International Hydrographic Review, Monaco, LXVI(2), July 1989

EVALUATION OF NR52 GPS RECEIVERS IN GEODESY (*)

by Alain FOURGASSIE (**)

Abstract

EPSHOM acquired two NR52 GPS receivers in March 1988. These receivers, marketed by SERCEL, have been specially designed for geodesy and determination of the trajectory of moving points. The GPS Mission programme, also distributed by SERCEL, makes it possible to process data recorded by these receivers for geodetic purposes.

Prior to their operational deployment by SHOM's hydro-oceanographic teams, this equipment and the programme were evaluated by EPSHOM. It became evident that the existing geodetic network was not sufficiently accurate to constitute a valid reference. It was, therefore, the repeatability criteria which was chosen to evaluate the accuracy of the measurements obtained by the GPS system. The results vary between 1 and 4 ppm for baselines from 0 to 130 km in length.

INTRODUCTION

In March 1988, EPSHOM acquired two NR52 GPS receivers. These receivers, marketed by SERCEL, have been specially designed for geodesy and for determination of the trajectory of moving points. They include sensors which render possible the simultaneous acquisition of data from five satellites (pseudo-ranges, phase, ephemeris and almanacs) with a view to post-mission processing.

The SERCEL company markets two programmes for development of the data recorded by the NR52 receivers:

(*) Study report No. 014/88, EPSHOM, December 1988.

(**) Ingénieur principal de l'Armement, Geodesy/Geophysics Section, EPSHOM, B.P. 426, 29275 Brest Cedex, France.

— The 'GPS Mission' programme, which permits calculation of the coordinates of fixed points. This programme has been acquired by EPSHOM. Its use and the results obtained are described in this report.

— A programme permitting the very accurate plotting (sub-metric precision) of the track of moving points. Execution times are rather long. 4 hours' processing are required for 1 hour of acquisition of data. This programme has not been bought by EPSHOM. It could be useful for photogrammetric surveys, when a more complete satellite constellation makes possible an appreciable increase in the length of observation periods (sessions).

1 — GENERAL

The value of GPS for geodetic determination is obvious, both for absolute positioning and relative positioning. The GPS Mission programme has been conceived for these two applications. The absolute positioning of a fixed point is effected thanks to exploitation of all the measurements of pseudo-ranges recorded during the observation period. The results obtained by this method during the various tests carried out are described in paragraph 3.1.

Relative positioning of two or more points can be obtained, either:

(a) *by simple differentiation of the coordinates resulting from calculations of* absolute positioning carried out for each point. The results are described in paragraph 3.2; or

(b) after processing by the technique of double differences in phase measurements, recorded simultaneously for the various fixed sites. This second method proves to be more accurate for baselines not exceeding a certain length. The results obtained are described in paragraph 3.3.

A programme of phase processing by double differences was worked out by EPSHOM in the context of a graduate project of the 'Ecole Nationale Supérieure des Ingénieurs des Etudes et Techniques d'Armement (ENSIETA)' (see ref. [1]), in 1987. The GPS Mission programme developed by SERCEL is more general and simpler to use; it can process simultaneously up to 9 sites and 9 observation periods (2 sites and 1 period in the ENSIETA programme). It has not been possible to compare the results provided by these two sets of software because each functions using data recorded by means of an acquisition programme specific to that software.

2 — CARRYING OUT A MISSION IN GEODESY

The setting up and operating of the NR52 receiver and the GPS Mission programme are described in detail in the papers referred to in references [2] and [3]. All the same, it is important to recall here certain principles concerning this.

A geodetic mission consists of three phases. Annex 1 sums up the various programmes in the GPS Mission software corresponding to each of the three phases.

2.1 — Preparation of the mission

This involves carrying out predictions of satellite passes, selecting the observation periods, and formatting and programming the diskettes on which the data will be recorded.

As the results in paragraph 3 will show, it is preferable, as soon as the distance between sites exceeds 10 km, to choose at least two long observation periods (the maximum allowed by the programme is 1 h 41 min 15 seconds for the standard recording rate of 15 seconds), even if five satellites do not remain in view for the whole duration of these periods.

The lengthening of the observation periods permits, in fact, an increase in the number of equations and an improvement in the geometry of the determination. The influence of the length of observation as a function of the length of the baseline is assessed in paragraph 3.3.

It is important to choose constellations providing good geometry. In this respect, it is relevant to note that the GDOP (Geometric Dilution of Precision) calculated by the pass prediction programme does not correctly describe the geometric quality of the double differences solution, but rather that of a determination by pseudo-ranges at a given moment. A new version of this programme, enabling calculation of a parameter of dilution of precision describing the geometry of the solution by double differences will be issued later by SERCEL.

The diskettes for recording the data must be formatted on a computer of the same type as that which will be used for the acquisition of measurements (GRID) and not on the computer used for processing (see paragraph 2.3); however, the latter is used for the programming of these diskettes.

2.2 — Data acquisition

2.2.1 — Installation

It is advisable, first of all, to proceed with care in installing the antenna. This must be free of any masking, at least as regards the sectors (azimuth and site) in which the satellites selected for the measurements will be situated.

The orientation of the antenna is not without significance. A compass must be used to direct the arrow situated on the upper part of the antenna mast towards the North. Actually, the absolute orientation of the antenna is of little importance; on the other hand, it is important to give the same orientation to the antennas of the various receivers.

As the geodesy effected using the GPS system is three-dimensional, the height of the phase centre of the antenna above the fixed site must be measured.

Installation of the equipment (antenna, receiver, calculator) in the field is illustrated by the photographs in Annex 5.

2.2.2 — Data logging

If the mission programme includes several observation sessions, it is necessary to ensure that the diskette has sufficient capacity to log all the data, or, if such is not the case, to envisage a change of diskette between two sessions. Conversely, it is not advisable to record two different missions on the same diskette. Indeed, that causes squeezing of the mission identifier file (MISSION-IDF) for the first mission, which cannot be processed unless the file has been re-created before transferring the data to the hard disk.

2.2.3 — Data checking

Apart from checking for correct functioning, which can be displayed on the GRID calculator during acquisition of measurements, use of the SGP programme, put into operation on the same calculator as soon as a session is over, enables calculation to be made of an approximate position (average of all the positions calculated by pseudo-ranges) and therefore validation of the mission before dismantling the equipment and leaving the site.

2.3 — Data processing

The activation of the 'PROCESS' processing system cannot be effected on a GRID data-acquisition calculator. It requires a computer of the IBM PC AT type, or one that is fully compatible, in the following configuration:

- 640 Kbyte RAM
- 80287 co-processor
- 3 1/2" diskette drive (720 Kbyte)
- hard disk (minimum 10 Mbyte)
- printer.

This programme consists of two principal phases:

(a) For each fixed site, calculation by least squares of a solution using pseudo-range measurements. This calculation uses all the measurements acquired during the session, even if certain recordings do not total the four pseudo-range measurements required for determination in 3 D + T mode. It thus differs from the SGP programme (see paragraph 2.2.3) which carries out a calculation of position for each recording (if the number of measurements is sufficient), then calculates an average of all the results retained.

(b) After the choice of a fixed site, formation of the double phase differences for sites 1-2, 2-3 ... and satellites 1-2, 2-3 ... Calculation of a solution for moving points and pre-selection of the double difference residuals.

At the operator's request, calculation of a second solution of fixed phase integers and of a covariance matrix permitting judgement of the quality of the results.

To obtain the final results of a mission consisting of several sessions, it is necessary to calculate manually, for each site, an average (weighted by variances) of the coordinates obtained during the various sessions. This latter phase of the calculation should be integrated into a subsequent version of the software.

3 — RESULTS

3.1 — Absolute positioning

The results set out below are those obtained with the PROCESS programme (see paragraph 2.3). The site chosen is that of the 'Scientific Instruments' building at EPSHOM, for which 10 periods of observation, spread over 6 days, were recorded.

The table below summarizes the various measurements taken.

Table 1

Day	Constellation (Number of satellites)	Duration	Name of mission	Observations	Number of session
18.05.88	3,9,11,13	1h00min	BSNUL		1
19.05.88	8,9,11,12,13	50min	BTNUL	also processed without satellite 8	2 and 2' *
20.05.88	6,8,9,11,12	50min	BCACO	also processed without satellite 8	3 and 3' *
20.05.88	3,9,11,12,13	1h04min	BCACO		4
26.05.88	8,9,11,12,13	54min	BCOAT	also processed without satellite 8	5 and 5' *
26.05.88	3,9,11,12,13	59min	BCOAT		6
30.05.88	8,9,11,12,13	1h00min	BHUEL	also processed without satellite 8	7 and 7' *
30.05.88	3,9,11,12,13	1h00min	BHUEL		8
01.06.88	8,9,11,12,13	1h00min	BQUES	also processed without satellite 8	9 and 9' *
01.06.88	3,9,11,12,13	1h10min	BQUES		10

* The numbers marked ' concern sessions processed without satellite 8.

The results obtained are set out in Table 2. The scatter of the points with reference to the 'target' is illustrated in the plan shown in Annex 2.

Table 2

Session No.	1	2	2'	3	3'	4	5	5'	6	7	7'	8	9	9'	10
ΔL (metres) (1)	5.1	16.4	7.6	-36.4	3.6	4.7	20.3	6.2	6.8	8.1	-0.5	5.5	12.9	7.1	6.9
ΔG (metres) (1)	8.1	-23.5	-3.8	11.7	-0.1	4.8	-16.9	-1.8	5.1	-4.1	7.1	8.4	-3.5	2.2	2.2
Δh (metres) (1)	-1.1	-52.6	-11.5	34.0	-4.0	6.6	-45.8	-5.0	4.4	-9.6	18.3	8.5	-9.8	6.3	4.6
GDOP *	7.4 to 4.8	4.2 to 4.8	47.1 to 36.8	5.6 to 6.1	6.6 to 7.4	5.0 to 4.2	4.3 to 4.8	50.2 to 37.8	5.0 to 4.2	4.3 to 4.7	51.0 to 38.3	5.0 to 4.2	4.3 to 4.7	51.0 to 38.6	5.0 to 4.2

* GDOP variation observed during the session for the relevant constellation.
(1) Differences between the calculated position and the reference position.

The reference position was obtained by transformation into WGS 84 (from standard parameters) of the NTF coordinates of the fixed point. These come from reference to an IGN third order position; the NTF height was based on the Clarke 1880 ellipsoid, using the NTF astro-geodetic geoid from the IGN.

It is noted that the sessions in which Satellite No. 8 is involved give results that are the furthest removed from the reference position. Indeed, as this satellite functions in a degraded mode (crystal clock), it supplies biased measurements. The results obtained from the same sessions processed without Satellite No. 8 are appreciably better, despite a very unfavourable GDOP.

A weighted average has therefore been calculated, omitting Satellite No. 8. It gives differences of:

$$\begin{cases} \Delta L = 9.3 \text{ m} \\ \Delta G = 4.4 \text{ m} \\ \Delta h = 8.7 \text{ m} \end{cases}$$

compared with the reference position which is referred to the WGS 84 datum, with an accuracy that can be assessed at within 1 to 5 metres.

Examination of the 'target' shows that the results obtained with a given constellation (for instance, sessions Nos. 1, 4, 6, 8, 10 for constellation 3, 9, 11, 12, 13) remain very closely grouped.

Annex 3.b gives an example of a printout of a calculation by pseudo-ranges.

To conclude, the GPS system gives, after about an hour's observation of a constellation with an appropriate GDOP (less than or equal to 6), an absolute, three-dimensional positioning fix to within 10 metres' accuracy. These results can be slightly improved upon over several observation sessions.

The degradation forecast for the C/A code is likely to be detrimental to the absolute positioning performances obtained.

3.2 — Differential positioning

This paragraph deals with the relative positioning of two positions obtained by coordinate differences arising from calculations of absolute positioning (see previous paragraph) for the two points considered.

The results obtained for the baselines of different length were compared with the reference positions (IGN 2nd or 3rd order) based on the WGS 84 datum, and are shown in Table 3.

Table 3

Day	Name of mission	Length of base-line (m)	Constellation (Number of satellites)	Duration of session	GDOP*	ΔL(m)	ΔG(m)	Δh(m)
18.05.88	BSNUL	0	3,9,11,13	1h00min	7.4 to 4.8	− 0.1	0.0	0.0
19.05.88	BTNUL	0	8,9,11,12,13	50min	4.2 to 4.8	0.0	0.2	0.6
20.05.88	BCACO	258	6,8,9,11,12	50min	5.6 to 6.1	0.8	0.8	1.1
20.05.88	BCACO	258	6,9,11,12	50min	6.6 to 7.4	0.5	0.9	1.3
20.05.88	BCACO	258	3,9,11,12,13	1h04min	5.0 to 4.2	− 0.1	− 0.4	0.0
26.05.88	BCOAT	7540	8,9,11,12,13	54min	4.3 to 4.8	−12.7	−10.4	− 21.5
26.05.88	BCOAT	7540	9,11,12,13	54min	50.2 to 37.8	17.4	57.8	−132.1
26.05.88	BCOAT	7540	3,9,11,12,13	59min	5.0 to 4.2	− 0.4	0.3	− 0.1
30.05.88	BHUEL	45400	8,9,11,12,13	1h00min	4.3 to 4.7	− 0.7	2.3	1.0
30.05.88	BHUEL	45400	9,11,12,13	1h00min	51.0 to 38.3	− 1.2	1.9	0.8
30.05.88	BHUEL	45400	3,9,11,12,13	1h00min	5.0 to 4.2	− 0.1	− 0.8	− 0.3
01.06.88	BQUES	189465	8,9,11,12,13	1h00min	4.3 to 4.7	0.6	0.8	− 0.9
01.06.88	BQUES	189465	9,11,12,13	1h00min	51.0 to 38.6	1.9	− 0.8	− 7.7
01.06.88	BQUES	189465	3,9,11,12,13	1h10min	5.0 to 4.2	1.4	1.5	− 0.1
09.06.88	PLEYB	45650	6,9,11,12	40min	6.6 to 6.4	− 0.1	0.4	− 0.6
09.06.88	PLEYB	45650	9,11,12,13	1h00min	50.7 to 39.8	− 0.4	− 0.1	− 0.1
09.06.88	PLEYB	45650	3,9,11,12,13	1h00min	5.1 to 4.2	0.1	1.2	0.2
14.06.88	BYELP	45650	6,9,11,12	1h35min	6.6 to 7.1	1.8	0.0	− 0.6
14.06.88	BYELP	45650	3,9,11,12,13	1h35min	5.1 to 4.3	− 0.5	− 0.5	− 0.5
28.06.88	BDIFF	67080	6,9,11,12,13	1h35min	5.1 to 5.0	− 2.5	5.6	14.1
29.06.88	BDIFF	67080	6,9,11,12,13	1h35min	5.1 to 5.0	− 0.7	1.2	2.3
28.06.88	BDIFF	67080	3,9,11,12,13	1h35min	5.2 to 4.3	− 0.9	− 3.2	− 0.8
29.06.88	BDIFF	67080	3,9,11,12,13	1h35min	5.2 to 4.3	− 0.5	1.2	− 0.1
28.06.88	BDIFF	63833	6,9,11,12,13	1h35min	5.1 to 5.0	28.5	− 3.4	− 30.0
29.06.88	BDIFF	63833	6,9,11,12,13	1h35min	5.1 to 5.0	2.6	1.5	− 2.0
28.06.88	BDIFF	63833	3,9,11,12,13	1h35min	5.2 to 4.3	5.6	4.2	− 0.7
29.06.88	BDIFF	63833	3,9,11,12,13	1h35min	5.2 to 4.3	5.7	1.6	− 2.5

*GDOP variation observed during the session for the constellation designated.

It is relevant to note that the biases of existing measurements are reduced by differential processing, except for one session on 26 May 1988 (BCOAT mission). The processing of the same session without using Satellite No. 8 gives even greater differences, partly explained by the poor GDOP of the 4-satellite constellation. It should also be noted that for this session, as well as for that of 28 June 1988 (BDIFF mission, 63,833 m baseline), it was only possible to put the receiver of one of the two sites into operation about ten minutes after the time envisaged for the start of observations. Not only does that provoke a reduction in the number of measurements available, but it would seem that it perturbs calculation of the position fix by pseudo-ranges for the site concerned. This poor quality of the fix is detectable in a study of the covariance matrix which reveals high figures.

The differences compared with the reference solution are, generally, in good GDOP conditions, of the order of one metre for each of the three coordinates and increase, only slightly, with the length of the baseline. This variation is very difficult to appreciate as, for baselines exceeding a few tens of kilometres, the reference is no longer sufficiently accurate. Noticeable, in fact, for the longest baselines is a certain trend in the differences observed over the various sessions, which would tend to show that the accuracy of the GPS solution is greater than that of the reference.

In conclusion, for baselines up to 200 km, this method enables one to obtain, in good GDOP conditions, a repeatability of about one metre for each coordinate.

3.3 — Double difference method

The results are summarized in Table 4, which shows the differences between the average calculated over the various sessions and the reference position. The double difference method (see ref. [1]) makes it possible to eliminate most of the errors of the receiver clock and the errors caused by the satellites (clocks, orbits, propagation).

The differences noted may appear considerable, particularly for baselines exceeding 40 km, but they are to a great extent caused by imperfections in the reference geodesy. It is relevant to note in this respect that the reference position of the Quiberon site does not come from the IGN but has been produced by a GPS tie with Nantes. This heterogeneity explains the considerable differences noted for baselines using this position.

It was therefore deemed advisable to calculate also the standard inter-session differences which shed light on the repeatability of the determinations.

The 'target' concerning determination at the 'Cap de la Chèvre' based on Quiberon (BDIFF mission) is shown in Annex 4. An example of the printout of results is given in Annexes 3.c and 3.d. The quality of the calculations can be evaluated by examining certain parameters appearing in the printout:

- statistics on the double difference residuals (see ref. [3], paragraph: 'Qualifying a mission');
- correlation matrix;
- number of integers fixed after one or more iterations.

The latter criterion is neither necessary nor sufficient: the integers may sometimes be fixed to erroneous values; inversely, for long baselines, determina-

Table 4

Name of mission	Length of baseline (m)	Number of observation sessions	Duration of observation sessions	Number of fixed integers	Difference from reference			Inter-sessions standard deviation				
					ΔL(cm)	ΔG(cm)	Δh(cm)	σ_L(cm)	σ_G(cm)	σ_h(cm)	$\sigma = (\sigma_L^2 - \sigma_G^2 - \sigma_h^2)^{1/2}$ (cm)	$\sigma = (\sigma_L^2 - \sigma_G^2 - \sigma_h^2)^{1/2}$ (ppm)
BSNUL and BTNUL	0	2	See paragraph 3.2	3/4 & 4/4	− 0.3	− 0.2	0.1	0.2	0.1	0.2	0.3	—
BCACO	258	2(3)		4/4 & 4/4	− 8.3	3.5	− 8.0	0.2	0.1	0.3	0.4	14.4
BCOAT	7540	2(3)		4/4 & 4/4	− 1.9	1.8	7.4	0.2	1.2	0.8	1.5	2.0
BHUEL	45400	2(3)		3/4 & 4/4	− 1.9	17.0	− 56.2	1.7	4.4	6.3	7.8	1.7
BQUES	189465	2(3)		4/4 & 4/4	164.5	−346.3	− 99.8	48.3	61.1	67.6	103.1	5.4
PLEYB and BYELP	45650	4(1)		2/3,3/4,1/3 & 3/4	5.2	17.4	− 59.0	0.3	9.1	13.3	16.1	3.5
BDIFF (2)	67080	4		3/4,4/4,3/4 & 4/4	10.8	− 79.2	35.1	3.5	18.3	14.0	23.3	3.5
BDIFF (2)	63833	4		3/4,4/4,3/4 & 4/4	490.8	186.9	−157.0	6.0	21.3	14.9	26.7	4.2
BDIFF (2)	130555	4		2/4,2/4,3/4 & 3/4	479.4	271.7	−143.5	1.9	25.5	26.5	36.8	2.8
BDIFF (2)	130913	4		6/8,8/8,6/8 & 7/8	483.7	267.2	−119.6	0.6	30.3	17.7	35.1	2.7

(1) The session corresponding to constellation 6,9,11,12 of 40 minutes duration has been omitted.

It involves differences of $\Delta L = -93.8$ cm, $\Delta G = 60.6$ cm, $\Delta h = 216.7$ cm with the average of the other four sessions.

(2) The BDIFF mission includes three sites: QUIBERON (1), TREVIGNON (2) and CAP DE LA CHÈVRE (3) almost in line.
The following baselines were calculated 2 — 3: length = 67,080 m
1 — 2: length = 63,833 m
1 — 3 (direct): length = 130,555 m
1 — 3 (via 2) : length = 63,833 + 67,080 = 130,913 m.

(3) Constellations chosen are: 8,9,11,12,13 and 3,9,11,12,13.

tions can be correct without all the integers being fixed (the wavelength of the GPS signal is 19 cm). Several factors have considerable influence on the accuracy of results.

(a) Length of baseline

The standard inter-session difference σ (see Table 4) is roughly proportional to the length of the baseline. A rule of the type: $\sigma = 0.3$ cm + 1 to 2 ppm has been established for baselines of less than 50 km. For longer baselines (up to 130 km), a variation is observed which can be expressed by the relation:

$$\sigma = 2 \text{ to } 4 \text{ ppm}.$$

A value $\sigma = 5.4$ ppm was obtained for the longest baseline (189 km). This value is greater than that obtained (3.5 ppm) on the same baseline, from the same two sessions, using the method described in paragraph 3.2. This particularity does not arise for the two 130-km baselines. It therefore seems that the double difference calculation is not justified for baselines exceeding 150 km.

The QUIBERON-CAP DE LA CHÈVRE baseline (130 km) was calculated directly, using an intermediate site (calculation of two baselines of 64 km and 67 km). The results obtained by the two methods are similar and therefore do not appear to justify such dividing. The latter may be useful for intermediate ranges of less than 50 km or when the total baseline length exceeds 150 km.

(b) Number of satellites observed and constellation geometry for each session

Separate examination of each session shows that 4-satellite constellations provide mediocre results on long baselines. The geometry of the constellation observed is also important but the GDOP is not the best criterion for assessing it (see paragraph 2.1).

Calculation of a more significant parameter will shortly be incorporated into the software and will make it possible to quantify the effect of this factor.

(c) Number and duration of observation sessions

Increase in the number of observation sessions makes possible a statistical improvement of the solution. In the light of the results obtained, the following rule may be adopted:

— baseline less than 10 km : one session
— baseline from 10 — 50 km : two sessions
— baseline from 50 — 150 km : four sessions spread over two days.

An observation session of too short a duration gives results which are the poorer as the length of the baseline increases. This was noted in respect of the 45,650 metre baseline (PLEYB mission) calculated from a 40-minute session with the constellation 6,9,11,12.

The degradation of the solution as a function of the duration of the observation session has been studied in detail for various baselines. Three parameters have been chosen to characterize this:

— the number of fixed integers after one or more iterations;

— d: distance between the position calculated for the observation session of the duration considered and the position calculated for the reference observation session (see Table 3, paragraph 3.2);

— σp: quadratic average of the sum of the diagonal terms of the correlation matrix (see Annex 3.d).

The results are summarized in the tables below.

Table 5

Baseline nil (Mission BSNUL — Constellation: 3,9,12,13)

Duration of observation session	Number of fixed integers	σp (mm)	d (cm)
60 minutes	3/3	0.428	—
45 minutes	3/3	0.467	0.0 cm
30 minutes	3/3	0.617	0.0 cm
15 minutes	3/3	0.931	0.1 cm
5 minutes	3/3	1.771	0.1 cm
1 minute	3/3	3.480	0.0 cm
30 seconds	2/3	184.206	734.4 cm

Only the session of 30 seconds duration gives a 'd' value exceeding 0.3 cm + 1 to 2 ppm (see para. 3.3, subpara. *a*). It has been separated from the other sessions in the table.

Table 6

Baseline 7,540 m (Mission BCOAT — Constellation : 3,9,11,12,13)

Duration of observation session	Number of fixed integers	σp (mm)	d
59 minutes	4/4	2.001	—
45 minutes	3/4	4.575	0.3 cm + 28.4 ppm
30 minutes	3/4	7.317	0.3 cm + 28.7 ppm
15 minutes	4/4	3.653	0.3 cm + 1.3 ppm
5 minutes	3/4	33.735	0.3 cm + 24.9 ppm

Strangely, the 15 minute observation session conforms to the norm, but the 45-, 30- and 5-minute sessions do not.

Table 7

Baseline 45,400 m (Mission BHUEL — Constellation : 3,9,11,12,13)

Duration of observation session	Number of fixed integers	σp (mm)	d
1 h 00 minute	4/4	4.928	—
50 minutes	4/4	4.309	0.3 cm + 0.4 ppm
40 minutes	4/4	4.486	0.3 cm + 0.5 ppm
30 minutes	4/4	3.936	0.3 cm + 0.5 ppm
20 minutes	3/4	19.430	0.3 cm + 5.3 ppm
10 minutes	3/4	31.212	0.3 cm + 5.4 ppm

The 20-min. and 10-min. sessions are outside the norm.

Table 8

Baseline 45,650 m (Mission BYELP — Constellation : 3,9,11,12,13)

Duration of observation session	Number of fixed integers	σp (mm)	d
1 h 35 minutes	3/4	7.969	—
1 h 15 minutes	3/4	9.552	0.3 cm + 2.9 ppm
1 h 00 minute	4/4	11.645	0.3 cm + 3.9 ppm
45 minutes	4/4	9.883	0.3 cm + 13.1 ppm
30 minutes	4/4	11.839	0.3 cm + 16.6 ppm
15 minutes	2/4	28.787	0.3 cm + 61.2 ppm

All sessions of less than 1 h 35 minutes are outside the norm.

The result is very different from that obtained for the baseline of a similar length considered in Table 7.

Table 9

Baseline 67,080 m (Mission BDIFF — Constellation : 3,9,11,12,13)

Duration of observation session	Number of fixed integers	σp (mm)	d (ppm)
1 h 35 minutes	4/4	12.821	—
1 h 15 minutes	4/4	13.402	3.8
1 h 00 minute	3/4	16.660	11.7
45 minutes	3/4	20.830	11.7
30 minutes	2/4	82.958	15.7
15 minutes	4/4	18.494	35.6

Sessions lasting less than 1 h 15 minutes are outside the norm.

An improvement in the σp parameter and a number 4/4 of fixed integers are noted for the 15 minutes session although the result of the calculation remains poor.

Table 10

Baseline 130,555 m (Mission BDIFF — Constellation : 3,9,11,12,13)

Duration of observation session	Number of fixed integers	σp (mm)	d (ppm)
1 h 35 minutes	2/4	18.460	—
1 h 15 minutes	3/4	14.077	1.9
1 h 00 minute	3/4	16.629	12.5
45 minutes	2/4	45.452	16.0
30 minutes	3/4	24.864	13.0
15 minutes	4/4	18.465	7.1

The sessions of less than 1 h 15 minutes duration are outside the norm.

These various results do not give the possibility of establishing a simple corresponding link between the length of the baseline and the minimum duration of the observation period guaranteeing reliable determination. It appears, however, that it is preferable to envisage sessions of over one hour's duration for baselines of over 40 km.

(d) Accuracy of meteorological observations

It is important to measure, with care, the meteorological parameters at each extremity of the baseline. Their influence is not without significance. For example, it has been noted that a modification of 1°C in the wet temperature or of 1 hpa in the pressure at one of the sites could result in a variation of about 1 ppm in the coordinates of the site calculated.

3.4 — Results obtained in levelling

GPS has been thoroughly tested as a levelling tool. Conventional geometric levelling over distances of several kilometres is, indeed, a long and delicate process which might, in the future, be replaced by GPS techniques.

Two points related to IGN benchmarks (4th order) and about 6 km apart were fixed. The measurements were taken with the constellation 3,9,11,12,13 on 6 September 1988 (a session of 1 h 20 min) and on 9 September 1988 (a session of 1 h 30 min).

On 6 September, a breakdown occurred on one of the channels of a receiver so that only 4 satellites (3,9,12,13) were able to be observed for this session at one of the sites.

Comparison of the altitudes from IGN with altitudes determined by GPS necessitates knowledge of the geoid. Two geoids were used successively:

- the NTF astro-geodetic geoid determined by the IGN and referred to Clarke's (1880) ellipsoid;
- the WGS 84 geoid currently used with the GPS system and referred to the WGS 84 ellipsoid.

The differences observed between the GPS determination and the reference were as follows:

Session	Δh (NTF geoid)	Δh (WGS 84 geoid)
6 September	4.6 cm	3.4 cm
9 September	6.9 cm	5.7 cm
Weighted average of the two sessions	6.0 cm	4.8 cm

The inter-session standard deviation noted (see Table 4) on GPS is:

$$\begin{cases} \sigma_L = 1.1 \text{ cm} \\ \sigma_G = 0.8 \text{ cm} \\ \sigma_h = 1.2 \text{ cm} = 0.3 \text{ cm} + 1.5 \text{ ppm} \end{cases}$$

$$\sigma = \sqrt{\sigma_L^2 + \sigma_G^2 + \sigma_h^2} = 1.8 \text{ cm} = 0.3 \text{ cm} + 2.5 \text{ ppm}$$

Most of the deviations from the reference can be explained by insufficient knowledge of the geoid. It must also be noted that the two benchmarks chosen (4th order) are not part of the same third order grid.

In conclusion, the accurate comparison of conventional geometric levelling and GPS levelling is limited by knowledge of the geoid: the simultaneous use of the two techniques would make precise determination of the geoid possible.

The linking of tidal observations to the general levelling grid is presently achieved by geometric levelling. The adoption of GPS would make it possible to simplify the measurements while guaranteeing 1 to 2 ppm repeatability. However, the reference surface would then be the WGS 84 ellipsoid. A good local knowledge of the geoid would make it possible to refer to the latter whilst a parallel geometric levelling was being carried out (perhaps accompanied by gravity measurements) so that the slope of the geoid might be determined with precision.

CONCLUSIONS AND PERSPECTIVES

GPS in ‘geodesy’ mode can already advantageously replace, as regards performance, most of the conventional geodetic instruments and makes it possible to reveal imperfections in geodetic systems. Its flexibility in use will be improved with the deployment of the final constellations.

The NR52 receivers showed themselves to be reliable during all the trials. The GPS Mission programme is very simple to use. Some improvements might be made to it:

- Calculation, during the pass predictions, of a significant parameter for the geometric quality of the double difference solution.
  This will facilitate selection of satellites and observation periods.
- Multi-session processing. This will avoid having to effect manual calculations to obtain the average of the various sessions.

Moreover, it seems that a problem exists as regards calculation of the solution when it was not possible to put one of the receivers into operation at the time envisaged. This fault may be due to an imperfectly stabilised oscillator beginning to record data despite the fact that ‘Oscillator O.K.’ is shown on the screen.

The results currently obtained by the double difference method are, on the whole, satisfactory, but are, nevertheless, inferior to the promises made by SERCEL (see ref. [4]) at the time of trials carried out at night and thus under more favourable conditions of ionospheric propagation. The ionospheric errors, negligible at night, may be evaluated at 1 to 2 ppm in daytime and will increase up to the period of maximum solar activity in 1991.

The absolute positioning performance is likely to be penalized from December 1988 when the Block II satellites were to be placed in orbit, to which deliberate degradation will be applied. Over a certain period, the present Block I satellites (without degradation) will co-exist with the Block II satellites. It will be important to choose only Block I satellites (if enough of them remain) for calculation of absolute positioning, or else to re-process the data with nondegraded ephemeris which should be available within a 15-day period. On the other hand, this degradation will have little effect (about 1 ppm) on relative positioning.

References

[1] F. LE CORRE, H. RIAHI: Logiciel de traitement géodésique des mesures de phase enregistrées sur le récepteur GPS SERCEL, EPSHOM (June 1987).

[2] SERCEL: NR52 — Installation et utilisation (February 1987).

[3] SERCEL: GPS Mission Package — User's Manual Preliminary Information (May 1988).

[4] G. NARD: GPS Geodesy and Kinematic Topography Measurements and Data Processing, International GPS Workshop, Darmstadt (April 1988).

(See Annexes on the following pages)

ANNEX 1

PRINCIPAL PROGRAMMES USED

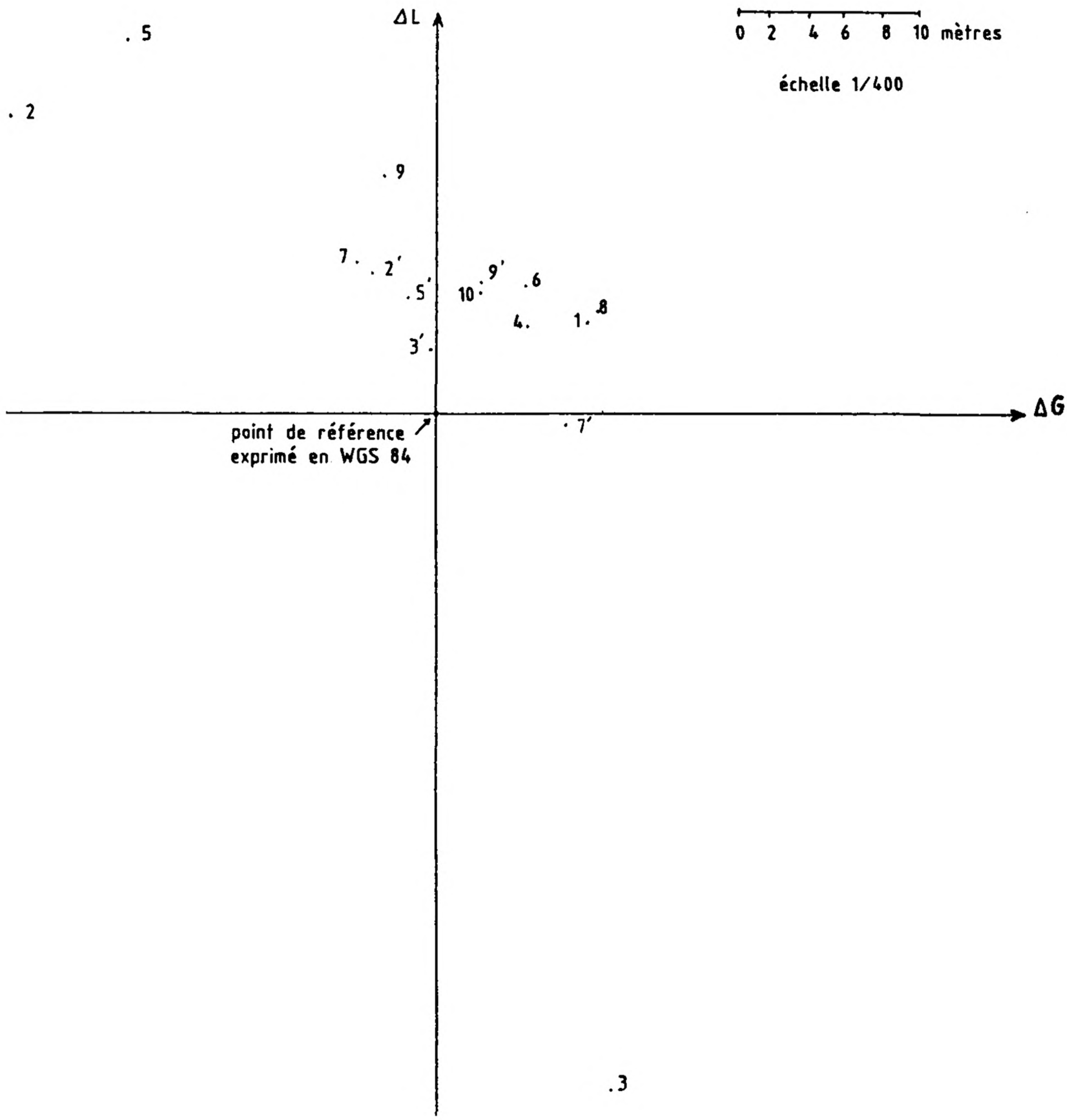
Phase	Name of programme	Type of computer *	Function	Observations
PREPARATION	PRED	Desk	Pass predictions	
	FORMAT	Field	Formatting of diskettes	Command MS/DOS
	MANAGER (Data base)	Desk	Creation of the mission	
	MANAGER (Generate)	Desk	Programmation of diskettes	
ACQUISITION	FIELD	Field	Acquisition of data	
	SGP	Field or desk	Calculation of an approximate position	Optional
PROCESSING	MANAGER (Collect)	Desk	Transfer of data from diskettes to hard disk	
	PROCESS	Desk	Processing	
	TRANSFO	Desk	Transformation of coordinates	Practical
	HUMID	Desk	Conversion of meteorological parameters	Practical

* Field computer: GRID (portable PC/XT — MS/DOS 3.2 — 3.5 inch drive).

Desk computer: PC/AT (co-processor 80287-640 KD — RAM — hard disk 10 Mbyte minimum — MS/DOS 3.2 — 3.5 inch drive).

ANNEX 2

PLANIMETRIC TARGET OBTAINED IN ABSOLUTE POSITIONING



ANNEX 3.a

```
GPS-Mission  (SERCEL V1.2, jan 1,1988)

Processing of Mission: BHUEL

 1 day(s) from  may 30,1988
 Smpl Rate:          15.0 s
 Ev Min   :          10.0 °
 Calibr.  :             5 mn

Processing Mode    : Interactive
Options :
 Meas. Parity test:        Yes
 Iteration Lim.   :      200.0m
 Integers Wind.   :      0.300cycle


Site(s)
  1  PLEYBEN6            48°14'59.1734"N    3°56'19.7910"W   h:  221.660 m
  2  IS1                 48°24'30.6131"N    4°30'10.4754"W   h:  113.901 m
Session(s)
  1 from:  12h10m 0.0s       to:  13h10m 0.0s       Svs:  8  9 11 12 13 ,Records:   241
  2 from:  13h20m 0.0s       to:  14h20m 0.0s       Svs:  3  9 11 12 13 ,Records:   241

----- 1st Day, 2nd Sess., 1st Site Preliminary Data -----
Measurements :    1 period(s), from 13h20m 0.0s to 14h20m 0.0s
Calib. Chan. :          1         2         3         4         5
       Code  :        0.0       0.4      -1.9       0.7      -0.6 ns
       Phase :      0.000    -0.301    -0.416    -0.105    -0.467 cy
Meteo :  Twet (°C)   Tdry (°C)   Pa (mb)
           13.6        16.0        991.2
Antenna height :     1.300 m
Phase Center Pos : 48°14'59.1734"N    3°56'19.7910"W  h:       222.960 m  (Geoid height:  51.2m)

----- 1st Day, 2nd Sess., 2nd Site Preliminary Data -----
Measurements :    1 period(s), from 13h20m 0.0s to 14h20m 0.0s
Calib. Chan. :          1         2         3         4         5
       Code  :        0.0       0.4       0.6       1.0      -2.3 ns
       Phase :      0.000     0.081    -0.058    -0.035    -0.020 cy
Meteo :  Twet (°C)   Tdry (°C)   Pa (mb)
           12.8        14.9       1004.0
Antenna height :    -0.020 m
Phase Center Pos : 48°24'30.6131"N    4°30'10.4754"W  h:       113.881 m  (Geoid height:  52.1m)
```

ANNEX 3.b

```
---- 1st Day, 2nd Sess., Pseudo-Range Solution ( WGS84 ) ----
  ( Receiver Clock Model: Tgps = t+ Ag + Bg*(t-to) + Cg*(t-to)² )
 -- 1st Site :                  PLEYBEN6
     48°14'59.3545"N       3°56'19.3449"W h:   233.073m (minus Ant. height, Geoid height: 51.162m)
 Xg:     4245139.827m Yg:      -292285.921m    Zg:      4735593.398m
 Ag:    2.8848594539s Bg:           11.509ns/s Cg:           -0.199ps/s² to:  134400.0s
 -- Correlation Matrix --
σp:     0.522 (m)
 X:     0.284 (m)
 Y:     0.411     0.357 (m)
 Z:     0.731     0.219     0.253 (m)
Ag:     0.725     0.693     0.609     1.274 (ns)
Bg:     0.023     0.044     0.024    -0.401     0.829 (ps/s)
Cg:    -0.037    -0.036    -0.032     0.338    -0.968     0.000 (ps/s²)

 -- 2nd Site :                      IS1
     48°24'30.7897"N       4°30'10.0639"W h:   125.057m (minus Ant. height, Geoid height: 52.072m)
 Xg:     4228839.884m Yg:      -333024.525m    Zg:      4747246.973m
 Ag:    1.1501549571s Bg:           10.070ns/s Cg:           -0.023ps/s² to:  134400.0s
 -- Correlation Matrix --
σp:     0.402 (m)
 X:     0.218 (m)
 Y:     0.405     0.276 (m)
 Z:     0.731     0.208     0.195 (m)
Ag:     0.725     0.690     0.608     0.979 (ns)
Bg:     0.019     0.054     0.015    -0.399     0.638 (ps/s)
Cg:    -0.031    -0.048    -0.019     0.335    -0.968     0.000 (ps/s²)
```

ANNEX 3.c

```
----- Measurements Count for 1st Day, 2nd Session ----
Site\SVs :          3         9        11        12        13
   1st            241       239       241       241       241
   2nd            241       234       241       241       241

-----  DoubleDifferences Combination  -----
Sites: 1-2
    Svs :  3-11 11-12 12-13 13- 9
 1st Site being Hold-Fixed

----- Integers (Before Fixing)-----
 1st- 2nd Sites
SVs 3-11:    -2.704
SVs11-12:     2.347
SVs12-13:    -2.003
SVs13- 9:    -1.251

----- Integers (After Fixing)-----
 1st- 2nd Sites
SVs 3-11:    -3.000
SVs11-12:     2.276
SVs12-13:    -2.000
SVs13- 9:    -1.000

----- Integers (After Fixing)-----
 1st- 2nd Sites
SVs 3-11:    -3.000
SVs11-12:     2.000
SVs12-13:    -2.000
SVs13- 9:    -1.000

----- Residuals Statistics (cycle) -----
 1st- 2nd Sites
   SVs       Mean      Std-Dev   Nb
 3-11:      0.069      0.223       241
11-12:      0.124      0.134       241
12-13:      0.048      0.087       241
13- 9:     -0.039      0.151       234
```

ANNEX 3.d

```
----- 1st Day, 2nd Session, DoubleDifferences Solutions ( WGS84 ) -----
All 'Integers' have been fixed.
-- 1:  BaseLine(s) --
1st- 2nd= dX: -16299.307m dY: -40737.580m dZ:  11654.590m L:  45398.759m
-- 2:  Sites       --
-- 1st Site :             PLEYBEN6 (Hold-Fixed)
     48°14'59.1734"N       3°56'19.7910"W h:  221.660m (Geoid height:    51.162m)
Xg:     4245134.912m Yg:     -292294.808m Zg:     4735580.190m

-- 2nd Site :                 IS1
     48°24'30.6159"N       4°30'10.4613"W h:  113.496m (Geoid height:    52.072m)
Xg:     4228835.605m Yg:     -333032.387m Zg:     4747234.780m
 - Correlation Matrix -
σp:     7.526 (mm)
 X:     3.186 (mm)
 Y:     0.614     5.993 (mm)
 Z:     0.803     0.410     3.252 (mm)
```

ANNEX 4

PLANIMETRIC TARGET OBTAINED BY THE DOUBLE DIFFERENCES METHOD FOR CAP DE LA CHÈVRE

Scale

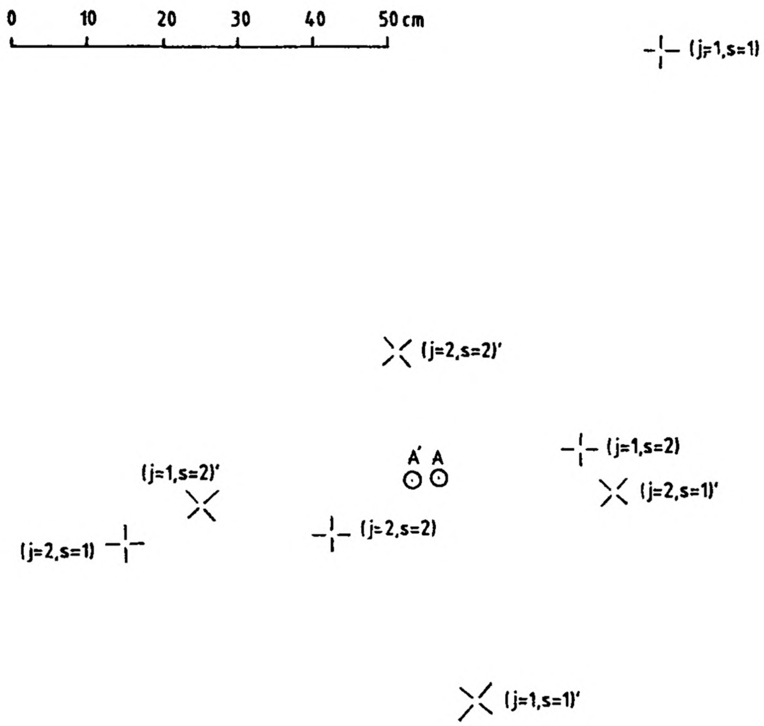
— A : point adopted by the first calculation (QUIBERON → TREVIGNON → CAP DE LA CHÈVRE)

— A′ : point adopted by the second calculation (QUIBERON → CAP DE LA CHÈVRE)

— (j,s) and (j,s)′ respectively represent the points obtained by the first and second calculations for day j and session s

j = 1 : 28.06.88; j = 2 : 29.06.88

s = 1 : satellites No. 6,9,11,12,13 ; s = 2 : satellites No. 3,9,11,12,13



ANNEX 5

INSTALLATION IN THE FIELD