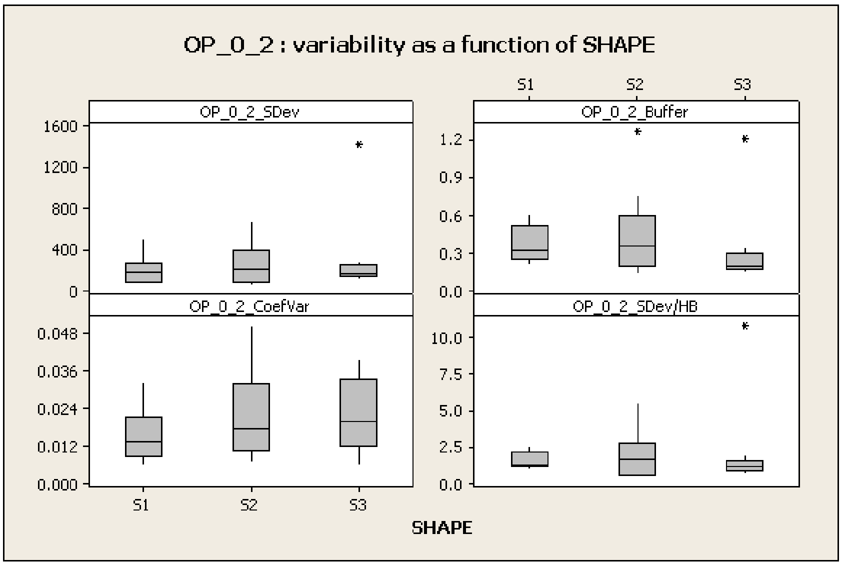
11	5	OP_0_2	12	12106.5	0	0	10	RE (BI)
12	5	OP_0_2	12	12277.1	0	0	10	RE (BI)
13	5	OP_0_5	2	11019.2	2	0	0	GE
14	5	OP_0_5	2	12129.9	2	0	0	GE
15	5	OP_0_5	2	12184.7	2	0	0	GE
16	7	OP_0_5	8	23169.2	2	0	0	GE
17	7	OP_0_5	8	24375.5	2	0	0	GE
18	7	OP_0_5	8	24284.7	2	0	0	GE
19	8	OP_1_0	2	28370.6	2	0	0	BI
20	8	OP_1_0	2	26967.1	2	0	0	BI
21	8	OP_1_0	2	28295.7	2	0	0	BI
22	8	OP_1_0	10	28538.7	2	0	0	BI
23	8	OP_1_0	10	27316	2	0	0	BI
24	8	OP_1_0	10	28214.4	2	0	0	BI
25	9	OP_0_2	12	23124.9	0	10	0	BI
26	9	OP_0_2	12	23826.4	0	10	0	BI
27	9	OP_0_2	12	23773	0	10	0	BI
28	10	OP_0_5	9	4433	2	0	0	GE
29	10	OP_0_5	9	4131.2	2	0	0	GE
30	10	OP_0_5	9	4165.1	2	0	0	GE
31	14	OP_0_2	11	14026	2	0	0	GE
32	14	OP_0_2	11	12537.4	2	0	0	GE
33	14	OP_0_2	11	12291.8	2	0	0	GE
34	15	OP_1_0	6	10420.8	2	0	0	BI
35	15	OP_1_0	6	11021.9	2	0	0	BI
36	15	OP_1_0	6	9993.1	2	0	0	BI
37	16	OP_1_0	12	41982.3	2	0	0	BI
38	16	OP_1_0	12	40869.2	2	0	0	BI
39	16	OP_1_0	12	42884.5	2	0	0	BI
40	17	OP_0_2	2	30622.2	2	0	0	BI
41	17	OP_0_2	2	28464.6	2	0	0	BI
42	17	OP_0_2	2	28455.7	2	0	0	BI
43	17	OP_0_5	2	30379.2	2	0	0	GE
44	17	OP_0_5	2	27987.9	2	0	0	GE
45	17	OP_0_5	2	27978.5	2	0	0	GE
46	17	OP_0_5	4	30657.3	2	0	0	RE (BI)
47	17	OP_0_5	4	30380.9	2	0	0	RE (BI)
48	17	OP_0_5	4	31448.2	2	0	0	RE (BI)
49	19	OP_1_0	7	3511.1	2	0	0	BI

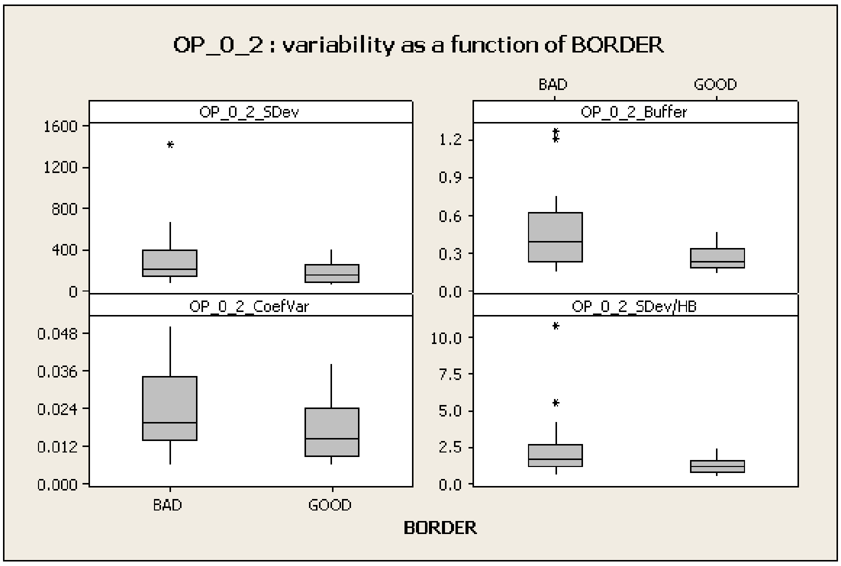
50	19	OP_1_0	7	3781.5	2	0	0	BI
51	19	OP_1_0	7	3851.1	2	0	0	BI
52	19	OP_1_0	11	3896.8	2	0	0	BI
53	19	OP_1_0	11	3721.3	2	0	0	BI
54	19	OP_1_0	11	3645.5	2	0	0	BI
55	24	OP_0_2	11	11575.1	2	0	0	RE (BI)
56	24	OP_0_2	11	11498.8	2	0	0	RE (BI)
57	24	OP_0_2	11	12326.8	2	0	0	RE (BI)
58	24	OP_1_0	8	12409.6	2	0	0	RE (BI)
59	24	OP_1_0	8	11383.6	2	0	0	RE (BI)
60	24	OP_1_0	8	12864.4	2	0	0	RE (BI)
61	24	OP_1_0	7	12502.3	0	0	10	RE (BI)
62	24	OP_1_0	7	12077.8	0	0	10	RE (BI)
63	24	OP_1_0	7	11954.4	0	0	10	RE (BI)
64	24	OP_1_0	11	12186.8	0	0	10	RE (BI)
65	24	OP_1_0	11	11840.1	0	0	10	RE (BI)
66	24	OP_1_0	11	12010.2	0	0	10	RE (BI)
67	26	OP_0_2	3	29276.4	0	10	0	BI
68	26	OP_0_2	3	29207.2	0	10	0	BI
69	26	OP_0_2	3	30009.4	0	10	0	BI
70	26	OP_1_0	11	28004.9	2	0	0	RE (BI)
71	26	OP_1_0	11	28869	2	0	0	RE (BI)
72	26	OP_1_0	11	27690.3	2	0	0	RE (BI)
73	28	OP_0_2	8	5156.3	2	0	0	BI
74	28	OP_0_2	8	5813.1	2	0	0	BI
75	28	OP_0_2	8	5612	2	0	0	BI
76	35	OP_0_2	6	44723.3	2	0	0	BI (bad border)
77	35	OP_0_2	6	42498.5	2	0	0	BI (bad border)
78	35	OP_0_2	6	43028.6	2	0	0	BI (bad border)
79	35	OP_1_0	6	42661.7	2	0	0	BI (bad border)
80	35	OP_1_0	6	44609.9	2	0	0	BI (bad border)
81	35	OP_1_0	6	42378.7	2	0	0	BI (bad border)
82	36	OP_1_0	5	40934.5	2	0	0	BI (bad border)
83	36	OP_1_0	5	42951.4	2	0	0	BI (bad border)
84	36	OP_1_0	5	44050.3	2	0	0	BI (bad border)

11.1.1.2 Boxplots of four transformations of the reproducibility as a function of size, shape and border for RS measurements

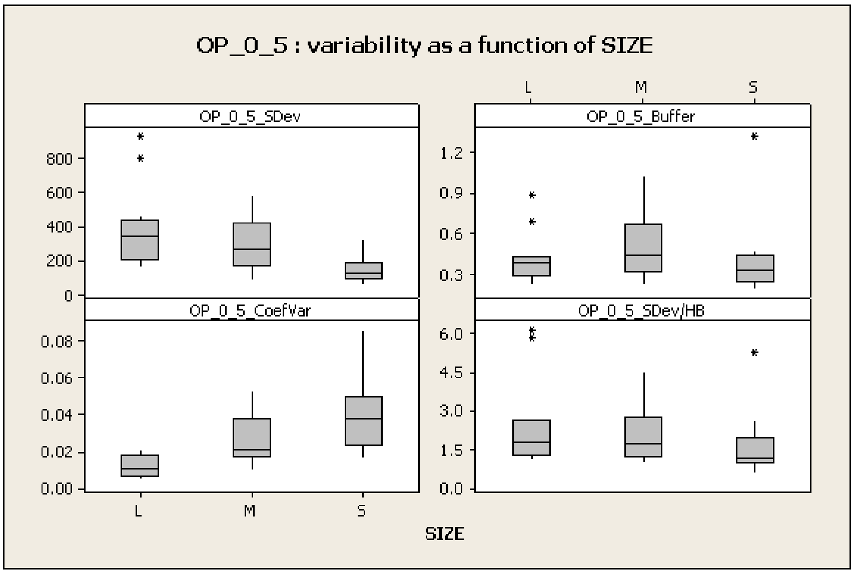
11.1.1.2.1 OP_0_2

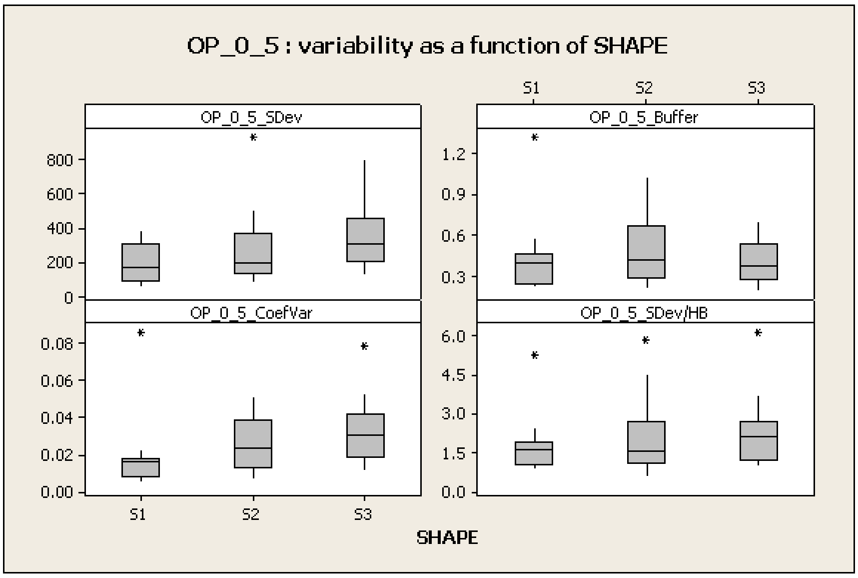


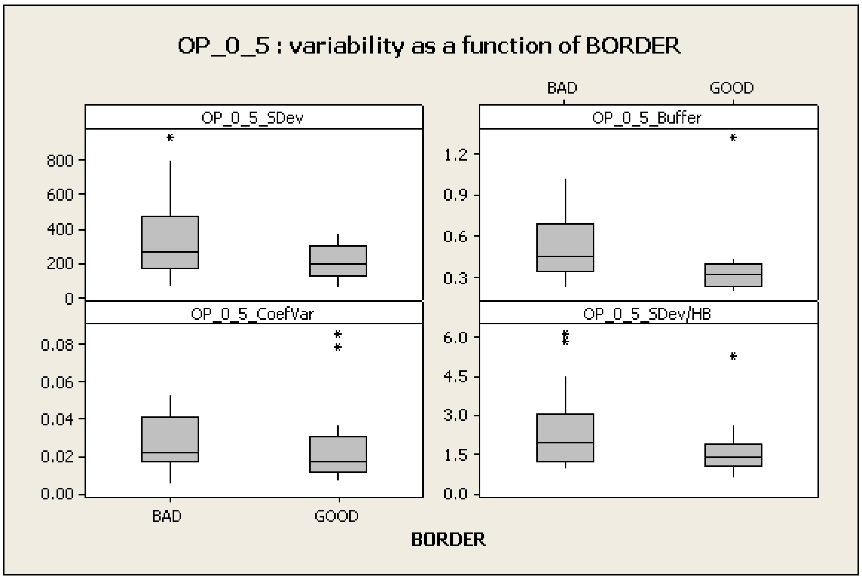



OP_0_2 : variability as a function of BORDER
OP_0_2_SDev
OP_0_2_Buffer
OP_0_2_CoefVar
OP_0_2_SDev/HB
BAD
GOOD
BORDER

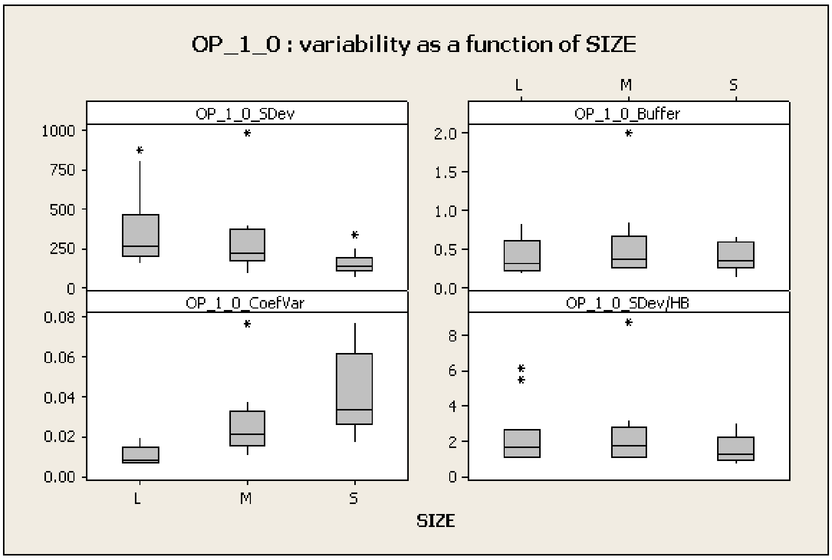
11.1.1.2.2 OP_0_5

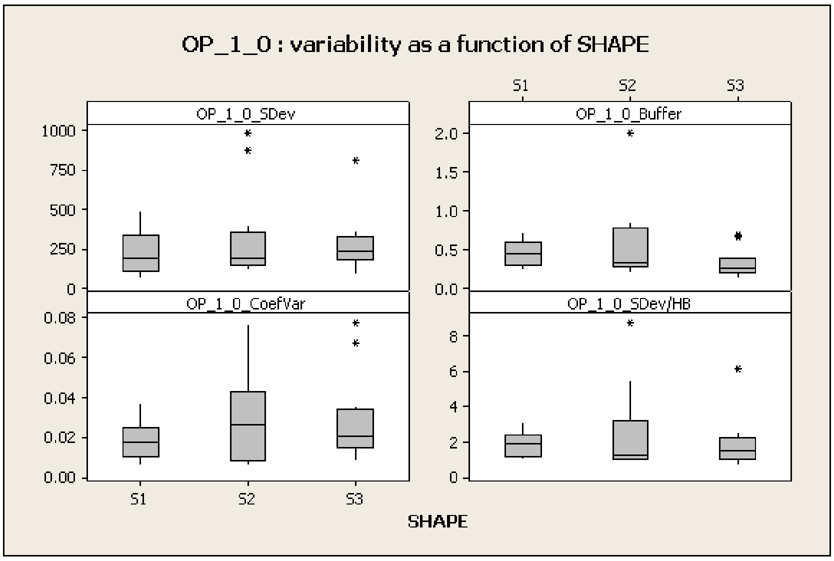

OP_0_5 : variability as a function of SIZE
OP_0_5_SDev
OP_0_5_Buffer
OP_0_5_CoefVar
OP_0_5_SDev/HB
L
M
S
SIZE

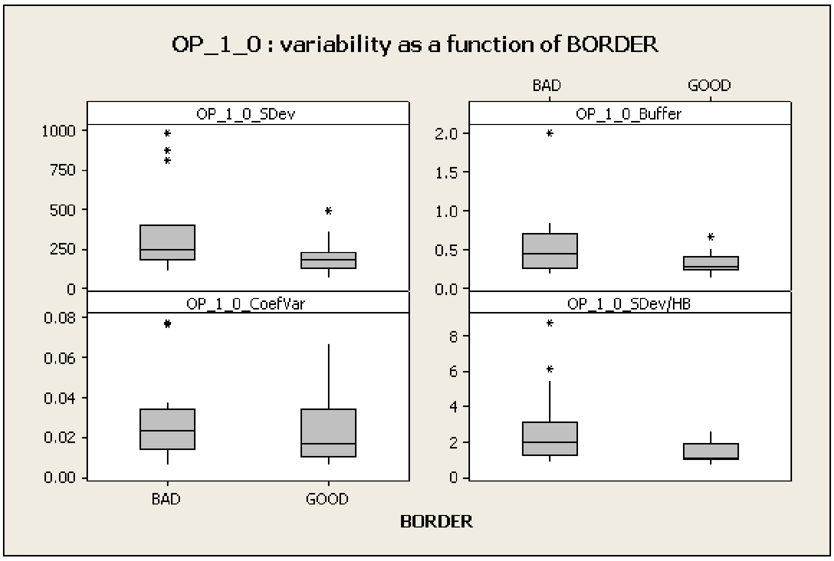

OP_0_5 : variability as a function of SHAPE
OP_0_5_SDev
OP_0_5_Buffer
OP_0_5_CoefVar
OP_0_5_SDev/HB
S1
S2
S3
SHAPE


OP_0_5 : variability as a function of BORDER
OP_0_5_SDev
OP_0_5_Buffer
OP_0_5_CoefVar
OP_0_5_SDev/HB
BAD
GOOD
BORDER

11.1.1.2.3 OP_1_0


OP_1_0 : variability as a function of SIZE
OP_1_0_SDev
OP_1_0_Buffer
OP_1_0_CoefVar
OP_1_0_SDev/HB
L
M
S
SIZE


OP_1_0 : variability as a function of SHAPE
OP_1_0_SDev
OP_1_0_Buffer
OP_1_0_CoefVar
OP_1_0_SDev/HB
S1
S2
S3
SHAPE



11.1.2 GPS – experiment A

11.1.2.1 List of discarded observations for experiment A. Explanation of the codes used in column COCHRAN, GRUBBS/1 and GRUBBS/2 is given in part 3.4.3.

Interpretation of outliers.

1) Garmin – 29 outliers which cannot be checked

2) Thales – 44 outliers:

    - 4 errors – 1 not significant
    - 39 outliers which can't be noticed in the field
    - 1 outlier which should be noticed in the field

3) Satcon – 46 outliers:

    - 1 error
    - 1 missing file
    - 19 Team 2 (missing file so far)
    - 16 outliers which can't be noticed in the field
    - 9 outliers which should be noticed in the field

Row	Parcel	GPS	Day	Data	COCHRAN	GRUBBS/1	GRUBBS/2
1	1	SATCON	2	2127	2	1	0
2	1	SATCON	1	6260	2	0	0
3	1	SATCON	1	4844	2	0	0
4	1	SATCON	1	5085	2	0	0
5	1	SATCON	1	4739	2	0	0

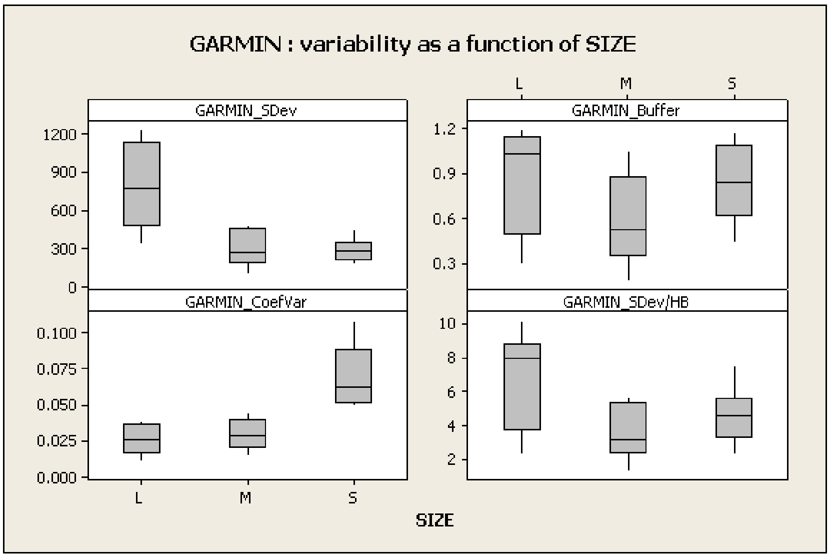
6	1	SATCON	1	4970	2	0	0
7	1	SATCON	1	5137	2	0	0
8	1	SATCON	5	5690	2	1	0
9	1	THALES	5	4710	2	0	0
10	1	THALES	5	4477	2	0	0
11	1	THALES	5	4660	2	0	0
12	1	THALES	5	4100	2	0	0
13	1	THALES	5	4700	2	0	0
14	1	THALES	5	4960	2	0	0
15	3	SATCON	5	17	2	1	0
16	3	SATCON	3	6457	2	1	0
17	3	SATCON	4	5142	2	1	0
18	3	SATCON	1	3803	2	1	0
19	4	SATCON	1	11254	2	0	0
20	4	SATCON	1	11755	2	0	0
21	4	SATCON	1	11289	2	0	0
22	4	SATCON	1	11786	2	0	0
23	4	SATCON	1	12030	2	0	0
24	4	SATCON	1	12048	2	0	0
25	4	THALES	1	10950	1	10	0
26	4	THALES	1	11450	1	10	0
27	4	THALES	1	12030	1	10	0
28	4	THALES	1	11280	1	10	0
29	4	THALES	1	11090	1	10	0
30	4	THALES	1	11330	1	10	0
31	5	GARMIN	4	12530	2	0	0
32	5	GARMIN	4	12340	2	0	0
33	5	GARMIN	4	12830	2	0	0
34	5	GARMIN	4	12210	2	0	0
35	5	GARMIN	4	10970	2	0	0
36	5	GARMIN	4	16640	2	0	0
37	5	GARMIN	2	10290	2	0	0
38	5	GARMIN	2	12640	2	0	0
39	5	GARMIN	2	12830	2	0	0
40	5	GARMIN	2	12740	2	0	0
41	5	GARMIN	2	12530	2	0	0
42	5	GARMIN	2	14780	2	0	0
43	5	THALES	2	10260	2	0	0
44	5	THALES	2	12330	2	0	0
45	5	THALES	2	12220	2	0	0
46	5	THALES	2	11760	2	0	0
47	5	THALES	2	12370	2	0	0

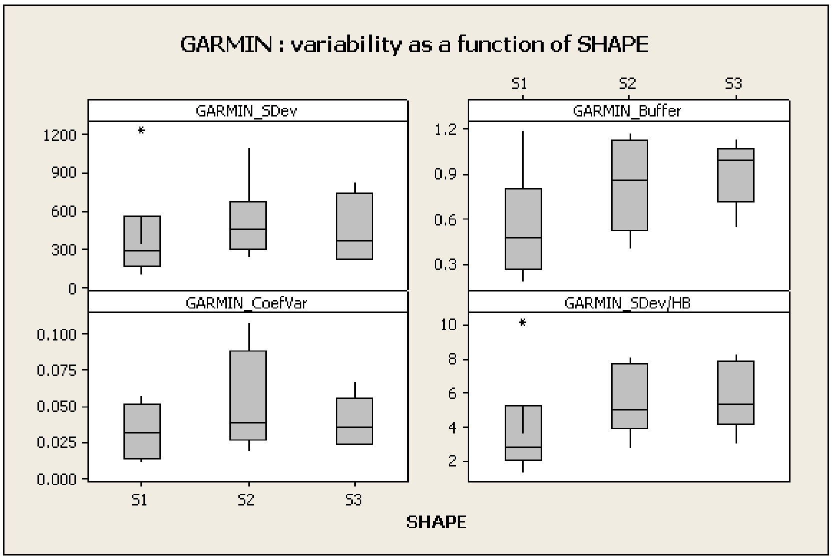
48	5	THALES	2	12590	2	0	0
49	7	SATCON	4	24590	2	1	0
50	7	SATCON	3	27809	2	0	0
51	7	SATCON	3	29393	2	0	0
52	7	SATCON	3	29505	2	0	0
53	7	SATCON	3	30085	2	0	0
54	7	SATCON	3	30030	2	0	0
55	7	SATCON	3	29908	2	0	0
56	11	SATCON	6	4150	2	0	0
57	11	SATCON	6	3670	2	0	0
58	11	SATCON	6	3610	2	0	0
59	11	SATCON	6	4120	2	0	0
60	11	SATCON	6	4230	2	0	0
61	11	SATCON	6	4110	2	0	0
62	12	SATCON	6	3590	1	1	0
63	13	THALES	5	6300	2	0	1
64	13	THALES	5	5300	2	0	1
65	13	THALES	6	6860	2	0	0
66	13	THALES	6	6760	2	0	0
67	13	THALES	6	7080	2	0	0
68	13	THALES	6	6990	2	0	0
69	13	THALES	6	5800	2	0	0
70	13	THALES	6	7140	2	0	0
71	13	THALES	3	6920	2	0	0
72	13	THALES	3	6470	2	0	0
73	13	THALES	3	7130	2	0	0
74	13	THALES	3	6870	2	0	0
75	13	THALES	3	6850	2	0	0
76	13	THALES	3	7080	2	0	0
77	14	GARMIN	1	7291	0	0	10
78	14	GARMIN	1	7572	0	0	10
79	14	GARMIN	1	7143	0	0	10
80	14	GARMIN	1	7534	0	0	10
81	14	GARMIN	1	8228	0	0	10
82	14	GARMIN	1	7483	0	0	10
83	14	GARMIN	3	7554	0	0	10
84	14	GARMIN	3	7731	0	0	10
85	14	GARMIN	3	7502	0	0	10
86	14	GARMIN	3	7945	0	0	10
87	14	GARMIN	3	7522	0	0	10
88	14	GARMIN	3	7781	0	0	10
89	16	SATCON	5	128230	2	1	0

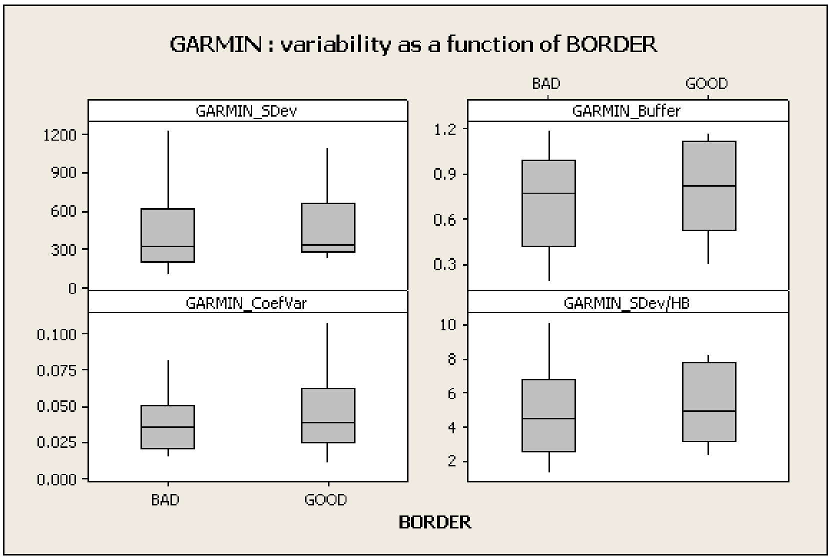
90	16	SATCON	2	34000	1	0	10
91	16	SATCON	2	33750	1	0	10
92	16	SATCON	2	33540	1	0	10
93	16	SATCON	2	34000	1	0	10
94	16	SATCON	2	33120	1	0	10
95	16	SATCON	2	34200	1	0	10
96	16	SATCON	6	33940	1	0	10
97	16	SATCON	6	33080	1	0	10
98	16	SATCON	6	33440	1	0	10
99	16	SATCON	6	33650	1	0	10
100	16	SATCON	6	33590	1	0	10
101	16	SATCON	6	33890	1	0	10
102	16	THALES	1	33350	2	0	0
103	16	THALES	1	32050	2	0	0
104	16	THALES	1	30620	2	0	0
105	16	THALES	1	33930	2	0	0
106	16	THALES	1	33420	2	0	0
107	16	THALES	1	33570	2	0	0
108	17	SATCON	6	22311	2	1	0
109	17	SATCON	3	26660	2	1	0
110	6	GARMIN	2	10696	2	0	0
111	6	GARMIN	2	10137	2	0	0
112	6	GARMIN	2	9724	2	0	0
113	6	GARMIN	2	9427	2	0	0
114	6	GARMIN	2	9742	2	0	0
115	6	GARMIN	2	9725	2	0	0
116	6	THALES	5	9450	2	0	0
117	6	THALES	5	9850	2	0	0
118	6	THALES	5	9490	2	0	0
119	6	THALES	5	9930	2	0	0
120	6	THALES	5	9360	2	0	0
121	6	THALES	5	9430	2	0	0

11.1.2.2 Boxplots of four transformations of the reproducibility as a function of size, shape and border for GARMIN, SATCON, THALES

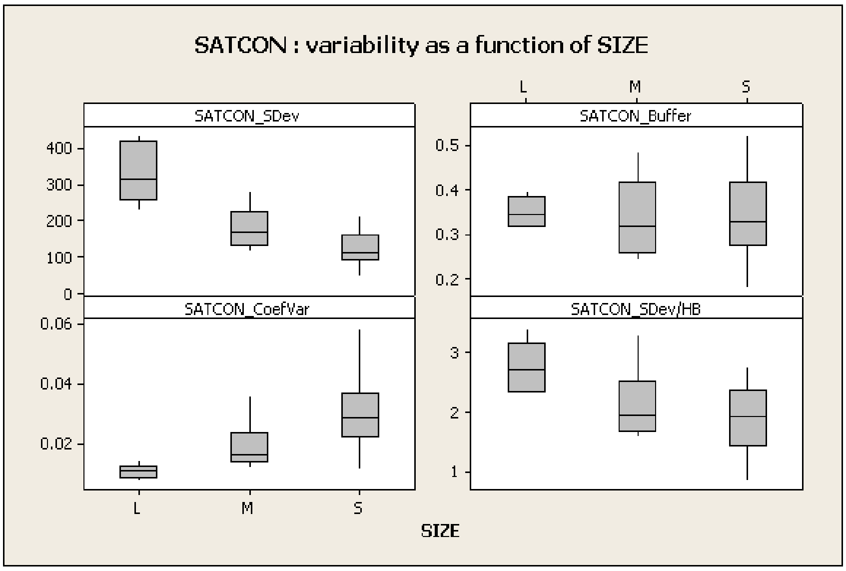
11.1.2.2.1 GARMIN

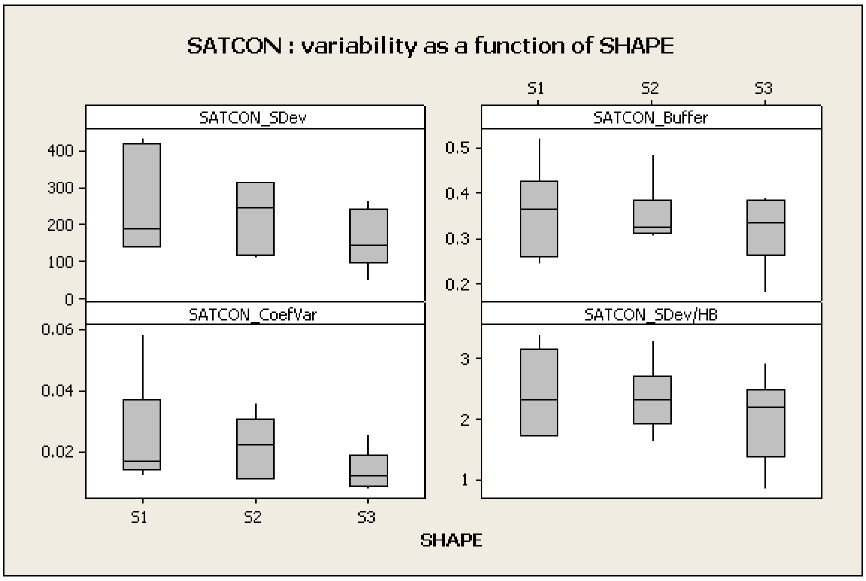


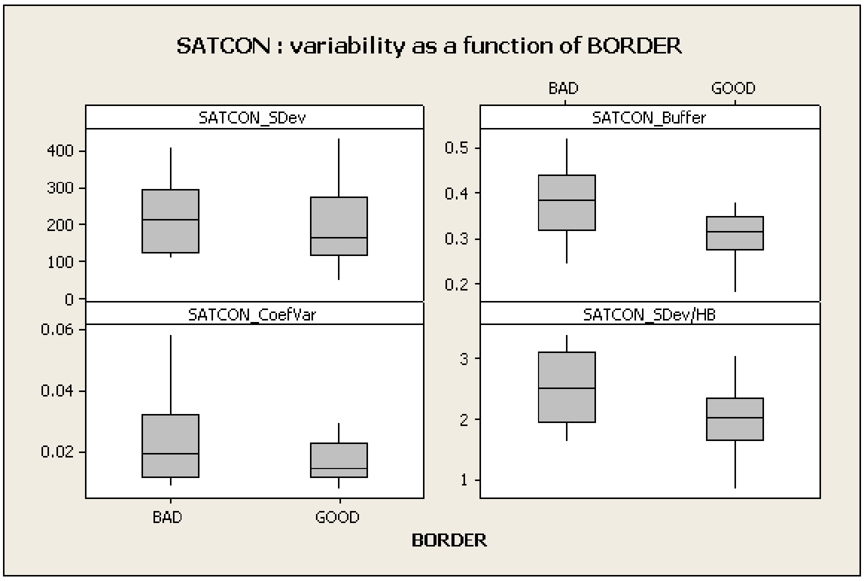




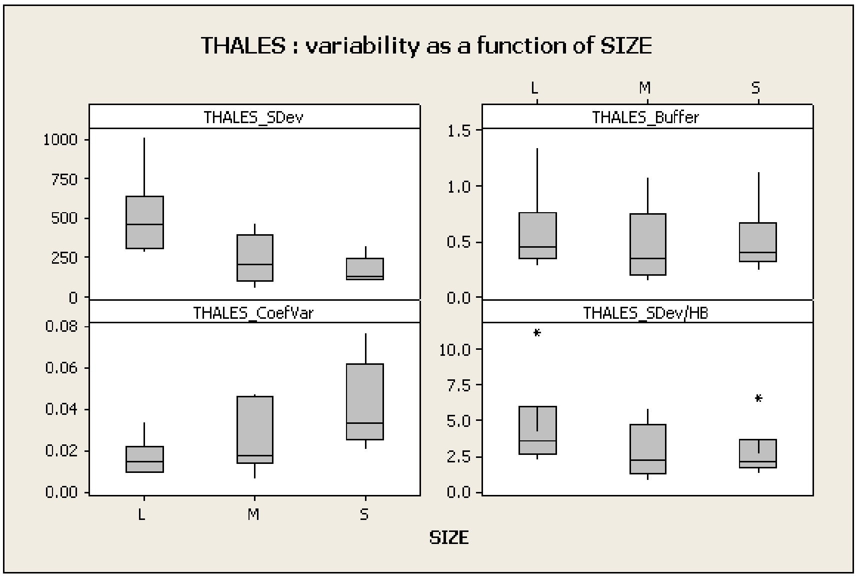
11.1.2.2.2 SATCON

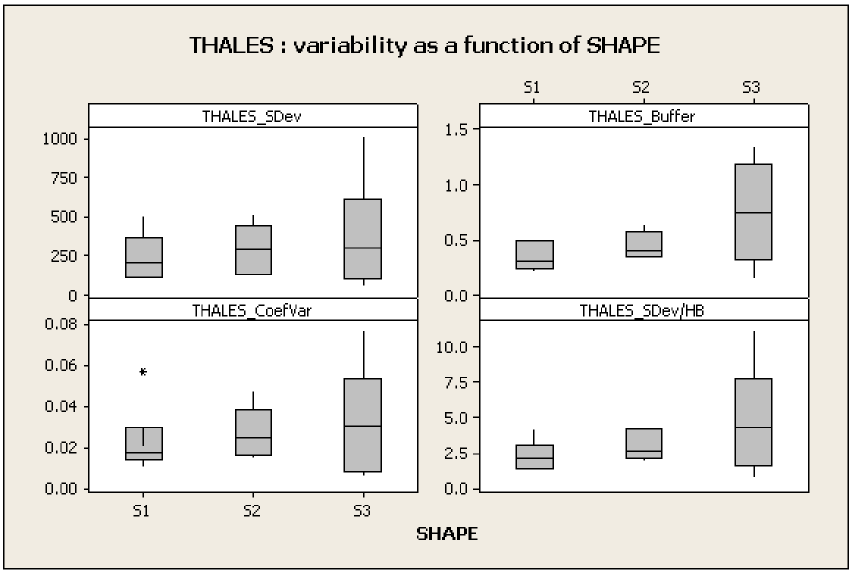


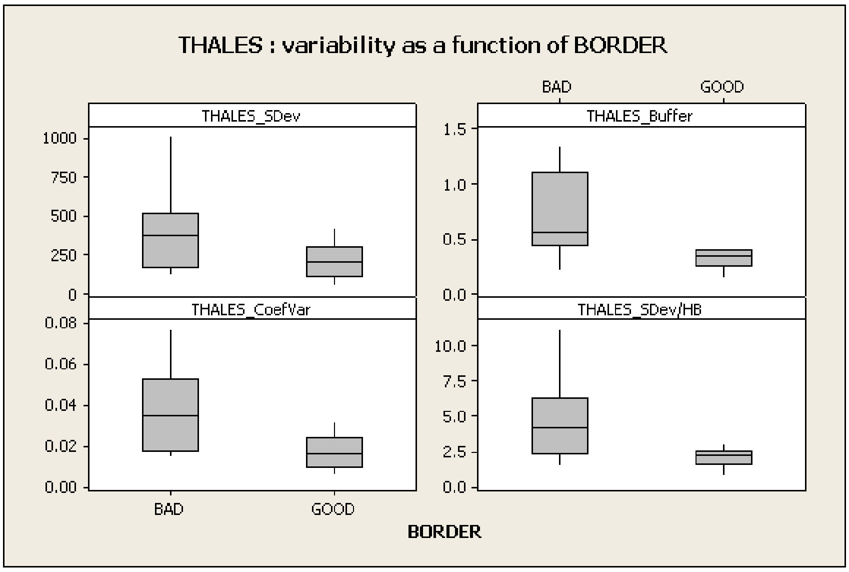

SATCON : variability as a function of SHAPE
SATCON_SDev
SATCON_Buffer
SATCON_CoefVar
SATCON_SDev/HB
S1
S2
S3
SHAPE


SATCON : variability as a function of BORDER
SATCON_SDev
SATCON_Buffer
SATCON_CoefVar
SATCON_SDev/HB
BAD
GOOD
BORDER

11.1.2.2.3 THALES







11.1.3 GPS measurement - experiment B

11.1.3.1 Experiment B – List of discarded observations. Explanation of the codes used in column COCHRAN, GRUBBS/1 and GRUBBS/2 is given in part 3.4.3

Interpretation of outliers.

1) Thales – 29 outliers:

   - 3 errors
   - 26 outliers which can't be noticed in the field
   - no outliers which should be noticed in the field

2) Satcon – 70+1 outliers:

   - 1 error (plus one more which was not found before because the result was swapped with Thales result)
   - 55 outliers which can't be noticed in the field
   - 14 outliers which should be noticed in the field

Row	Parcel	GPS	Day	Data	COCHRAN	GRUBBS/1	GRUBBS/2
1	19	SATCON_3	2	4992	0	0	10
2	19	SATCON_3	2	5029	0	0	10
3	19	SATCON_3	2	4959	0	0	10
4	19	SATCON_3	2	4746	0	0	10
5	19	SATCON_3	5	5043	0	0	10
6	19	SATCON_3	5	5051	0	0	10
7	19	SATCON_3	5	4841	0	0	10
8	19	SATCON_3	5	5275	0	0	10
9	19	THALES_3	6	5230	2	0	0

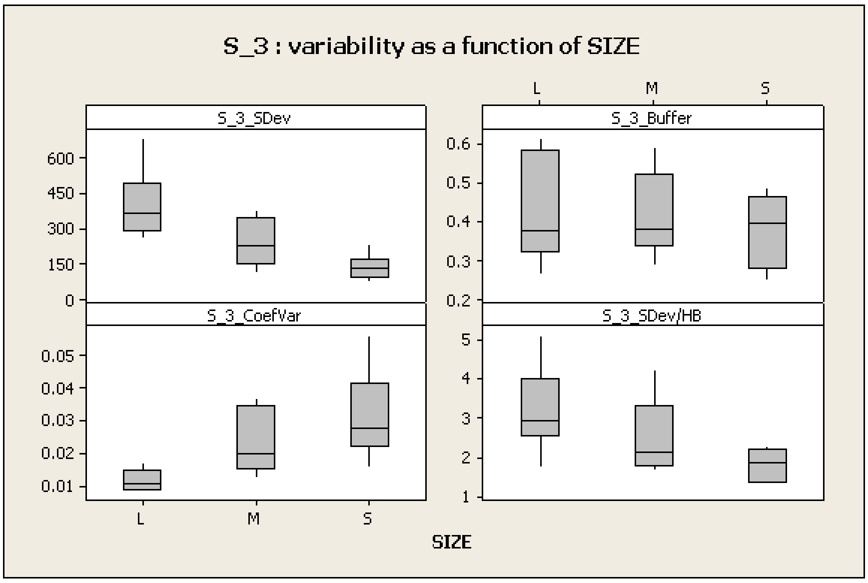
10	19	THALES_3	6	4440	2	0	0
11	19	THALES_3	6	4500	2	0	0
12	19	THALES_3	6	4680	2	0	0
13	21	THALES_3	2	4020	2	0	0
14	21	THALES_3	2	4110	2	0	0
15	21	THALES_3	2	3830	2	0	0
16	21	THALES_3	2	4180	2	0	0
17	23	SATCON_3	6	9848	2	0	0
18	23	SATCON_3	6	9964	2	0	0
19	23	SATCON_3	6	11890	2	0	0
20	23	SATCON_3	6	11561	2	0	0
21	23	SATCON_4	6	13874	2	0	0
22	23	SATCON_4	6	13949	2	0	0
23	23	SATCON_4	6	11545	2	0	0
24	23	SATCON_4	6	10997	2	0	0
25	25	SATCON_4	4	14733	2	1	0
26	25	THALES_3	4	30340	0	10	0
27	25	THALES_3	4	30270	0	10	0
28	25	THALES_3	4	29990	0	10	0
29	25	THALES_3	4	30630	0	10	0
30	26	SATCON_3	6	32908	2	0	0
31	26	SATCON_3	6	32727	2	0	0
32	26	SATCON_3	6	27745	2	0	0
33	26	SATCON_3	6	28968	2	0	0
34	26	SATCON_4	6	23569	2	0	0
35	26	SATCON_4	6	24706	2	0	0
36	26	SATCON_4	6	40164	2	0	0
37	26	SATCON_4	6	41167	2	0	0
38	26	THALES_4	2	30090	2	0	0
39	26	THALES_4	2	30660	2	0	0
40	26	THALES_4	2	29330	2	0	0
41	26	THALES_4	2	30030	2	0	0
42	27	SATCON_3	3	183372	2	1	0
43	28	SATCON_3	5	34824	2	1	0
44	28	SATCON_3	2	8449	1	1	0
45	28	SATCON_3	4	7541	2	1	0
46	28	SATCON_3	3	6686	2	0	0
47	28	SATCON_3	3	4262	2	0	0
48	28	SATCON_3	3	4358	2	0	0
49	28	SATCON_3	3	4085	2	0	0
50	28	SATCON_4	5	9287	2	1	0
51	28	SATCON_4	3	5757	2	0	0

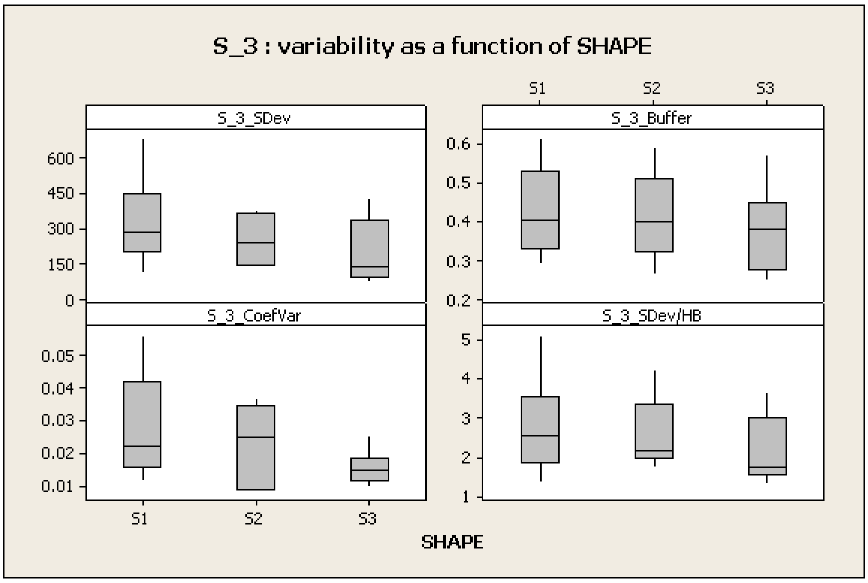
52	28	SATCON_4	3	4029	2	0	0
53	28	SATCON_4	3	4118	2	0	0
54	28	SATCON_4	3	3959	2	0	0
55	28	THALES_4	5	4020	2	0	0
56	28	THALES_4	5	4860	2	0	0
57	28	THALES_4	5	5290	2	0	0
58	28	THALES_4	5	4230	2	0	0
59	29	SATCON_4	6	4701	2	0	0
60	29	SATCON_4	6	4434	2	0	0
61	29	SATCON_4	6	4321	2	0	0
62	29	SATCON_4	6	4033	2	0	0
63	31	SATCON_4	6	9222	2	0	0
64	31	SATCON_4	6	8709	2	0	0
65	31	SATCON_4	6	6056	2	0	0
66	31	SATCON_4	6	9390	2	0	0
67	31	SATCON_4	3	8465	0	10	0
68	31	SATCON_4	3	8545	0	10	0
69	31	SATCON_4	3	9241	0	10	0
70	31	SATCON_4	3	9197	0	10	0
71	32	SATCON_3	4	11608	2	0	0
72	32	SATCON_3	4	11473	2	0	0
73	32	SATCON_3	4	14100	2	0	0
74	32	SATCON_3	4	11284	2	0	0
75	32	SATCON_4	6	12300	2	0	0
76	32	SATCON_4	6	12192	2	0	0
77	32	SATCON_4	6	11306	2	0	0
78	32	SATCON_4	6	11402	2	0	0
79	33	SATCON_3	2	9321	0	10	0
80	33	SATCON_3	2	9290	0	10	0
81	33	SATCON_3	2	9475	0	10	0
82	33	SATCON_3	2	9284	0	10	0
83	33	SATCON_4	3	47443	2	1	0
84	33	SATCON_4	1	8005	2	0	0
85	33	SATCON_4	1	9170	2	0	0
86	33	SATCON_4	1	9096	2	0	0
87	33	SATCON_4	1	8923	2	0	0
88	33	THALES_4	6	8250	2	0	0
89	33	THALES_4	6	8700	2	0	0
90	33	THALES_4	6	8790	2	0	0
91	33	THALES_4	6	8400	2	0	0
92	36	SATCON_3	2	31137	2	0	0
93	36	SATCON_3	2	30850	2	0	0

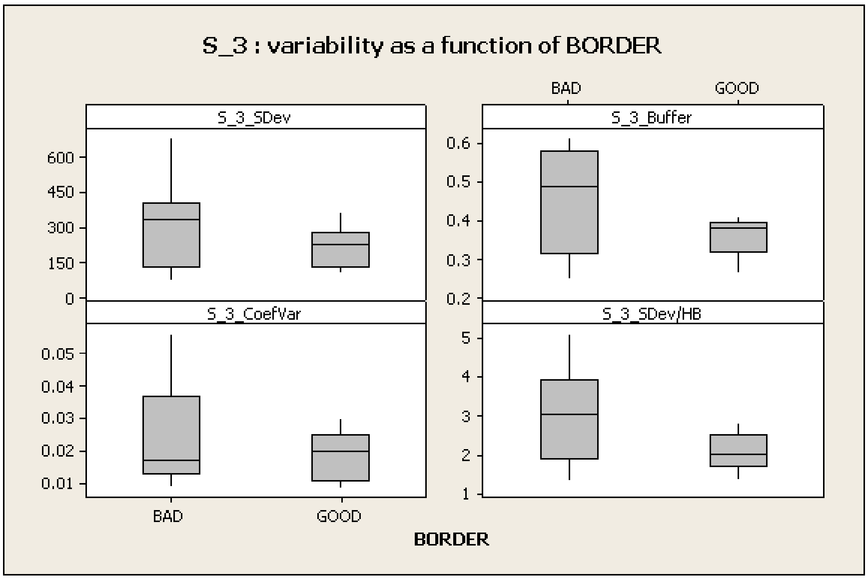
94	36	SATCON_3	2	30566	2	0	0
95	36	SATCON_3	2	31939	2	0	0
96	36	THALES_4	5	30730	2	0	0
97	36	THALES_4	5	31260	2	0	0
98	36	THALES_4	5	30100	2	0	0

11.1.3.2 Boxplots of four transformations of the reproducibility as a function of size, shape and border for SATCON S3, SATCON S4, for THALES T3 and for THALES T4

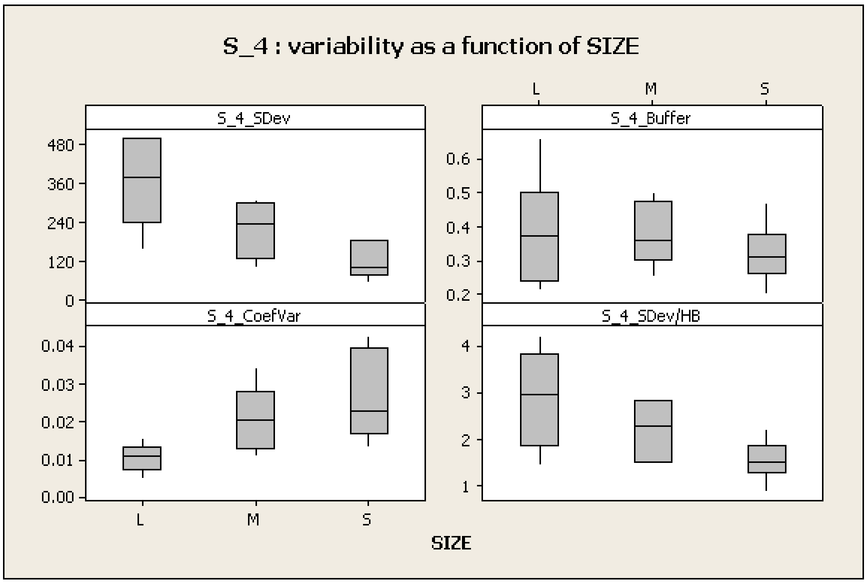
11.1.3.2.1 SATCON S3

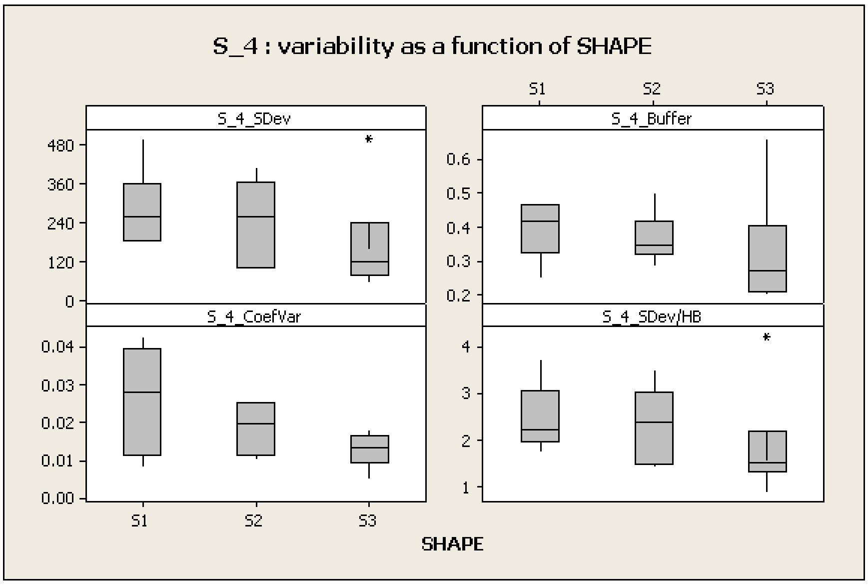


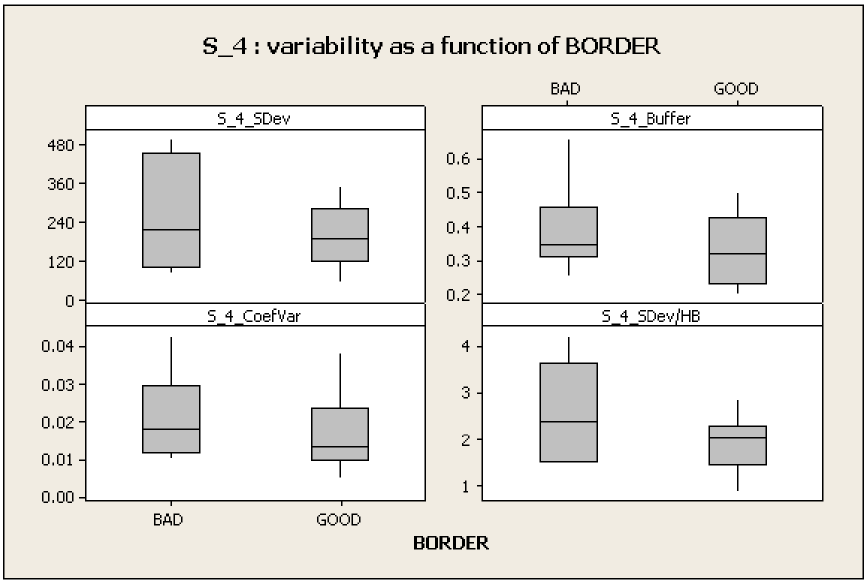

S_3 : variability as a function of SHAPE
S_3_SDev
S_3_Buffer
S_3_CoefVar
S_3_SDev/HB
S1
S2
S3
SHAPE
600
450
300
150
0
0.6
0.5
0.4
0.3
0.2
0.05
0.04
0.03
0.02
0.01
5
4
3
2
1



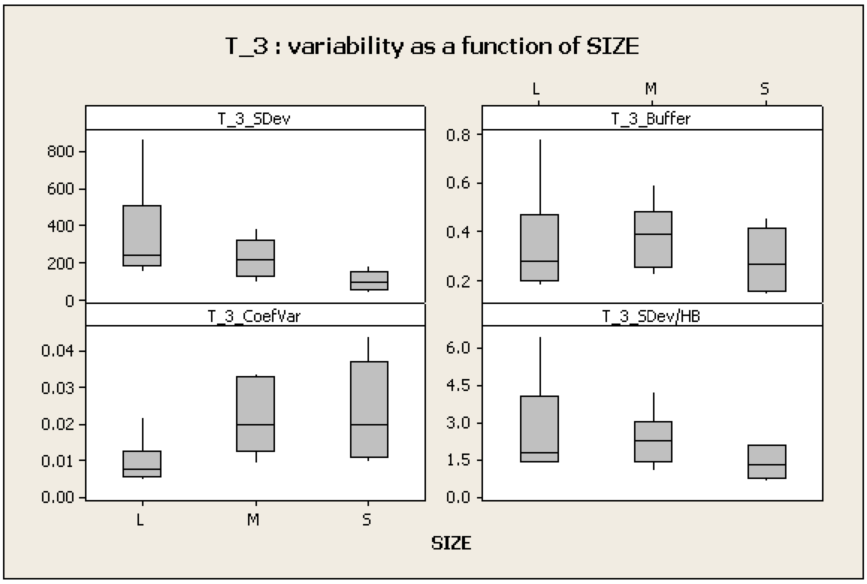
11.1.3.2.2 SATCON S4

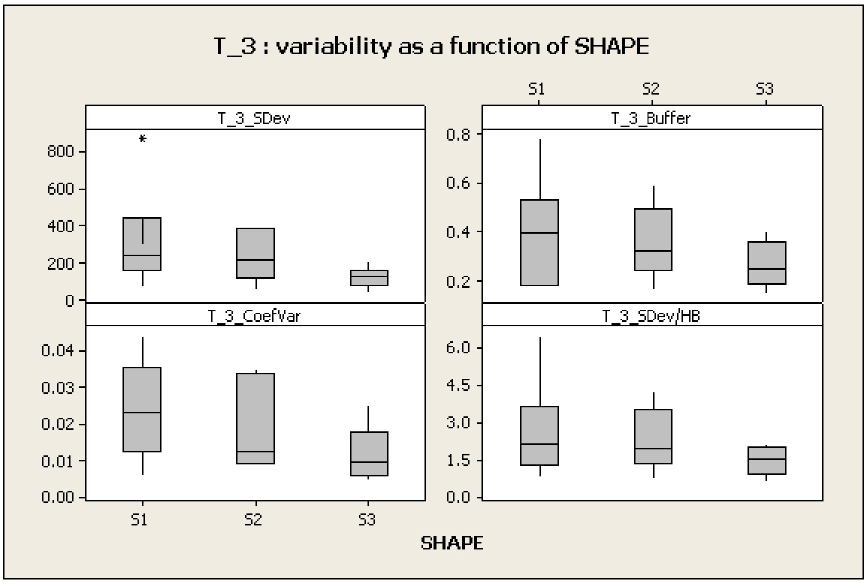


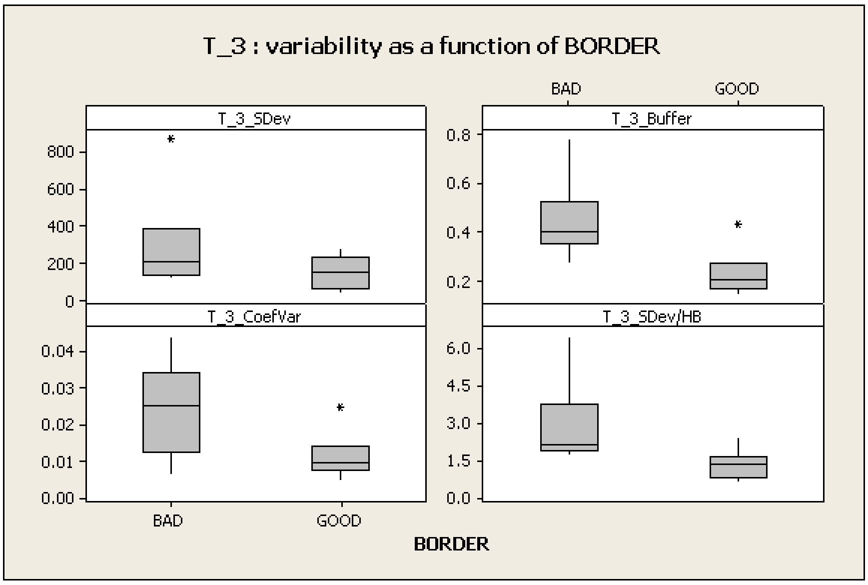




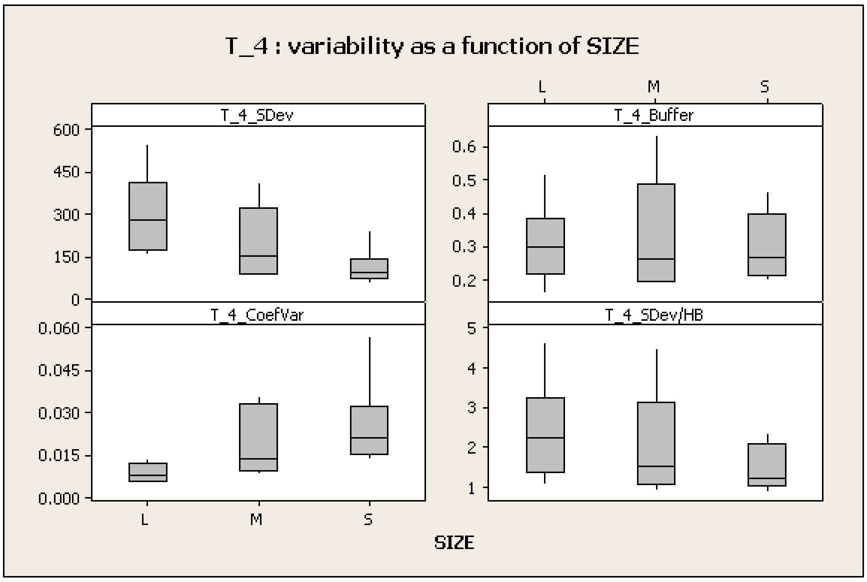
11.1.3.2.3 Thales 3

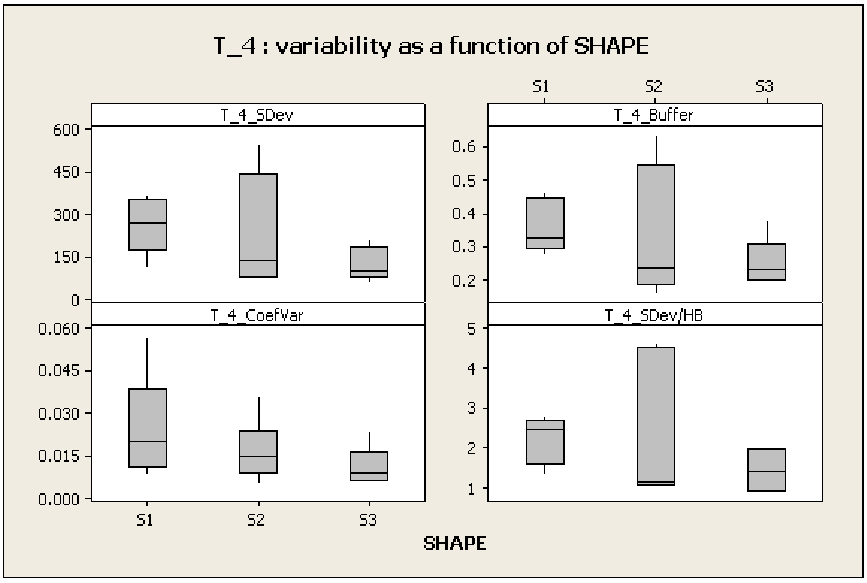

T_3 : variability as a function of SIZE
T_3_SDev
T_3_Buffer
T_3_CoefVar
T_3_SDev/HB
L
M
S
SIZE

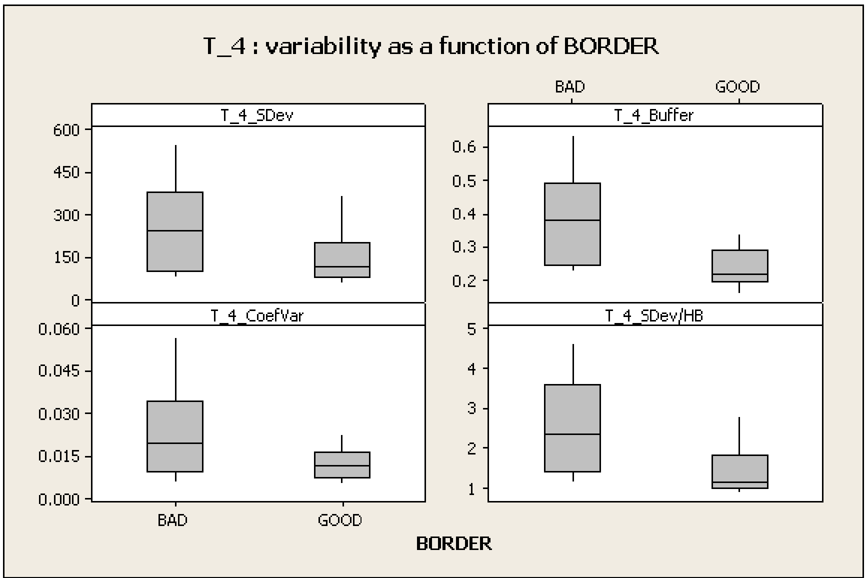

T_3 : variability as a function of SHAPE
T_3_SDev
T_3_Buffer
T_3_CoefVar
T_3_SDev/HB
S1
S2
S3
SHAPE

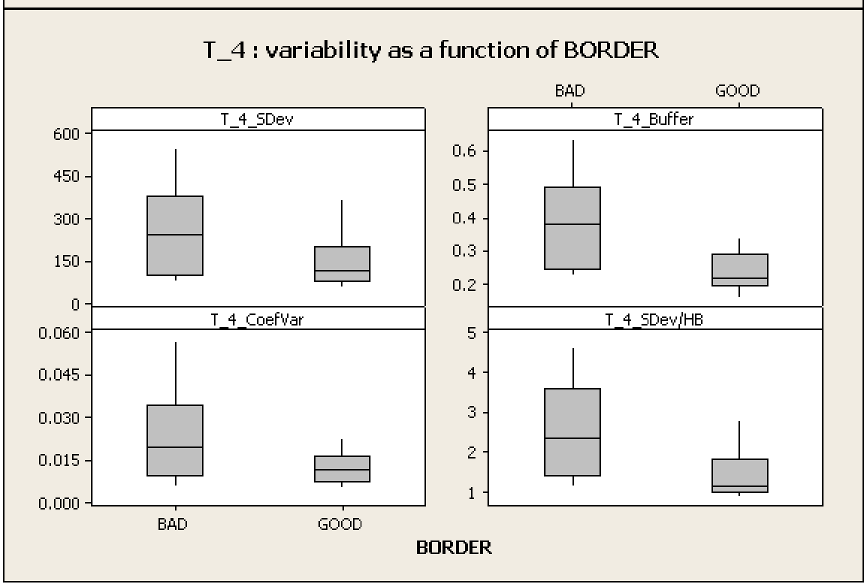


11.1.3.2.4 THALES T4




T_4 : variability as a function of SHAPE
T_4_SDev
T_4_Buffer
T_4_CoefVar
T_4_SDev/HB
S1
S2
S3
SHAPE
0
150
300
450
600
0.2
0.3
0.4
0.5
0.6
0.000
0.015
0.030
0.045
0.060
1
2
3
4
5


T_4 : variability as a function of BORDER
T_4_SDev
T_4_Buffer
T_4_CoefVar
T_4_SDev/HB
BAD
GOOD
BORDER
0
150
300
450
600
0.2
0.3
0.4
0.5
0.6
0.000
0.015
0.030
0.045
0.060
1
2
3
4
5


T_4 : variability as a function of BORDER
T_4_SDev
T_4_Buffer
T_4_CoefVar
T_4_SDev/HB
BAD
GOOD
BORDER
0
150
300
450
600
0.2
0.3
0.4
0.5
0.6
0.000
0.015
0.030
0.045
0.060
1
2
3
4
5