PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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United Kingdom Doppler campaigns: field operations and instrumentation

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Following an agreement between the Ordnance Survey and the University of Nottingham to cooperate in the field of satellite Doppler techniques, two observational campaigns were carried out in the United Kingdom.

The first campaign, which was held in 1976, aimed at obtaining the geocentric Doppler coordinates of 13 stations forming part of the primary triangulation network of Great Britain. These were supplemented in 1978 by observations carried out by Decca Survey Ltd on seven additional stations which, together with the other 13 stations, covered the area of the whole network.

The second major observational campaign was conducted in June 1978 and involved nine primary triangulation stations along the Edinburgh–Malvern–Dover precise traverse. These observations were carried out in order to test the accuracies that can be achieved by the 'short arc' technique.

Details are given of the organization of the field observations, the equipment used and the logistics, concentrating on the precautions taken to avoid or minimize the effects of instrument malfunction and operator errors.

1. Introduction

The first series of geodetic satellite Doppler observations made in the United Kingdom was carried out by the Doppler Sections of the 512 Specialist Team of Royal Engineers. This was followed by an investigation conducted into the absolute and relative accuracies that could be achieved in terrestrial positioning by Doppler methods (Ashkenazi & Richards 1976). This investigation comprised two campaigns carried out jointly by the University of Nottingham and the Ordnance Survey of Great Britain and with the assistance of Decca Survey Ltd. Additional equipment was also obtained from the University of Oxford, the Directorate of Overseas Surveys and the Science Research Council's Appleton Laboratory.

The first campaign, carried out in 1976, aimed at establishing the translation parameters between the origin of the system of geocentric Cartesian Doppler coordinates and the centre of the OSGB reference ellipsoid. It was also expected that the campaign would lead to an assessment of the consistency of Doppler-derived coordinates and would provide evidence of any systematic errors in the terrestrial network.

The second campaign, carried out in 1978, was designed to study the accuracy of relative positioning based on satellite techniques. This was to be achieved by comparing the results of Doppler observations, processed by using an 'orbit relaxation' program coupled with simultaneous translocation observations, with the known coordinates of a precise terrestrial traverse.

This paper describes the fieldwork during the first (§2) and the second (§3) campaigns, concentrating especially on the logistic and instrumental problems, and on the precautions that were taken before and during the field observations.

2. 1976 campaign: fieldwork

For this campaign it was decided to observe at 13 ground stations, all of which were pillars either belonging to or connected (by measurements of a primary standard) to the Scientific Triangulation Network of the Ordnance Survey of Great Britain (OSGB). The stations were sited in clusters of two or three points, separated from one another by 30–60 km, covering five regions of the United Kingdom. This was decided upon because of the assumption that any maladjustment or systematic model errors would be small for short lines. Close agreement in the computed values of the translation parameters (from the satellite datum to the OSGB datum) *within* the clusters would therefore indicate good Doppler results, whereas similarity *between* the clusters would correspond to a good terrestrial network.

At a later date, seven additional stations were observed in the western part of the United Kingdom, an area which had not been fully covered by the original series of observations. The equipment used for the original observations was a single Canadian Marconi CMA 722B receiver, powered by a 1.25 kW Honda generator which, in turn, could be operated with either petrol or propane gas. The use of a generator combined with the need for hourly meteorological data and frequent paper tape changes necessitated continuous manning of each station. This was achieved by using three surveyors working on an 8 h shift system. Each station was occupied for between 4 and 5 days, leading to a total duration of 3 months for the whole campaign.

The results obtained from the campaign indicated a significant difference between the translation parameters obtained by using the broadcast ephemeris, on the one hand, and those calculated with the precise ephemeris, on the other (Ashkenazi *et al.* 1977*a*; Ashkenazi & Sykes, 1978). It thus became apparent that the straightforward application of translation parameters, to convert satellite derived geocentric coordinates into a national or other local reference system, could lead to confusion, if used without proper geodetic advice.

The analysis of the results was affected by several problems that were encountered during the campaign. The most serious of these problems was an instrumental fault in the Marconi receiver, which has not yet (1978) been diagnosed and corrected. The fault manifested itself during the analysis as an along-track error in the two-dimensional solution of approximately 120 m for over 50 % of the passes recorded by the receiver. This error seemed to be of a random nature, with no apparent correlation with any of the pass geometry or other parameters involved. This large error led to the rejection of many of the data during the filtering stage, leaving very few passes to contribute to the cumulative three-dimensional least squares solution. This was particularly detrimental when the data were processed with the precise ephemeris, which is based on only two satellites. In one case, 4 days of observation led to five accepted passes. Data from this instrument have since been processed by using two other independently written software packages with the same results, clearly indicating a malfunction of the receiver.

Moreover, the instrument also demonstrated intermittent random jumps (of the order of 10 Hz) in the frequency generated by the reference oscillator. Although this fault should not in itself affect the results obtained, it is indicative of an unacceptable instability in the oscillator.

There appeared to be no correlation between the frequency jumps and the along-track error in the solution described above.

The other problems encountered during this campaign involved logistics, data handling and communications. First, sites that were only accessible on foot were made very difficult to observe from because of the size and weight of the generator and propane gas bottles. The refuelling of the generator also proved to be a problem because of the need for continuous operation. The occupation of each station for up to 5 days continuously led to several generator breakdowns and necessitated two back-up generators.

The data handling and communications problems were mainly due to the operators' being unaware of what was required of them, the tendency being to assume that an automated 'black box' eliminated the need for some of the basic tenets of practical field surveying. This is of course not true, the traditional qualities of a field surveyor, such as self-reliance, initiative and meticulous attention to detail, being of critical importance especially in the event of a breakdown or instrument malfunction.

3. 1978 Campaign: fieldwork

For this campaign, nine stations on the precise Edinburgh–Malvern–Dover traverse were to be occupied by four receivers (of which two belonged to Decca Survey, one to Oxford University and one to Nottingham University) operating simultaneously for a 3 week period. A spare instrument (owned by the Directorate of Overseas Surveys) was available for emergency use. Figure 1 shows the stations, detailing the periods of observation at each, and table 1 gives the combinations of distances between stations observed simultaneously. The choice of stations was decided upon after much discussion, to provide a full range of inter-station distances. Careful planning made sure there were no local obstructions to the horizon, or nearby radio masts or antennae. The order of occupation of the stations was such that a minimum of travelling was necessary between locations. The close proximity of the four receivers (three JMR 1 and one CMA 722B) during the first week of observation was also planned, so that a roving controller could quickly check on the operation of each instrument during the first 2 days of the campaign. The decision to occupy Malvern throughout the campaign had been taken to enable the operation of the Marconi CMA 722B from a mains power supply, which was adjacent to the pillar at this station, thus avoiding the generator problems encountered in the first campaign.

Table 1. Inter-station distances (kilometres)

distance/km	week 1	week 2	week 3
0–100	30 80	30	90
100–200	100 110 130	170	
200–300	200	200 280	250
300–400		310	300 320
400–600		470	420 600

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

As in the 1976 campaign the stations were manned continuously by three men working a shift system, and were occupied for 5 days each week, the weekends being used for inter-station travel.

Bearing in mind the experience gained previously, the approach adopted to the preparation of the 1978 observations was thorough and comprehensive. It was decided to run a 2 day course at Nottingham University for the Ordnance Survey observers who were to be involved. Lectures were given in the theory and operation of the receivers and a valuable session concentrated on instrument fault finding and remedial action. The opportunity was also taken to

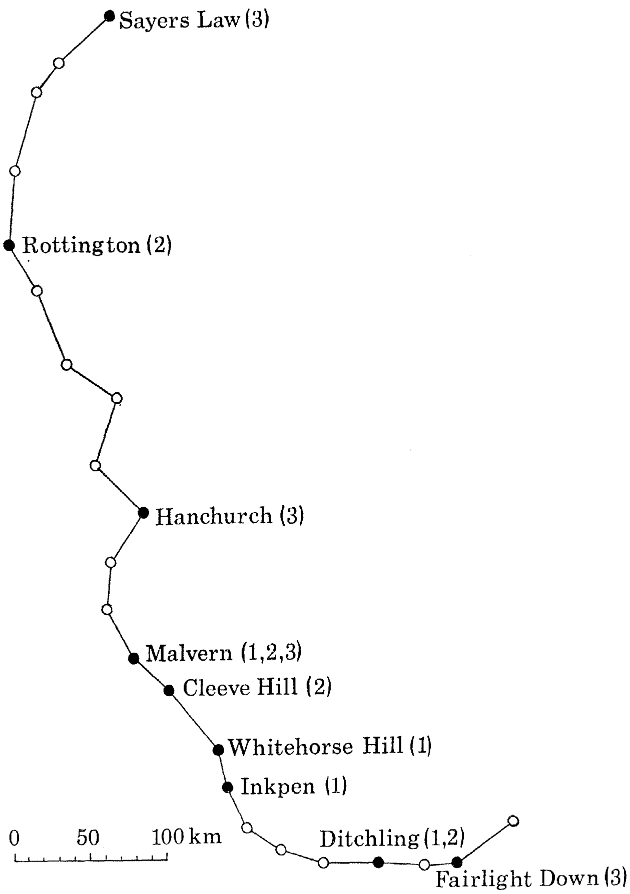

Figure 1. The Dover–Edinburgh precise traverse: o, traverse station; •, occupied station; Inkpen (1), station name and week(s) of occupation.

explain to the observers the purpose of the campaign in addition to the detailed briefing on the programme of observations involved. Clear and simple instructions were given concerning the collection and presentation of data and the importance of keeping a station log was stressed. Standardized booking sheets were issued so that the processing of the data could be efficiently carried out after the campaign. Time was allowed for the surveyors to become familiar with the equipment and to check that it was functioning correctly. Following the course the observers were confident in their ability to operate the equipment and they had a greater understanding of the purpose of the campaign and of their part in it.

As a precaution against malfunction, all of the instruments were tested for a period of 3 days before the campaign. This testing included the calibration of all meteorological measuring equipment. During the test period it was discovered that the Marconi 722B, recently returned from being repaired by the manufacturers, was still regularly producing large along-track errors. In view of this it was decided to operate this instrument at Nottingham throughout the campaign and to send a fourth (the back-up) JMR-1 to Malvern. This left no spare instrument for use in the case of any further malfunctions; however, the S.R.C. Appleton Laboratory kindly lent their JMR-1, at very short notice, to the campaign organizers. A further, temporary, problem in obtaining a lock-on to satellites was experienced with another receiver but after cleaning and checking connections this fault was apparently cured.

The results and performance of the instruments (see table 2) proved the value of the pre-campaign course, as several problems arose. First, the instrument at Malvern failed to lock-on to any satellites from the first day of the campaign. Through good communications this failure was quickly reported and the spare instrument sent to the station. Furthermore, all of the

Table 2. Instrument performance (broadcast ephemeris)

instrument no.	sites occupied: week	sites occupied: name	accepted passes: number	accepted passes: percentage	standard error/m	instrument faults
77–131	1	Malvern	74	63	±0.15	intermittent
	2	Malvern	66	51	±0.16	timing jumps
	3	Malvern	99	71	±0.16	
75–297	1	Whitehorse Hill	77	66	±0.11	no lock-on to
	2	Rottington	75	61	±0.12	SE satellites (week 2)
	3	Sayers Law	98	71	±0.13	frequency jump
76–223	1	Inkpen	79	71	±0.12	
	2	Cleeve Hill	64	56	±0.12	none
	3	Hanchurch	100	79	±0.12	
76–139	1	Ditchling	57	46	±0.45	generally less
	2	Ditchling	03	03	±1.44	accurate data
	3	Fairlight Down	68	52	±0.38	

operators were informed of the problem and asked to extend their stay at their first stations to 6 days, leaving only 1 day for travel to their next sites.

At Ditchling a slight malfunction during the first day of observation was quickly diagnosed by the operators and remedial action taken. Also, during the second week, the instrument at Rottington failed to pick up satellites which rose from one particular section of the horizon. This failure has been attributed to the proximity of the Lake District hills. Again the problem was diagnosed by the operators and the instrument was operated manually (rather than in its automatic mode) for those satellite passes that would otherwise have been missed. All of these faults could have led to a serious loss of data had it not been for the continual manning of the sites by surveyors who were well versed in the operation of the equipment.

As a final precaution against loss of data the first tapes from each week's observations were sent to be processed after 1 day of operation. No data loss was discovered from these tapes.

The results of the analysis of the data showed several unusual occurrences. First, all the results for the second week, processed with the use of the broadcast ephemeris, were much less accurate than those for the first and third weeks (Ashkenazi & Sykes, this symposium). The absolute coordinates for each of the three stations occupied during that week indicated an error manifested as a shift in the satellite ephemeris datum of the order of 10 m. This shift was not apparent when the results were processed with the use of the precise ephemeris and, since it was a systematic error, did not affect the accuracy of the results of the inter-station distances computed by an orbit relaxation translocation model. At first it was thought that this error may have been caused by the high sunspot activity during the period of the campaign, which would create ionospheric disturbance. However, this seems unlikely as the precise ephemeris results would have been similarly affected. There remains the possibility of a 'hiccup' in the broadcast ephemeris.

Secondly, the JMR-1 receiver used at Ditchling and Fairlight Down showed less accuracy than the other three receivers (expressed in terms of internal consistency it achieved a standard error of ± 0.4 m compared with ± 0.1 m; see table 2). This, combined with the generally poor results obtained during the second week of the campaign, probably led to the very small number of acceptable passes received at Ditchling during that particular week.

Thirdly, the JMR-1 used at Sayers Law exhibited on one occasion a frequency jump (of approx. 10 Hz) and, finally, the receiver at Malvern gave intermittent timing errors, each being of an integral number of minutes. These last two errors, once recognized, did not affect the overall results obtained but are of interest because of their occurrence and therefore their possible recurrence in future campaigns.

The most important outcome from this campaign, with regard to the organization, was the overwhelming advantage gained from good planning and communication. Any observing programme should be carefully thought out in advance, but it is of equal importance, in a campaign such as this, that this programme be flexible. One of the main problems associated with the control of such a campaign is communication; delays or difficulties at one station will inevitably affect others and rapid reassessment and replanning has to be followed immediately by the communication of new instructions to all field parties. The use of a roving controller and a regular 'reporting in' system proved very successful in this campaign.

The success of the fieldwork was directly attributable to the well briefed observers backed up by a team in the office. The value of the pre-campaign instruction course (a seemingly expensive exercise) was inestimable as on several occasions the quick action of the observers in remedying faults prevented a severe loss of valuable data. The fact that the observers were also aware of the aims of the campaign contributed to their overall cooperation in what can be tiresome and frustrating work. Were it not for the need to record meteorological data regularly (as well as to check on the correct operation of the instrument) a considerable saving in manpower could have been made. Automatic meteorological recording apparatus would therefore be of great advantage, provided regular checks are still kept on the performance of the receivers.

MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES
THE ROYAL SOCIETY A
PHILOSOPHICAL TRANSACTIONS OF

4. Conclusions

(1) Careful planning of the observation programme is essential for the success of a Doppler campaign.

(2) The calibration and testing of all equipment, both before and during the observations, will prevent the loss of data and may improve the accuracy of that collected.

(3) The issuing of clear and simple instructions to the observers will ensure the correct collection and easy collation of the Doppler and atmospheric data, for processing after the campaign.

(4) An efficient communication system is essential for quick intervention in, and revision of, the campaign in the event of delays or instrument malfunction.

(5) A pre-campaign course for the observers, not only to instruct them in the use of the equipment but also to explain the aims of and reasons behind the campaign, is invaluable in increasing the efficiency and cooperation of the surveyors.

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES