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THE USE OF REFINED AUXILIARY DATA IN STRIP AND BLOCK ADJUSTMENTS

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by

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1. Introduction

Very little use is made of auxiliary data such as APR and statoscope in photogrammetric practice in spite of the fact that their effectiveness in reducing the ground control requirements in height has been established beyond doubt on numerous occasions [1-3,5-12].

Explanations offerred for this limited use include an assumed lack of adequate strip and block adjustment programs which can incorporate auxiliary data; limitations imposed by factors such as the instability of the isobaric surface, the quality of the reflecting surface which affects the reliability of the profile heights, the limited precision, etc.; the additional effort required to ensure that the statoscope is connected to an independent source of static pressure and finally, a possible assumption that auxiliary data is only applicable to small scale mapping projects with insufficient control.

Now, in an attempt to redirect the photogrammetrist's attention to the tremendous potentials of applying statoscope and APR data in strip and block adjustments, a review is given in § 2 of their current applications and limitations. Furthermore, since it is felt that a possible instability of the isobaric surface is the major constraint affecting the reliability of the auxiliary data, an investigation has been conducted to see what improvement can be obtained by means of a post-adjustment in which refined or filtered auxiliary data is used. The experiments and the computational module are outlined in § 3, the results are presented in § 4 and the conclusions are given in § 5.

2. Review of main applications and limitations

Applications

There are two main modes of application of APR and statoscope data to photogrammetric projects, namely:

a) the use of the Airborne Profile Recorder, as an alternative to ground survey methods, to determine height control for mapping purposes.
   Two major, and at the same time successful applications in practice concern the 1/50.000 and 1/100.000 mapping programmes of the Saudi Arabian Aerial Survey Department and the 1/100,000 programme of the Australian Division of National Mapping.

   The Saudi Arabian programmes requires that the Rub al Khali region or Empty Quarter be mapped at a scale of 1/100,000 and the remaining two-thirds of the country at a scale of 1/50,000. Ground control consists of a primary traverse and levelling net, with a spacing of some 200 kms between the loops. Supplementary height control for mapping was provided by a network of APR lines, with a spacing of 50 kms in longitude and 150 kms in latitude.

   Radar APR was used exclusively in the 1/50,000 mapping programmes. This necessitated that an aerial triangulation be performed of the simultaneously acquired strip identification photography in order to improve the relative accuracy of the APR data up to the level of the aerial triangulation itself [12].

In the Rub al Khali area, a laser APR, developed in France by CILAS, is currently being used to establish the required network of APR lines. The use of the laser APR equipment has the advantage over radar that, due to its high relative accuracy, it is no longer necessary to triangulate the strip photography - this photography is now only required for identification purposes and to assist in the adjustment of the APR network to the levelling net by means of a photogrammetric determination of datum differences at all intersections.

In the Australian programme, a laser profiler developed by WREMAPS is used to supply height control for mapping. The pattern of APR lines established depends upon the method to be used in the triangulation and adjustment of the mapping photography.

If the independent model triangulation method is to be used followed by a block adjustment, a grid of APR lines is established as supplementary height control, as in the Saudi Arabian programme. If the slotted template method is to be used to supply plan control, full height control is obtained in each model by a suitable selection of points from the continuous profiles flown along the block edges and in the common lateral overlap of adjacent strips of the mapping photography. This is supplemented with tie profiles flown at regular intervals.

In both cases now, the APR network is adjusted to the levelling net by means of the datum differences determined at the intersections of E-W and N-S profiles and at crossings of the profiles with the level lines [11-13].

b) the use of APR or statoscope data in an aerial triangulation in order to reduce the amount of ground height control required. Although two modes of application of the data in a triangulation are possible, namely either in the instrumental phase or the adjustment phase, the former found very little application in practice, possibly due to the comparatively poor relative accuracy of the auxiliary data which lead to discontinuities and gaps between consecutive models in the instrumental triangulation.

The application to the adjustment phase has, on the other hand, been fairly widespread and a number of experiments have been conducted in Canada, the United Kingdom and the United States in which the effectiveness of statoscope and APR data in reducing the ground control requirements in height was clearly demonstrated [1-6].

With the further development of sophisticated computer programs, such as Stuttgart University's PAT - M 43, which allow the simultaneous adjustment of strips or blocks of independent models onto both ground control and APR or Statoscope data, it was expected that the number of applications in practice would increase.

This has not been the case, however, as is borne out by the following, not all that impressive list of projects where statoscope or APR data have been used in normal production mapping, and in ~~which~~ only one project was adjusted with a sophisticated program.

Canadian Aero Service have used statoscope data in 1/50,000 mapping projects with 50 ft and 25 ft contours in Nigeria and Canada respectively and in a 1/5,000 railway mapping project in Gabon [8].
Terra Surveys have used APR and statoscope in a 1/50,000 mapping project with 50 ft contours in Guyana[10].

Hunting Surveys have used APR in a 1/50,000 reservoir mapping project with 20 ft contours in Nigeria [7] and in a 1/25,000 micro-wave route mapping project with 10m contours in Ghana. Finally, KLM Aerocarto have used APR for mapping mining sites in Saudi Arabia at scales of 1/2500 and 1/5000 with contour intervals of 2, 5, 10 or 20 m, depending on the type of terrain, and statoscope data in a 1/50,000 mapping project with 25m contours in Suriname.

Constraints

What constraints have then limited the application of statoscope and APR data to mapping projects in the past and do these still hold?

With regard to the APR equipment itself, the radar-type equipment certainly has limitations due to its low precision-limiting its usefulness to projects with long bridging distances i.e. mapping at smaller scales with large contour intervals - and its wide beam width - limiting its application to either low flying heights or to the flatter types of terrain with limited vegetation coverage.

These constraints are, however, no longer applicable to the laser-type equipment. Its narrow pencil beam samples such a small area - 50 cm diameter from a flying height of 5000 m - that it has a greater profiling potential, not only in the heavily vegetated areas but also in the more rugged areas, the latter since the reliability of the profile heights is less dependent on slope.

Furthermore, it is also expected that the accuracy improvement that can be achieved with APR - with radar APR only for bridging distances longer than 10 to 15 models - will be reduced to the order of 5 models when laser APR is used, but this does require experimental verification.

As far as the statoscope is concerned, two factors play a role, namely a constraint in the somewhat limited precision of the statoscope equipment - accuracy of statoscope heights of 0.6 m from a flying height of 2000 m [12] - and an inconvenience in the necessity of mounting a separate probe on the aircraft in order to obtain a reliable source of static pressure. The latter remains a necessity, but it is hoped that the recent developments of improved statoscopes, by both KLM Aerocarto and Zeiss Oberkochen, will prove in practice to have reduced the former constraint- a not over optimistic hope since KLM Aerocarto reports obtaining an accuracy of 30 cm with their statoscope.

A final constraint remains the fact that the reliability of both statoscope and even laser APR data is unfavourably influenced by, on the one hand, local irregularities - the "ripple effect" - which seem to occur in the data and, on the other hand, by the uncertainties in the isobaric surface.

If statoscope and laser APR data are to find a wider application in practice, particularly to larger mapping scales with smaller contour intervals, it is imperative that the reliability of the reference plane for the data, the isobaric surface, be improved.

The aim of this investigation is to determine whether an improvement can be obtained by using filtered data in a post-adjustment.

3. Outline of the computational modules and the experiments

The computational modules

The computational module is based on the PAT-M 43 program, developed at Stuttgart University, which permits the simultaneous adjustment of independent models and statoscope or APR data. The program is well documented in [16] and the advantages of a combined adjustment have been proven in [3], so that no further elaboration is needed here.

A problem, however, is that it is impossible to predict in advance whether linear of higher order correction terms should be used in the program to describe the isobaric surface. An interesting alternative is therefore to base the correction procedure for the statoscope or APR readings on a post-analysis of their residuals after an initial adjustment, the aim being to obtain a set of auxiliary data, corrected for local irregularities in the isobaric surface, which can then be used in a final combined adjustment.

It was furthermore decided to use the method of least squares interpolation in the post-analysis, this in view of its successful application to similar photogrammetric problems, (such as the correction of irregular film deformation from reseau measurements, the post-adjustment of aerial triangulations from the relative discrepancies, etc.) in which a separation has to be enforced between the truly random or noise component of residuals and their systematic or signal component.

The potentials of the method were initially investigated in [15]. As can be inferred from fig. 1, the large number of computational steps proved to be rather inefficient, both in terms of storage requirements and in computational time. A more serious problem, however, was the fact that the Gaussian correlation function used in the study proved to be somewhat inadequate in describing the systematic undulations present in the data.

The problem of reducing the computational effort was solved by modifying the PAT-M program such that the whole process of analyzing the residuals and determining the corrections to the statoscope readings is incorporated into the adjustment algorithm, as is shown in fig. 2. An additional saving is achieved in the covariance computation by assuming the projection centres to be equal distances apart and by using a limited number of reference points in interpolating the signal component at any point. These simplifications do not affect the accuracy of the results.

With regard to the determination of the covariance function, the problem is simplified in this particular application by the fact that no interpolation is needed between the reference points and therefore it is only necessary to determine the signal (correlated) component of the residuals at the perspective centres.

This direct use of the estimated correlation between the residuals considerably reduces the computational effort and moreover, avoids the risk of choosing an improper covariance function. A problem is, however, that an estimate is needed of the signal to noise ratio.

Combined adjustment with PAT-M

↓

Program 1: computes successively the residuals the trend correction and the variances and covariances

↓

Program 2: computes the covariance function and the signal component

↓

Program 3: computes the corrected statoscope data

↓

Repeat PAT-M adjustment with corrected statoscope data

Fig. 1: Initial procedure

Modified PAT-M program

- iterative plan-height solution
- compute residuals between adjusted perspective centres and stat. data
- compute the variance and covariances between residuals; compute the signal component and substitute this for the statoscope readings
- repeat iterative plan-height solution

Fig. 2: Modified procedure

This estimate is obtained empirically, as is shown in the following computational steps:

- compute the variance of the residuals V and the correlation between the reference points.

- assume an initial value for the variance of the signal component V_s e.g. $V_s = 0.1\ V$

- compute an apriori estimate of the variance of the random component V_r from $V_r = V - V_s$

- compute the signal and random components at individual reference points i from

  $$s_i = \underline{C}_i^T \ G \ \underline{1}$$

  $$r_i = l_i - s_i$$

  where $\underline{1}$ is the vector of residuals and the elements of vector C represent the correlation between point i and the reference points. Its ith element is V_s. Compute the variance of the random components V_r'.

- compare Vr and Vr'. If they differ by more than a threshold value, repeat the above two steps with a new value for V_s e.g. $V_s' = V_s + 0.1\ V$.

A safety factor is incorporated in this empirical determination which interrupts the least squares interpolation should the noise dominate the signal or the signal the noise i.e. should the successive steps end with a value for V_s which is either less than or greater than a certain percentage of V.

Aims of experiments

As mentioned above, the main aim of the experiment is to see what additional improvement is possible if strip and block adjustments are performed using refined instead of original APR and statoscope data. A secondary objective is, given refined data, what configurations of ground and auxiliary control in strip and block adjustments satisfy various mapping requirements. Finally, since the same material was used as in [3, 5 & 6], it was also considered useful to investigate some of the anomalies found in the results, such as the deterioration in accuracy when statoscope data was introduced.

Data

Data from the well-known South-West Ontario APR test block was used for the experiments. Fig. 1 shows the location of the 5 strips, of length approx. 240 kms, each flown with simultaneous radar APR from a flying height of 5250 m giving a photo scale of 1/32,000 and the 10 radar APR cross profiles flown from an altitude of 2000 m. Some 440 height control points, evenly distributed throughout the block, are available for control and checking purposes.

Pre-experiments

In order to limit the total number of experiments to be performed, it was decided to examine the effect of some of the influencing factors by means of preliminary investigations. The various pre-experiments conducted and their aims are listed below:

(i) Since the various experiments are to be compared according to the residual errors at check points, the results should not be unfavourably influenced by gross errors in the ground heights. To check this and to obtain an indication of the measuring accuracy, the block was adjusted on all control points.

(ii) theoretical investigations [14], have shown that assumptions regarding the weight ratio between the auxiliary data, the photogrammetric observations and the ground control can unfavourably influence both the relative and absolute accuracy of the triangulation. These weight ratios were therefore varied with particular control configurations in order to obtain an optimum to be used in all other experiments.

(iii) in the practical adjustments of strips using APR data it was found necessary to allocate a higher weight to the end APR points, in order to obtain a better connection of strips both to sea level and to overlapping strips along the same line 12 . Different weight ratios were therefore examined in order to derive conclusions for the other experiments.

(iv) previous investigations with a strip, [15], revealed slight differences in the results depending upon the method used to obtain the refined data, this then to be used in a post-adjustment. Experiments were therefore conducted in which not only the effect of varying the weight ratio of the auxiliary data compared to the photogrammetric measurements was examined in a least squares filtering, but also the effect of applying a preliminary trend correction before going to the phase of least squares filtering.

Main experiments

In this investigation, it was felt justified to confine the filtering experiments to statoscope data, since:

- to the authors' opinion, statoscope has a greater potential in practice. The equipment costs are low, it does not require an operator in the aircraft and virtually no additional effort is required in the preparation and measuring phases of the triangulation.
- it was expected that the statoscope data of the S.W. Ontario block would be more precise than the APR data - in view of their independance of the terrain and vegetation coverage and the fact that no observational errors are involved - and therefore that they would have a greater effect in filtering i.e. give a better determination of irregularities in the isobaric surface.

Using the traditional bands of height control, the main experiments were designed to take the following four parameters into account:

- the block configuration (single strip or block)
- the type of auxiliary data (none, APR, statoscope, filtered statoscope)
- the bridging distance between the bands of control
- the effect of APR cross profiles.

Additional experiments

Finally, in order to investigate the effect of different configurations of ground and auxiliary control, the above main experiments were partially repeated using three other ground control configurations, namely:

- a limited number of control, 12 points, randomly distributed throughout the block
- full control along the perimeter of the block
- full control in the outer strips of the block.

4. Results

Pre-experiments

The results of the pre-experiments were as follows:

- in the adjustment using all control points, gross errors of up to 8 m were found in six points, which were subsequently not used as check points. The block itself was found to be extremely homogeneous, the standard deviations of the residuals at model and control points being respectively 0.33 mm (0.06 ‰ H) and 0.40 m (0.08 ‰ H).

- although slight variations in the weight ratios between the ground control, the photogrammetric observations and the auxiliary data, the latter having different weights for data in the first and last three models of each strip and in the strip centres, did not significantly affect the residuals at the check points, the following weights gave the most homogeneous results in terms of residuals in the four sets of observations and were used in all experiments: ground control (2); model points (1); end APR or statoscope (0.8) and central APR or statoscope (0.6).

- in the least squares filtering experiments, the best results were obtained when the block or strip was first adjusted onto the relevant ground control using an extremely low weight for the statoscope, namely 0.01. Thereafter, little difference was found whether a preliminary polynomial correction was applied before the least squares filtering or not, which confirmed the findings in [15], namely that the isobaric surface was extremely stable in South West Ontario test block. Increasing the number of sections used in the preliminary trend correction also had little effect. The results presented refer to experiments in which a preliminary trend correction was applied using a single section, before proceeding to the least squares filtering.

Main and additional experiments

Although the results of the block adjustments performed without auxiliary data and with APR were homogeneous as far as the residuals at check points in individual strips are concerned, a striking contradiction was found between the results in the upper and lower halves of the block in the adjustments using statoscope data, this to the extent that the residuals do not belong to the same population. Furthermore, these contradictions remained in the adjustments using filtered statoscope data, as can be seen in the following table:

Block half \ Bands of control	2	3	5	9	
strips 1 - 3	3.63 m	2.53 m	2.08 m	1.57 m	original statoscope
strips 4 - 5	9.96 m	7.75 m	6.00 m	3.14 m	
strips 1 - 3	3.46 m	2.23 m	1.83 m	1.39 m	filtered statoscope
strips 4 - 5	6.43 m	4.35 m	3.08 m	1.45 m	

In order to find an explanation for these anomalies, reference height correction curves were derived for each individual strip from the block adjustment results using all ground control points and these were compared with the correction curves derived from the statoscope data. Now, whilst the two sets of curves had similar patterns in strips 1 - 3, this was not at all the case in strips 4 - 5, and therefore it was concluded that there is something wrong with the statoscope data of these last two strips.

Further investigations were not possible since the original data was not at our disposal. However, considering the above results and the fact that in the investigations of Allam et al [5], with the same data, the accuracy also deteriorated when statoscope data was used, it was felt justified to only use the first three strips in the statoscope investigations. Hence, in order to be consistent, the results presented of other block adjustment experiments refer to check point discrepancies in the first three strips, even though the whole block was included in the adjustment.

The results of the block and strip adjustments using bands of height control are summarized in tables 1 and 2, whilst table 3 contains the results of the experiments conducted with other configurations of ground control.

The code to the various types of adjustment is as follows:

V = vertical control without auxiliary data
A = vertical control with simultaneous APR
C = vertical control with cross APR
AC = vertical control with simultaneous and cross APR
S = vertical control with statoscope
SF = vertical control with filtered statoscope.

The tabulated results are also illustrated graphically in figures 2 to 4.

5. Conclusions

The following conclusions can be drawn from the results of the various experiments performed:

1. Fig. 2, showing the results of adjustments carried out without auxiliary data, with APR and with statoscope for different bridging distances, confirms the findings of other investigations regarding the tremendous improvement in accuracy obtainable with statoscope and APR data, for bridging distances exceeding 10 models.

2. With regard to the principal experiments, performed to see what additional improvement can be obtained with filtered statoscope data, the following observations can be made from the results shown in fig. 3:

   - the improvement with filtered statoscope data is greater in strips (30% - 40%) than in blocks (10%). This is partially to be expected since the same tendency is seen when normal statoscope data is introduced in an aerial triangulation adjustment. A surprising result is, however, the fact that the strip adjustment is just as accurate, or, in the case of the longest bridging distance, is even more accurate than the block adjustment with filtered data. A possible explanation could be the fact that the systematic irregularities which are removed in the filtering process are not similar in adjacent strips and hence the deterioration when the block is formed.

   - the improvement holds for the shortest bridging distance used of 9 models and could possibly even apply to shorter bridging distances.

   In assessing the numerical values of the results, it should be borne in mind that the extent to which filtered statoscope data gives an additional improvement and the limiting bridging distance from which this improvement becomes effective is dependent on the precision of the statoscope readings and whether there are any irregularities in the isobaric surface.

   That the improvement was only slight in this investigation is largely due to the regularity of the South West Ontario data, the least squares filtering only revealing slight systematic errors. The data itself was extremely reliable, the standard deviation of the random statoscope errors being 0.5 m.

3. The results, given in table 3, of the additional experiments conducted with other configurations of ground control, permit the following conclusions to be drawn:

   - experiments 30-37 show that, provided statoscope or simultaneous APR data is used, it is perfectly feasible to adjust a block onto only a limited number of randomly distributed control points. The disadvantage that omega is not properly controlled is readily overcome by the inclusion of additional APR cross strips (see further 5.4).

- the results of experiments 30-48 performed either with full perimeter control or with the outer strips controlled were in so far inconclusive in that, whilst the results improved with a better control of omega through the use of APR cross strips (see also 5.4), the inclusion of simultaneous APR in general only made matters worse. A contributing factor could, however, be the limited block width of only 5 strips, two of which were fully controlled.

4. As is to be expected, the effect of using additional APR cross strips in order to control omega depends on the extent to which this has already been controlled, either through ground control or by means of APR cross strips. A summary of the results follows below, some of which have been illustrated graphically in fig. 4:

- in the experiments without simultaneous APR, the greatest improvement was obtained in the experiments with only two bands of control. The addition of a single APR cross strip lead to an improvement of 13% and adding a further two to an additional improvement of 14% (see experiments 1, 2 & 3). The improvement with full perimeter control is less spectacular: adding one cross strip gives an improvement of 6%, a further two an additional improvement of 11% and a further seven 21%. (see experiments 38 to 41). A comparable total improvement of 35% is also obtained with the addition of seven APR cross strips to an adjustment with full control in the outer strips and 3 APR cross strips (experiments 45 & 46).

- in the adjustments with simultaneous APR, the greatest improvement was again obtained when only two bands of control were used. Hence, adding one APR cross strip reduced the accuracy by as much as 33%. Adding a further two cross strips, however, only gave an additional reduction of 3% (see experiments 4-6). If three bands of control are used, adding 2 APR cross strips only gives an improvement of 6% (experiments 10 & 11).

An initially spectacular improvement is also obtained with the addition of APR cross strips to adjustments on a limited number of randomly distributed control points. Adding two cross strips gives an improvement of 24%; adding a third an additional reduction of 13%; a further two only 3 % and a further five only 2% (experiments 31-35).

If full perimeter control is used with simultaneous APR and a single APR cross profile in the centre of the block, an addition of two cross strips gives an improvement of 11% and a further seven an additional reduction of 16% (see experiments 42-44). A comparable result is also obtained in the adjustment with full control in the outer strips and three APR cross strips. Adding a further seven cross strips gives a reduction of 11% (experiments 47 & 48).

6. The final conclusions to be drawn concern the configurations of ground and auxiliary control in strip and block adjustments that satisfy various mapping requirements. In this discussion, the ground control configurations will be restricted to the two most interesting in practice, namely bands of control and a limited number of randomly distributed points. Furthermore,

it is assumed that the instrument to be used for contouring has a C-factor of 1500 and that the specifications require 90% of the heights to be accurate to within one half of the contour interval.

The requirements for the plotting of 20 m contours are readily satisfied by all of the experiments using auxiliary data i.e. with bridging distances in excess of 240 kms.

The requirements for the plotting of 10 m contours are satisfied by the following configurations of ground and auxiliary control in block adjustments:

- with simultaneous APR, bridging distance 210 kms between bands
- with statoscope, bridging distance of 150 kms between bands
- with filtered statoscope, bridging distance of 180 kms between bands
- with simultaneous APR and omega control through APR cross strips at 120 km intervals, briding distance in excess of 240 kms between bands
- with simultaneous APR and limited random control, APR cross strips at 240 km intervals.

In strip adjustments with statoscope data, bands of control would be required at 80 km intervals. This bridging distance could be increased to over 240 kms if the statoscope data were to be filtered.

The requirements for the plotting of 5 m contours from this 1/32,000 scale photography can only be satisfied if a more precise instrument is used for contouring, namely one with a C-factor of 1800. Configurations which now satisfy the requirements are blocks with simultaneous APR data or filtered statoscope data, both with bands of control at 30 km intervals.

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Expt. no.	Adj. type	Ground control bands	Ground control kms.bridged	Add omega control bands	Add omega control kms.bridged	no. check points	σ (m) model	σ (m) control	σ (m) check	σ (m) APR/STAT.
1	V	2	240	–	–	239	0.29	0.39	10.57	–
2	C			1	120		0.30	0.39	9.21	0.46
3	C			3	60		0.30	0.39	7.73	0.66
4	A			–	–		0.31	0.39	3.15	0.90
5	AC			1	120		0.32	0.38	2.11	0.90
6	AC			3	60		0.32	0.38	2.03	0.90
7	S			–	–		0.31	0.37	3.63	0.46
8	SF			–	–		0.30	0.36	3.46	0.48
9	V	3	120	–	–	232	0.29	0.58	9.62	–
10	A			–	–		0.32	0.40	1.88	0.90
11	AC			2	60		0.32	0.40	1.76	0.90
12	S			–	–		0.32	0.51	2.53	0.49
13	SF			–	–		0.30	0.34	2.23	0.50
14	V	5	60	–	–	213	0.30	0.49	2.96	–
15	A			–	–		0.33	0.39	1.65	0.93
16	S			–	–		0.35	0.66	2.08	0.50
17	SF			–	–		0.31	0.33	1.83	0.50
18	V	9	30	–	–	181	0.30	0.42	1.56	–
19	A			–	–		0.33	0.37	1.36	0.93
20	S			–	–		0.36	0.58	1.57	0.53
21	SF			–	–		0.32	0.29	1.39	0.51

Table 1: Block adjustments with bands of control

22	S	2	240	–	–	70	0.30	0.30	4.35	0.40
23	SF			–	–		0.29	0.34	2.56	0.35
24	S	3	120	–	–	68	0.30	0.41	3.40	0.42
25	SF			–	–		0.29	0.33	2.20	0.39
26	S	5	60	–	–	64	0.31	0.51	2.62	0.42
27	SF			–	–		0.30	0.31	1.99	0.38
28	S	9	30	–	–	55	0.31	0.51	1.66	0.43
29	SF			–	–		0.30	0.26	1.14	0.42

Table 2: Strip adjustments with bands of control

30	V	Random (12 points)		–	–	256	0.29	0.33	11.38	–
31	A			–	–		0.31	0.32	3.72	0.90
32	AC			2	240		0.31	0.37	2.82	0.90
33	AC			3	120		0.31	0.30	2.33	0.91
34	AC			5	60		0.31	0.34	2.23	0.90
35	AC			10	15 to 60		0.32	0.32	2.16	0.89
36	S			–	–		0.30	0.34	3.71	0.50
37	SF			–	–		0.29	0.20	4.35	0.59
38	V	Full perimeter control		–	–	197	0.31	0.26	2.06	–
39	C			1	120		0.32	0.28	1.94	0.39
40	C			3	60		0.31	0.26	1.72	0.65
41	C			10	15 to 60		0.32	0.25	1.27	0.75
42	AC			1	120		0.33	0.27	2.10	0.88
43	AC			3	60		0.33	0.28	1.86	0.88
14	AC			10	15 to 60		0.34	0.28	1.54	0.87
45	C	Full control in outer strips		3	120	217	0.31	0.23	2.02	0.65
46	C			10	15 to 60		0.32	0.24	1.31	0.75
47	AC			3	120		0.33	0.25	1.75	0.86
48	AC			10	15 to 60		0.33	0.25	1.55	0.86

Table 3: Block adjustments with other control configurations.

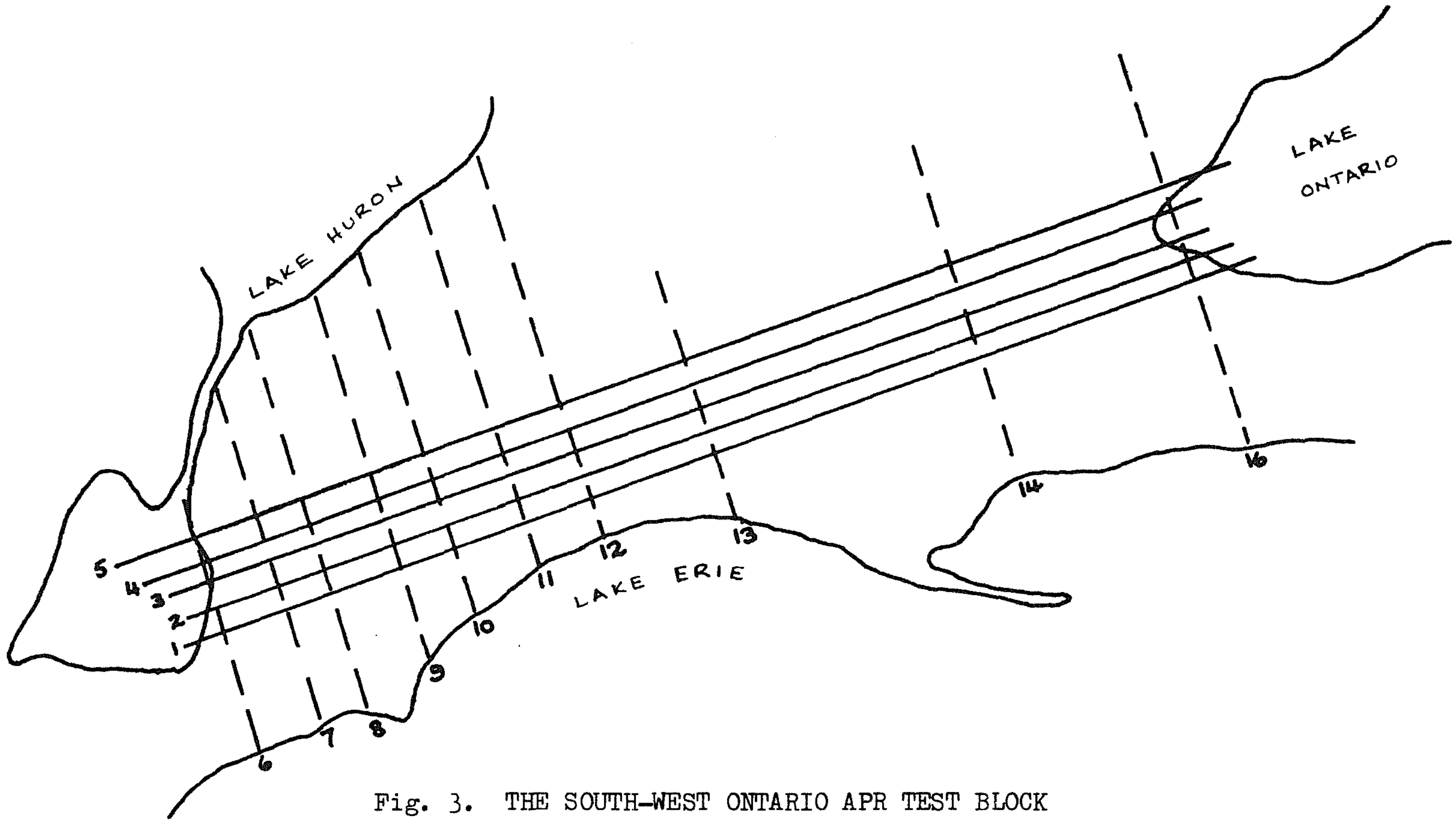

Fig. 3. THE SOUTH-WEST ONTARIO APR TEST BLOCK

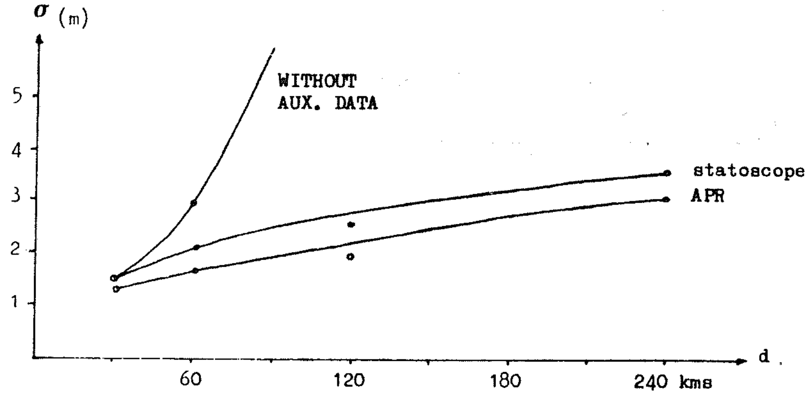

Fig. 4. Effect of using auxiliary data

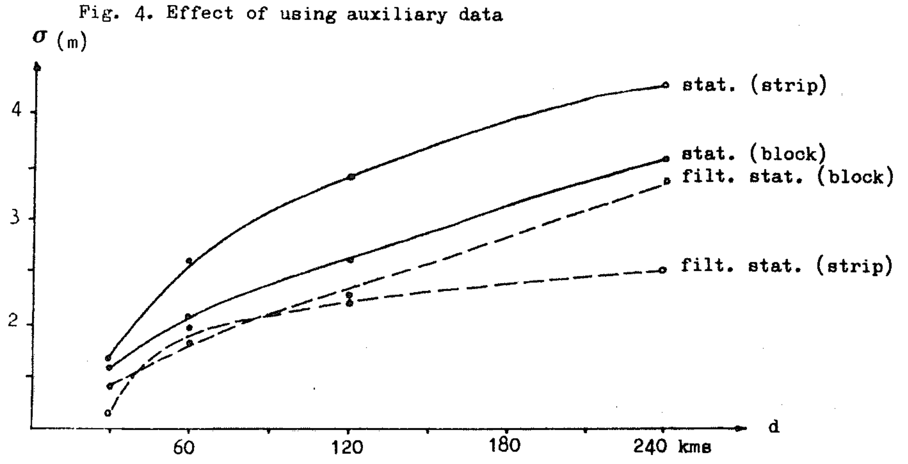

Fig. 5. Effect of using filtered statoscope data

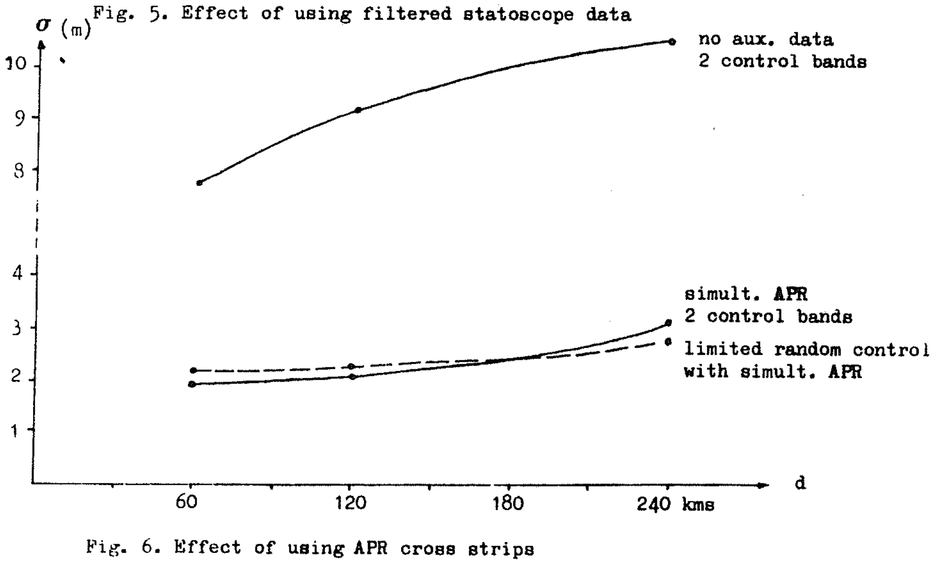

Fig. 6. Effect of using APR cross strips