The British EUREF GB 2001 GPS Campaign

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1. Introduction

This report details the processing and analysis of the EUREF GB 2001 GPS campaign carried out by Ordnance Survey, the National Mapping Agency of Great Britain.

Great Britain has an existing network of EUREF (European Reference Frame) stations – EUREF GB 92 [DENYS et al 1995]. This network consists of 26 ground marked stations and includes two fiducial stations from the original EUREF89 network – Solar Pillar, Herstmonceaux (an eccentric station to the current International GPS Service station HERS on the same site) and Buddon, a temporary VLBI site.

Over the past 2 years Ordnance Survey have developed a nation-wide network of 30 continuously operating GPS receivers (COGRs), known as the Ordnance Survey Active GPS Network. Data and coordinates from this network are now the primary source of GPS control for the whole of Great Britain and are freely available to the public on the Ordnance Survey GPS web site (http://www.gps.gov.uk).

The coordinates of the stations in the Active GPS Network are computed in the European Terrestrial Reference System 1989 (ETRS89) and are therefore compatible with other EUREF stations.. However, at present the "official" EUREF network for Great Britain is still EUREF GB 92.

The purpose of the EUREF GB 2001 campaign was to compute new ETRS89 coordinates for all of the stations in the Active GPS Network. The coordinates are of the highest possible quality and have been computed following the latest recommended methods of the EUREF Technical Working Group (TWG). It is hoped that the TWG will accept these results and ratify a sub set of Active GPS Network stations as the new official extension to the EUREF for Great Britain.

Ordnance Survey wishes to acknowledge the kind assistance of the following:

- The Institute of Engineering Surveying & Space Geodesy (IESSG) at Nottingham University, for the loan of 2 choke ring antennas. Also Dr. Richard Bingley of IESSG for information on the coordinate time series of the IESSG COGR and for supplying the UKGauge96 coordinates;
- STEFAN SCHAER & MICHEAL MEINDL of the Astronomical Institute of the University of Berne (AIUB) for the computation of ocean tide loading coefficients. Also Pierre Fridez of AIUB for advice on implementing the DE200 planetary ephemerides.
- HANS VAN DER MAREL of Delft University of Technology, LOTTI JIVALL of National Land Survey of Sweden and AMBRUS KENYERES of FOMI Satellite Geodetic Observatory for information and guidance regarding the height change at ONSA.

2. Planning and Observations

2.1 Network Design

The EUREF GB 2001 GPS Campaign is based on observations at the 30 permanent GPS stations which comprise the Ordnance Survey Active Network, four additional stations and six IGS stations in Europe. In all, data from 40 stations were processed, of which 20 are proposed to become official EUREF stations. Fig. 1 shows their distribution.

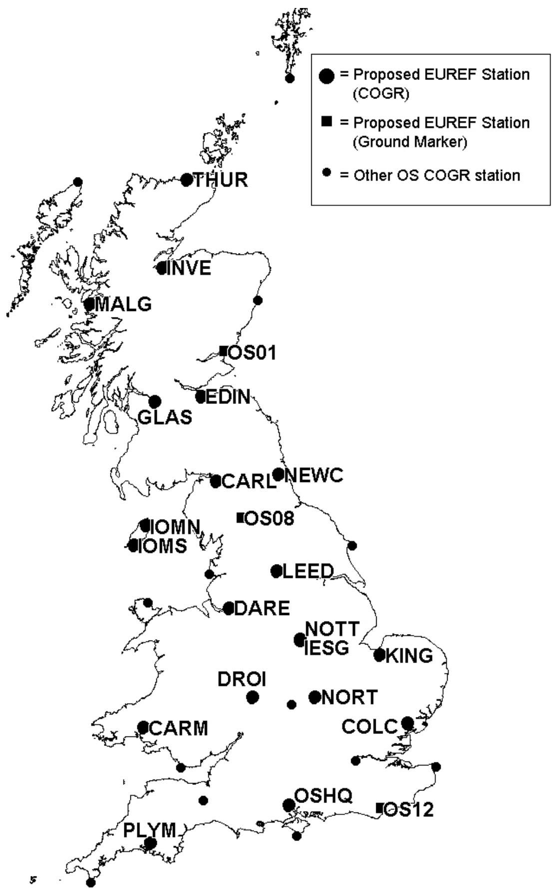

Figure 1. The EUREF GB 2001 Campaign Map of GB Stations

The stations at Buddon (OS01), IESSG Nottingham (IESG), Kirkby Stephen (OS08) and Solar Pillar at Herstmonceux (OS12) were included to provide a measure of external quality control, through comparisons with previously determined co-ordinates. Buddon, Kirkby Stephen and IESG were

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observed in the 1999 Ordnance Survey FBM Project campaign. All four stations were observed during the EUVN 97 GPS campaign. Combinations of Buddon, Kirkby Stephen and Solar were also observed during the UKGauge campaigns and during two previous EUREF campaigns in Great Britain – EUREF EIR/GB 95 and EUREF GB 92.

The six IGS stations were included as potential fiducial stations with known, high accuracy coordinates in the International Terrestrial Reference Frame 1997 (ITRF97). These 6 stations were also chosen because they are the closest 6 IGS stations that are used to define the ITRF97 in the weekly EUREF analysis. Furthermore all 6 are part of the global network used by IGS to compute the precise satellite orbits that were used in the processing. It was not possible to include the IGS station at Herstmonceux because data was not available due to receiver / antenna problems. The European Permanent Network station at the National Physical Laboratory, London was not included because it is not yet part of an IGS solution and could therefore not act as a fiducial station of the same order as the other IGS stations.

A list of proposed and existing EUREF stations included in the computation is given in Table 1.

Table 1. List of Proposed and Existing EUREF Stations.

Stn. ID	Station	OS Ref No.	DOMES No.	Station Description
CARL	Carlisle	A1NY3956	13205S001	Proposed EUREF Station
CARM	Carmarthen	A1SN4120	13206S001	Proposed EUREF Station
COLC	Colchester	A1TL9925	13207S001	Proposed EUREF Station
DARE	Daresbury	A1SJ5783	13208S001	Proposed EUREF Station
DROI	Droitwich	A1SO8961	13209S001	Proposed EUREF Station
EDIN	Edinburgh	A1NT1970	13217S001	Proposed EUREF Station
GLAS	Glasgow	A1NS5664	13219S001	Proposed EUREF Station
IESG	IESSG Nottingham	N/A	13220S001	Existing EUREF Station
INVE	Inverness	A1NH6746	13221S001	Proposed EUREF Station
IOMN	Isle of Man North	A1SC4495	13222S001	Proposed EUREF Station
IOMS	Isle of Man South	A1SC2768	13224S001	Proposed EUREF Station
KING	Kings Lynn	A1TF6219	13225S001	Proposed EUREF Station
LEED	Leeds	A1SE2233	13215S001	Proposed EUREF Station
MALG	Mallaig	A1NM6797	13226S001	Proposed EUREF Station
NEWC	Newcastle	A1NZ2465	13227S001	Proposed EUREF Station
NORT	Northampton	A1SP7462	13228S001	Proposed EUREF Station
NOTT	Nottingham	A1SK5440	13220S002	Proposed EUREF Station
OSHQ	Ordnance Survey HQ	A1SU3814	13274S002	Proposed EUREF Station
PLYM	Plymouth	A1SX5062	13229S001	Proposed EUREF Station
THUR	Thurso	A1NC9967	13230S001	Proposed EUREF Station
OS01	Buddon	H1NO5132	13296M002	Existing EUREF Station
OS08	Kirkby Stephen	H1NY7505	N/A	Existing EUREF Station
OS12	Solar Pillar Herstmonceux	B1TQ6410	N/A	Existing EUREF Station
GRAS	Observatoire de Calern	N/A	10002M006	IGS Reference Station
KOSG	Kootwijk Observatory	N/A	13504M003	IGS Reference Station
ONSA	Onsala	N/A	10402M004	IGS Reference Station
REYK	Reykjavik	N/A	10202M001	IGS Reference Station
VILL	Villafranca	N/A	13406M001	IGS Reference Station
WTZR	Wettzell	N/A	14201M010	IGS Reference Station

2.2 GPS Observations

A two week period of data was collected at the permanent GPS stations and at Solar Pillar, Herstmonceux, from 00:00 hrs GMT Sunday 15th July to 23:59:30 GMT Saturday 28th July 2001. This time span corresponds to GPS weeks 1123 and 1124.

In addition to the permanent GPS stations, observations were also taken from Buddon and Kirkby Stephen. These observations were carried out from Friday 20th to Friday 27th July 2001 in seven 24 hour sessions starting at 12:00 GMT. In order to minimise heighting errors at these stations, the slope antenna height was measured three times per session at three positions around the circumference of the choke ring. This was measured in both millimetres and inches for a gross error check and the mean was taken. The tribrach was rotated between each session to minimise any centring errors. A comprehensive Station Occupation Report was designed in order to ensure these field procedures were adhered to.

The period between 12:00 GMT and no later than 12:30 GMT was used for the simultaneous downloading of data, re-centring and the re-measurement of antenna heights. Because of this break in the data and the subsequent small change in antenna heights at Buddon and Kirkby Stephen, the observations at all of the stations from Julian Days 202 to 207 were split to create two sessions per day. Session one running 00:00:00 to 12:00:00 GMT and session two from 12:05:00 to 23:59:30 GMT. A summary of these observation sessions is given in Table 2.

Table 2. Summary of Observation Sessions

Date	GPS Week and Day No.	Session Number	Start Time (GMT)	Stop Time (GMT)
15-July-2001	11230	1960	00:00:00	23:59:30
16-July-2001	11231	1970	00:00:00	23:59:30
17-July-2001	11232	1980	00:00:00	23:59:30
18-July-2001	11233	1990	00:00:00	23:59:30
19-July-2001	11234	2000	00:00:00	23:59:30
20-July-2001	11235	2010	00:00:00	23:59:30
21-July-2001	11236	2021	00:00:00	12:00:00
		2022	12:05:00	23:59:30
22-July-2001	11240	2031	00:00:00	12:00:00
		2032	12:05:00	23:59:30
23-July-2001	11241	2041	00:00:00	12:00:00
		2042	12:05:00	23:59:30
24-July-2001	11242	2051	00:00:00	12:00:00
		2052	12:05:00	23:59:30
25-July-2001	11243	2061	00:00:00	12:00:00
		2062	12:05:00	23:59:30
26-July-2001	11244	2071	00:00:00	12:00:00
		2072	12:05:00	23:59:30
27-July-2001	11245	2080	00:00:00	23:59:30
28-July-2001	11246	2090	00:00:00	23:59:30

The stations at Buddon and Kirkby Stephen were occupied with Leica SR500 series receivers using Leica AT504 choke ring antennas. The Active GPS Network stations and Solar Pillar are a mixture of Ashtech ZFX receivers with Dorne Margolin type choke ring antennas and Leica CRS1000 receivers with Leica AT504 choke ring antennas. A full list of the GPS receivers and antennas used at any specific station is given in Table 3.

Full data sets were obtained at all stations. The observations were recorded with an elevation angle cut-off of 10 degrees and an epoch interval of 30 seconds.

Table 3. Receiver / Antenna Information.

Stn. ID	Station	Receiver (IGS Code)	Antenna (IGS Code)
CARL	Carlisle	LEICA CRS1000	LEIAT504 LEIS
CARM	Carmarthen	LEICA CRS1000	LEIAT504 LEIS
COLC	Colchester	LEICA CRS1000	LEIAT504 LEIS
DARE	Daresbury	LEICA CRS1000	LEIAT504 LEIS
DROI	Droitwich	ASHTECH UZ-12	ASH700936E SNOW
EDIN	Edinburgh	LEICA CRS1000	LEIAT504 LEIS
GLAS	Glasgow	LEICA CRS1000	LEIAT504 LEIS
IESG	IESSG Nottingham	ASHTECH Z-XII3	ASH700936D_M SNOW
INVE	Inverness	ASHTECH UZ-12	ASH700936E SNOW
IOMN	Isle of Man North	LEICA CRS1000	LEIAT504 LEIS
IOMS	Isle of Man South	LEICA CRS1000	LEIAT504 LEIS
KING	King Lynn	ASHTECH UZ-12	ASH700936E SNOW
LEED	Leeds	ASHTECH UZ-12	ASH700936E SNOW
MALG	Mallaig	LEICA CRS1000	LEIAT504 LEIS
NEWC	Newcastle	ASHTECH UZ-12	ASH700936E SNOW
NORT	Northampton	ASHTECH UZ-12	ASH700936E SNOW
NOTT	Nottingham	ASHTECH UZ-12	ASH700936E SNOW
OSHQ	Ordnance Survey HQ	ASHTECH UZ-12	ASH700936E SNOW
PLYM	Plymouth	LEICA CRS1000	LEIAT504 LEIS
THUR	Thurso	LEICA CRS1000	LEIAT504 LEIS
OS01	Buddon	LEICA SR530	LEIAT504
OS08	Kirkby Stephen	LEICA SR520	LEIAT504
OS12	Solar Pillar	ASHTECH UZ-12	ASH700936E
GRAS	Observatoire de Calern	ROGUE SNR-12 RM	AOAD/M_T
KOSG	Kootwijk Observatory	AOA SNR-12 ACT	AOAD/M_B DUTD
ONSA	Onsala	ASHTECH Z-XII3	AOAD/M_B OSOD
REYK	Reykjavik	AOA SNR-8000 ACT	AOAD/M_T
VILL	Villafranca	ASHTECH Z-XII3	AOAD/M_T
WTZR	Wettzell	AOA SNR-8000 ACT	AOAD/M_T

3. Data Processing

All processing was carried out at Ordnance Survey HQ using the Bernese GPS Software version 4.2 [BEUTLER et al 2001] from the AIUB. The processing was automated using the Bernese Processing Engine (BPE) except for the normal equation stacking stage.

The processing strategy followed the most recent EUREF guidelines given in the proceedings of the 3rd Analysis Centre Workshop held in Warsaw, Poland, May 31st to June 1st 2001. The minutes of the workshop are available at http://www.epncb.oma.be/papers/elacw003/elacw003.html.

3.1 External Data Used in Processing

Observations covered the period 00:00 Sunday 15th July 2001 (day 196) to 23:59:30 Saturday 28th July 2001 (day 209). This time period corresponds to GPS weeks 1123 and 1124. Table 4 gives details of the various external files used in the processing.

3.2 Reference Frame Coordinates

The ITRF97, epoch 1997.00 coordinates of the 6 IGS stations and their corresponding velocities were input to the program COOVEL to compute ITRF97 coordinates at the mid epoch of the two week period – 00:00:00, Sunday 22nd July 2001 (Day 203), epoch 2001.55. The inputs and results are given in Table 5.

3.3 Antenna Height and Site Displacement Modelling

All antenna heights given in the input RINEX files were vertical from the station marker to the antenna reference point (ARP) as per RINEX conventions [Gurtner 2001]. All phase centre offsets from the ARP and satellite elevation dependant corrections were applied using the official IGS models from the "igs_01.pcv" file.

To achieve the best possible results in station height, ocean tide loading corrections were also applied. The effects of tidal constituents M2, S2, N2, K2, K1, O1, P1, Q1 were computed at all stations using the model FES95.2 and stored in the "EUREF.BLQ" file. This computation was kindly performed by STEFAN SCHAER and MICHAEL MEINDL at AIUB using the same procedures as in the recently announced automated service for computing BLQ tables [SCHAER 2001].

Bernese GPS Software Version 4.2 also applies corrections to model solid Earth tides and the polar tide according to International Earth Rotation Service (IERS) Standards 1996 [BEUTLER et al 2001].

Table 4. External files used.

File Type	File Names	Obtained from
IGS Precise Orbits	igs11230.sp3 to igs11246.sp3	ftp://igscb.jpl.nasa.gov/igscb/product/*wwww/* (where *wwww* = GPS week No.)
IGS Precise Earth rotation parameters	igs11227.erp to igs11257.erp	ftp://igscb.jpl.nasa.gov/igscb/product/*wwww/* (where *wwww* = GPS week No.)
CODE ionosphere files	COD11230.ION to COD11246.ION	ftp://ftp.unibe.ch/aiub/CODE/2001/
CODE troposphere files	COD01196.TRP to COD01209.TRP	ftp://ftp.unibe.ch/aiub/BSWUSER/ATM/2001/
ITRF97 coordinates and velocities	ITRF97.CRD and ITRF97.VEL	ftp://ftp.unibe.ch/aiub/BSWUSER/STA/
Ocean tide loading parameters	EUREF.BLQ (an arbitrary name)	Provided by STEFAN SCHAER and MICHAEL MEINDL at AIUB. Coefficients interpolated at apriori coords of all network stations.
Antenna phase centre offsets	igs_01.pcv	ftp://igscb.jpl.nasa.gov/igscb/station/general/

Table 5. ITRF97 coordinates of IGS stations.

Station	DOMES Number	X (m)	Y (m)	Z (m)
IGS Station Coordinates in the ITRF97 at Epoch 1997.00				
Observatoire de Calern	10002M006	4581691.0258	556114.6863	4389360.6849
Kootwijk Observatory	13504M003	3899225.2583	396731.8151	5015078.3414
Onsala	10402M004	3370658.6756	711877.0294	5349786.8684
Reykjavik	10202M001	2587384.5001	-1043033.5002	5716563.9689
Villafranca	13406M001	4849833.7962	-335049.1807	4116014.8247
Wettzell	14201M010	4075580.6968	931853.6663	4801568.0423
IGS Station Velocities from the ITRF97 (Epoch 1997.00) Velocity Field				
Observatoire de Calern	EURA	-0.0118	0.0185	0.0090
Kootwijk Observatory	EURA	-0.0130	0.0158	0.0092
Onsala	EURA	-0.0136	0.0147	0.0084
Reykjavik	NOAM	-0.0201	-0.0035	0.0083
Villafranca	EURA	-0.0071	0.0187	0.0110
Wettzell	EURA	-0.0158	0.0171	0.0071
IGS Station Coordinates in the ITRF97 at Epoch 2001.55				
Observatoire de Calern	10002M006	4581690.9721	556114.7705	4389360.7259
Kootwijk Observatory	13504M003	3899225.1991	396731.8870	5015078.3833
Onsala	10402M004	3370658.6137	711877.0963	5349786.9066
Reykjavik	10202M001	2587384.4086	-1043033.5161	5716564.0067
Villafranca	13406M001	4849833.7639	-335049.0956	4116014.8748
Wettzell	14201M010	4075580.6249	931853.7442	4801568.0746

3.4 Orbit Strategy

The precise International GPS Service (IGS) Earth rotation parameter files were renamed *.iep (Bernese "foreign" format files). These files were then converted to Bernese format *.erp pole files and merged (using program POLUPD) to form a single precise pole file covering the whole campaign – actually from 8th July to 4th August (a week either side of the campaign). This pole file was then used in the program PRETAB to translate the daily IGS orbits in "sp3" format to daily tabular ephemerides in the J2000.0 celestial system.

Program ORBGEN was used to compute daily standard orbits from the PRETAB tabular files. Orbit model "B" was used which applies (from [BEUTLER et al 2001]):

– the JGM3 gravity model;
– the DE200 development ephemerides from JPL (accounts for the gravity of Jupiter and Mars);
– elastic Earth tidal corrections according to (IERS) 1996 conventions;
– corrections for the change of the gravity potential due to ocean tides, up to 4 terms larger than 0.05 cm (CSR, Texas, ocean tide model);
– general relativistic corrections.

The precise IGS orbits are considered to be the most accurate available so no further orbit improvement was performed.

3.5 Data Pre Processing and Cycle Slip Fixing

The zero difference code measurements (L_3 ionosphere free linear combination) were used in the program CODSPP to carry out single point positioning and receiver clock synchronisation. The computed receiver clock offsets were stored with both the phase and code observations. All subsequent stages of the processing used only the phase observations.

The phase single differences (baselines) between receivers were formed using program SNGDIF, employing the OBSMAX strategy to maximise the number of observations in each baseline.

The data was then cleaned and checked for cycle slips using the program MAUPRP. Data cleaning consisted of marking (i.e. flagging as not to be used):

– data below the elevation cut of angle of 10/;
– unpaired observations (e.g. L1 but no L2);
– observations with small data periods (< 5 minutes)

Cycle slips were identified and fixed if possible using the residuals from a triple difference solution. Where a cycle slip could not be fixed a new ambiguity parameter was introduced.

3.6 Troposphere and Ionosphere Modelling

The troposphere and ionosphere modelling strategy for the data processing (see 3.7 and 3.8 below) followed that recommended for Bernese GPS Software version 4.2 [BEUTLER et al 2001] and also the recommendations of the Analysis Centre Workshop.

An elevation angle of 10/ with elevation dependent weighting of observations was used throughout the processing. No a priori troposphere model was used but instead the full delay was estimated using the dry Neill mapping function. Troposphere parameters were estimated every 2 hours at each station with loose constraints (5 m) between consecutive parameters. The exception to this was at the 6 IGS stations where computed troposphere delays (every 2 hours) were introduced and treated as fixed. These delays came from the IGS solution computed by the Centre for Orbit Determination in Europe (CODE).

The effects of the ionosphere were removed by processing the ionosphere free L_3 linear combination whenever possible. The exception to this was at the ambiguity resolution stage of processing (see 3.7 below) where an ionosphere model, the CODE final ionosphere product, was used.

3.7 Ambiguity Free Processing and Ambiguity Resolution

All processing was carried out at the double difference level using the program GPSEST.

The first run of processing was on a baseline by baseline basis using the ionosphere free L_3 linear combination with no ambiguities resolved. The residuals from this stage of the processing were saved and used to detect outliers in the data. In accordance with Bernese GPS Software Version 4.2 guidelines [BEUTLER et al 2001] normalised residuals were saved because elevation dependent weighting of observations was being used. Programs RESRMS and SATMRK were used to detect and mark, as an outlier, any observation with a residual larger than 0.0025 m. This value is also as recommended by [BEUTLER et al 2001] when elevation dependent weighting is used.

The second processing run carried out ambiguity resolution and was also run on a baseline by baseline basis. The QIF (Quasi-Ionosphere-Free) algorithm was used to resolve the ambiguities. QIF ambiguity resolution requires that both frequencies (L1 & L2) have to be processed in parallel rather than processing the ionosphere free L_3 linear combination, so, as recommended by [BEUTLER et al 2001], an a priori ionosphere model was introduced (see 3.6 above).

3.8 Final Network Processing

The final GPSEST processing used all the data from a session in a single run. The aim of this step was to produce and save a set of normal equations from a session that could be subsequently combined to give a final solution based on the entire 2 week data set.

Double differences in the ionosphere free L_3 linear combination were processed and the previously resolved ambiguities (see 3.7 above) were introduced as known integer values. Unresolved ambiguities (real valued parameters) were pre-eliminated. To maintain flexibility in the normal equation files no station was held fixed but for numerical reasons at least one station must be constrained. Station KOSG (Kootwijk Observatory) was therefore constrained to its a priori coordinates (see Table 5) using a sigma of 0.001 m.

3.9 Normal Equation Stacking

Program ADDNEQ was used to combine the normal equations saved from the final GPSEST run (see 3.8 above) and produce solutions based on the entire 2 week data set.

First an unconstrained solution was produced holding station KOSG fixed to it's coordinates in ITRF97, epoch 2001.55. The session-to-session coordinate repeatabilities were analysed from this solution. Possible outliers were detected using the built in ADDNEQ criteria that uses the individual formal RMS values with a detection level of 3 times the mean formal RMS of all the contributing solutions [Beutler et al 2001]. Any outliers identified in this way were pre eliminated from the combination using a station problem file.

Also from the unconstrained solution the coordinates of the IGS fiducial stations were compared to their known coordinates in the ITRF97 epoch 2001.55 using a 3 parameter (translation) transformation.

Once outliers had been removed, a constrained solution was produced by constraining all six IGS fiducial stations to within 0.1 mm of their ITRF97 epoch 2001.55 coordinates. The session-to-session coordinate repeatabilities from this solution were analysed and the resulting coordinates were compared to the ones from the unconstrained solution.

3.10 Transformation to ETRS89

The coordinates from the final accepted constrained solution were transformed to coordinates in the ETRS89, epoch 2001.55 using the methods and parameters detailed in [BOUCHER and ALTAMIMI 2001]. The transformation is given below.

$$X^E(t_c) = X^I_{97}(t_c) + \begin{bmatrix} T1_{97} \\ T2_{97} \\ T3_{97} \end{bmatrix} + \left[\begin{pmatrix} 0 & -\dot{R}3_{97} & \dot{R}2_{97} \\ \dot{R}3_{97} & 0 & -\dot{R}1_{97} \\ -\dot{R}2_{97} & \dot{R}1_{97} & 0 \end{pmatrix} \times X^I_{97}(t_c) \cdot (t_c - 1989.00) \right]$$

$$X^E(89) = X^E(t_c) + \dot{X}^E \cdot (1989.00 - t_c)$$

Where

$X^E(t_c)$ = coordinates in ETRS89 at the observation epoch (2001.55);

$X^I_{97}(t_c)$ = coordinates in ITRF97 at the observation epoch (2001.55);

$X^E(89)$ = coordinates in ETRS89 at epoch 1989.00.

$\dot{X}^E = 0$ so $X^E(89) = X^E(t_c)$

The parameters used in the transformation are given in Table 6.

Following transformation to ETRS89, the resulting final coordinates were compared with coordinates in the ETRS89 from previous campaigns.

Table 6. ITRF97 to ETRS89 Transformation Parameters.

Parameter	Value
t_c, observation epoch	2001.553
$T1_{97}$, translation in X	+ 0.041 m
$T2_{97}$, translation in Y	+ 0.041 m
$T3_{97}$, translation in Z	- 0.049 m
$\dot{R}1_{97}$, rotation in X	+ 0.20 (0.001"/year)
$\dot{R}2_{97}$, rotation in Y	+ 0.50 (0.001"/year)
$\dot{R}3_{97}$, rotation in Z	- 0.65 (0.001"/year)
$\dot{X}^E$, estimation of velocity of station in ETRS89	0 (for stable part of Eurasian plate)

4. Processing Results

Initial processing showed that the Ordnance Survey Active GPS Network station LOND (*not* a proposed EUREF station) suffered from bad data during most of the campaign and was therefore removed from the processing.

The average percentage of resolved ambiguities per session is shown in Figure 2. The average overall ambiguity resolution was 75% and the slightly lower ambiguity resolution of the 12 hour sessions (2021 to 2072) can be seen. The unit weight errors of the individual daily solutions varied between 1.3 mm and 1.4 mm.

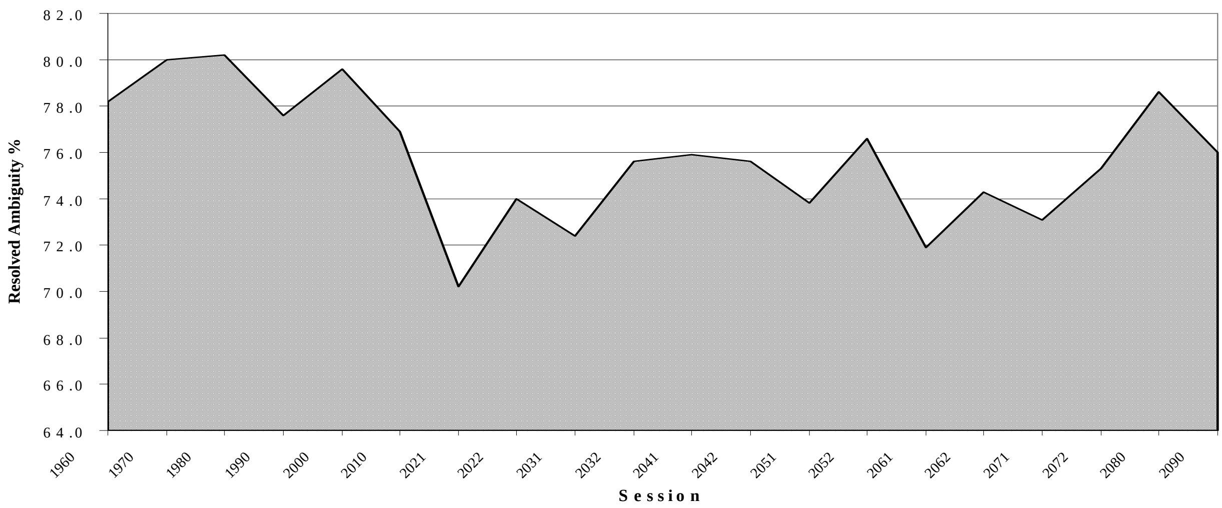

Figure 2. Graph of mean percentage of ambiguities resolved per session.

4.1 Unconstrained Solution

The unit weight error of the unconstrained solution was 1.4 mm. Figure 3 shows the repeatability of all possible baselines. The graph shows data for baselines between *all* stations not just the EUREF stations. The increased height RMS of some of the shorter baselines could possibly be due to two factors:

– The longer baselines are the ones to the IGS fiducial stations. The lower height RMS's at these stations could stem from the fact that the troposphere parameters were fixed from the CODE troposphere product, instead of being computed from the observed GPS data.

– Many of the larger height RMS's come from baselines involving stations from the Ordnance Survey Active GPS Network that are not proposed EUREF stations. Some of these stations are located at lighthouses whose antennas are of regular survey ground plane design, rather than geodetic choke rings.

The RMS repeatabilities of the proposed EUREF stations and the IGS fiducial stations are shown in Figure 4 and Table 7. The North and East repeatabilities range from 1.1 mm to 3.5 mm with overall RMS's of 2.0 mm and 2.3 mm respectively. The height repeatabilities range from 3.4 mm to 8.5 mm with an overall RMS of 6.3 mm. Outlier detection showed that sessions 2052 and 2062 contained more noise than the other sessions and this was causing a large number of stations to be flagged as outliers on these days. Sessions 2052 and 2062 were therefore removed from the combined solution.

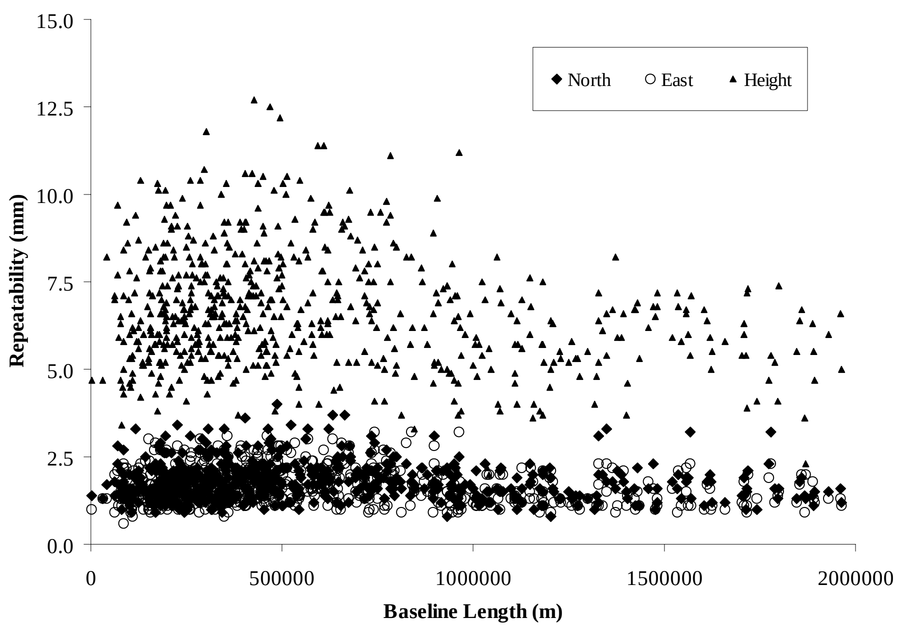

Figure 3. Unconstrained Solution Baseline Repeatability.

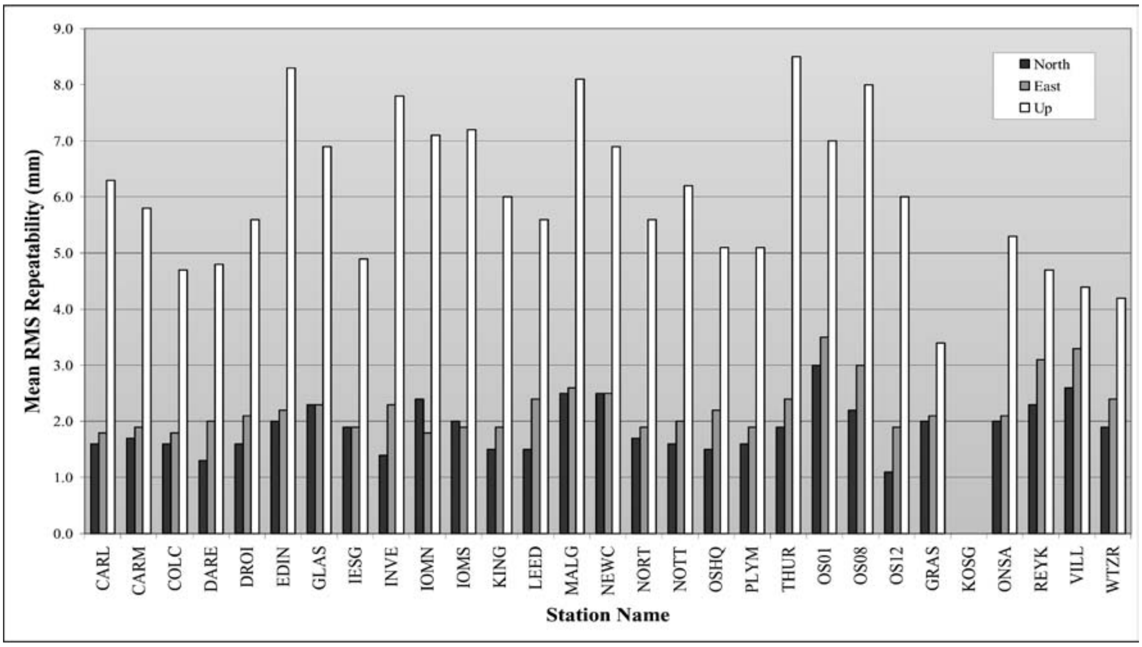

Figure 4. Graph of Unconstrained Solution RMS Repeatabilities for each station

Table 7. Unconstrained Network Solution. Session-to-Session RMS Coordinate Repeatabilities.

Station Name	Station ID	North (mm)	East (mm)	Up (mm)
Carlisle	CARL	1.6	1.8	6.3
Carmarthen	CARM	1.7	1.9	5.8
Colchester	COLC	1.6	1.8	4.7
Daresbury	DARE	1.3	2.0	4.8
Droitwich	DROI	1.6	2.1	5.6
Edinburgh	EDIN	2.0	2.2	8.3
Glasgow	GLAS	2.3	2.3	6.9
IESSG Nottingham	IESG	1.9	1.9	4.9
Inverness	INVE	1.4	2.3	7.8
Isle of Man North	IOMN	2.4	1.8	7.1
Isle of Man South	IOMS	2.0	1.9	7.2
Kings Lynn	KING	1.5	1.9	6.0
Leeds	LEED	1.5	2.4	5.6
Mallaig	MALG	2.5	2.6	8.1
Newcastle	NEWC	2.5	2.5	6.9
Northampton	NORT	1.7	1.9	5.6
Nottingham	NOTT	1.6	2.0	6.2
Ordnance Survey HQ	OSHQ	1.5	2.2	5.1
Plymouth	PLYM	1.6	1.9	5.1
Thurso	THUR	1.9	2.4	8.5
Buddon	OS01	3.0	3.5	7.0
Kirkby Stephen	OS08	2.2	3.0	8.0
Solar Pillar	OS12	1.1	1.9	6.0
Observatoire de Calern (DOMES 13504M003)	GRAS	2	2.1	3.4
Kootwijk (DOMES 10002M006)	KOSG	FIXED	FIXED	FIXED
Onsala (DOMES 10402M004)	ONSA	2	2.1	5.3
Reykjavik (DOMES 10202M001)	REYK	2.3	3.1	4.7
Villafranca (DOMES 13406M001)	VILL	2.6	3.3	4.4
Wettzell (DOMES 14201M010)	WTZR	1.9	2.4	4.2
Overall RMS		*2.0*	*2.3*	*6.3*

Table 8. Coordinate Recoveries of IGS Fiducial Stations.

Station	DOMES Number	X (m)	Y (m)	Z (m)
Accepted Coordinates in the ITRF97 at Epoch 2001.55 Computed from Velocity Field				
Observatoire de Calern	10002M006	4581690.9721	556114.7705	4389360.7259
Kootwijk Observatory	13504M003	3899225.1991	396731.8870	5015078.3833
Onsala	10402M004	3370658.6137	711877.0963	5349786.9066
Reykjavik	10202M001	2587384.4086	-1043033.5161	5716564.0067
Villafranca	13406M001	4849833.7639	-335049.0956	4116014.8748
Wettzell	14201M010	4075580.6249	931853.7442	4801568.0746
Estimated Coordinates in the ITRF97 at Epoch 2001.55 from Unconstrained Solution				
Observatoire de Calern	10002M006	4581690.9670	556114.7693	4389360.7320
Kootwijk Observatory	13504M003	3899225.1991	396731.8870	5015078.3833
Onsala	10402M004	3370658.6157	711877.0900	5349786.9026
Reykjavik	10202M001	2587384.4075	-1043033.5070	5716563.9943
Villafranca	13406M001	4849833.7484	-335049.0870	4116014.8770
Wettzell	14201M010	4075580.6323	931853.7395	4801568.0864
Residuals from 3 Parameter (Translation) Transformation between Accepted and Estimated Coordinates				
Observatoire de Calern	10002M006	-0.0059	0.0020	-0.0023
Kootwijk Observatory	13504M003	0.0020	0.0010	-0.0008
Onsala	10402M004	0.0057	0.0074	0.0013
Reykjavik	10202M001	0.0092	-0.0081	0.0094
Villafranca	13406M001	-0.0112	-0.0084	0.0068
Wettzell	14201M010	0.0002	0.0061	-0.0144

The figures in Table 7 indicate the good precision of the unconstrained solution. The likely improvement in height RMS at the IGS stations, due to better troposphere parameters, can also be seen in Table 7.

A further test on the quality of the unconstrained solution was to look at the coordinate recoveries of the IGS fiducial stations. The comparison was between the accepted ITRF97, epoch 2001.55, coordinates derived from the station velocities (see Table 5) and the coordinates from the unconstrained solution. The comparison was done using the residuals from a 3 parameter (translation) transformation between the two coordinate sets. The results are in Table 8 and show that the ITRF97 is being realised to generally better than 10 mm.

4.2 Onsala (ONSA) Tests

It was debated whether or not the IGS station ONSA should be included as a constrained station in the final solution. This debate stemmed from the apparent height change of ~ -20 mm detected at ONSA during the SWEREF-99 analysis [JIVALL, L. & LIDBERG, M. 2000]. On the one hand a height change was shown but on the other the ”EUREF Community” was still using the station and it’s original coordinates in the European Permanent Network (EPN) solutions, for computing products such as troposphere and ionosphere models and ONSA was still part of the IGS network used for computing precise orbits and Earth rotation parameters.

Tests were carried out to study the effect of ONSA on the final solution and to see if a height change was apparent. Information and advice about the ONSA height change, supplied by HANS VAN DER MAREL of Delft University of Technology, LOTTI JIVALL of National Land Survey of Sweden and AMBRUS KEYNERES of FOMI Satellite Geodetic Observatory, is gratefully acknowledged.

The coordinate recoveries at ONSA, from the results of the unconstrained solution, do not show any obvious height change. It has been suggested (by Lotti Jivall) that this could be because the fixed troposphere parameters used for ONSA come from a CODE solution that constrained ONSA to pre height change coordinates. These are the same coordinates used in the EUREF GB 2001 solution, in which case it is to be expected that ONSA will fit very well.

Two tests were carried out using the coordinates of ONSA computed from the accepted ITRF97 coordinates and velocity field (Table 5) as a ”base”:

- Direct comparison with the ONSA coordinates from the unconstrained solution;
- A constrained solution was computed where ONSA was not fixed and the ITRF was defined by constraining the remaining IGS stations.

The results of these tests are in Table 9.

It can be seen from Table 9 that when the coordinates from the unconstrained solution are compared directly with the accepted coordinates there is no height change apparent, this concurs with the results from the comparison using a 3 parameter translation transformation.

Table 9. ONSA coordinate recovery tests.

Accepted ITRF97 (e2001.55) ONSA Coordinates from ITRF97 coordinates + velocities			
station	X (m)	Y (m)	Z (m)
ONSA	3370658.6137	711877.0963	5349786.9066
Direct comparison with unconstrained solution			
	X (m)	Y (m)	Z (m)
ONSA	3370658.6157	711877.0900	5349786.9026
	North (m)	East (m)	Up (m)
ONSA	-0.0027	-0.0066	-0.0030
Comparison with constrained solution (ONSA unconstrained, other IGS constrained)			
	X (m)	Y (m)	Z (m)
ONSA	3370658.6135	711877.0884	5349786.8955
	North (m)	East (m)	Up (m)
ONSA	-0.0044	-0.0077	-0.0103

The comparison with coordinates from a constrained solution, in which ONSA was unconstrained but the other IGS stations (GRAS, KOSG, REYK, VILL, WTZR) were constrained to their ITRF97 (e2001.55) coordinates, shows an apparent height change of just over -10 mm. This height change does not match the -20 mm suggested by the SWEREF99 processing but it does match a height change found by Ambrus Kenyeres in processing for the EPN time series. On the standard EPN time series it is not so easy to see this jump because of the noise in the height component and on the improved time series it is already eliminated.

To test the effect of ONSA on the coordinates of the EUREF GB 2001 stations a constrained solution was computed where all IGS stations (including ONSA) were constrained to their ITRF97 (e2001.55) coordinates. The coordinates from this solution were compared to the coordinates from the previous constrained solution (where ONSA was unconstrained). The comparison showed that the constraining/unconstraining of ONSA introduced shifts of just -1.2 mm in North, -1.5 mm in East and -1.3 mm in height into the EUREF GB 2001 coordinates.

It was decided to constrain the coordinates of ONSA in the final solution for the following reasons:

- The change introduced by constraining / unconstraining ONSA is very small;
- The size of the height jump at ONSA is still being debated;
- Despite the suspected height jump the original ITRF97 coordinates of ONSA are still accepted and being used by the "EUREF Community", i.e. – fixed station in EPN, computation of CODE products. Ordnance Survey wishes to follow the EPN solution as closely as possible.

4.3 Constrained Solution

The unit weight error of the constrained solution was 1.4 mm.

The RMS repeatabilities for the constrained solution are shown in Figure 5 and Table 10. The figures in Table 10 are a further indication of the good quality of the solution.

The coordinates of the proposed EUREF stations from the constrained solution were compared with the coordinates from the unconstrained solution. The results of this comparison are in Table 11. The effect of fixing the 6 IGS fiducial stations has been to systematically shift the unconstrained solution coordinates by 1.7 mm in North, 0.7 mm in East and 3.2 mm in height. These small shifts further indicate the quality of the solution and their systematic nature shows the high level of consistency between the IGS stations.

The coordinates from the constrained solution were accepted as the final coordinates. A full list of final ITRF97, epoch 2001.55, coordinates is given in Appendix A.

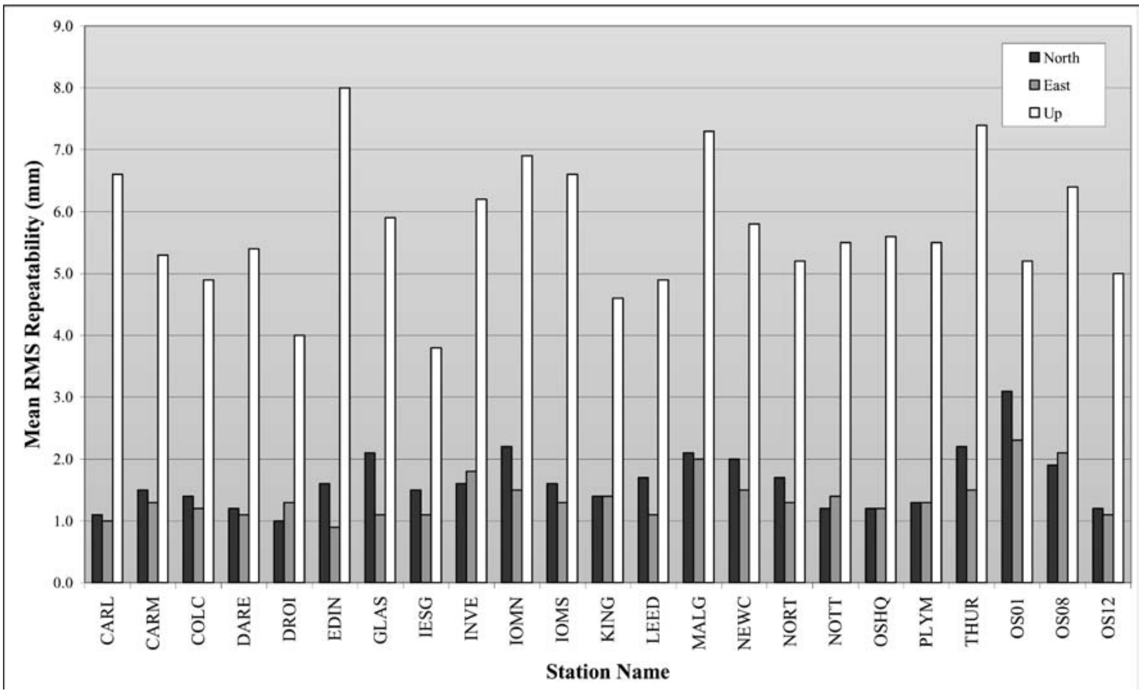

Figure 5. Graph of Constrained Solution RMS Repeatabilities for each station.

Table 10. Constrained Network Solution. Session-to-Session RMS Coordinate Repeatabilities.

Station Name	Comp ID	North (mm)	East (mm)	Up (mm)
Carlisle	CARL	1.1	1.0	6.6
Carmarthen	CARM	1.5	1.3	5.3
Colchester	COLC	1.4	1.2	4.9
Daresbury	DARE	1.2	1.1	5.4
Droitwich	DROI	1.0	1.3	4.0
Edinburgh	EDIN	1.6	0.9	8.0
Glasgow	GLAS	2.1	1.1	5.9
IESSG Nottingham	IESG	1.5	1.1	3.8
Inverness	INVE	1.6	1.8	6.2
Isle of Man North	IOMN	2.2	1.5	6.9
Isle of Man South	IOMS	1.6	1.3	6.6
Kings Lynn	KING	1.4	1.4	4.6
Leeds	LEED	1.7	1.1	4.9
Mallaig	MALG	2.1	2.0	7.3
Newcastle	NEWC	2.0	1.5	5.8
Northampton	NORT	1.7	1.3	5.2
Nottingham	NOTT	1.2	1.4	5.5
Ordnance Survey HQ	OSHQ	1.2	1.2	5.6
Plymouth	PLYM	1.3	1.3	5.5
Thurso	THUR	2.2	1.5	7.4
Buddon	OS01	3.1	2.3	5.2
Kirkby Stephen	OS08	1.9	2.1	6.4
Solar Pillar	OS12	1.2	1.1	5.0
Observatoire de Calern (DOMES 13504M003)	GRAS	FIXED	FIXED	FIXED
Kootwijk (DOMES 10002M006)	KOSG	FIXED	FIXED	FIXED
Onsala (DOMES 10402M004)	ONSA	FIXED	FIXED	FIXED
Reykjavik (DOMES 10202M001)	REYK	FIXED	FIXED	FIXED
Villafranca (DOMES 13406M001)	VILL	FIXED	FIXED	FIXED
Wettzell (DOMES 14201M010)	WTZR	FIXED	FIXED	FIXED
Overall RMS		*1.7*	*1.5*	*6.0*

Table 11. Comparison of Coordinates between Constrained & Unconstrained Solutions.

Station Name	Comp ID	North (mm)	East (mm)	Up (mm)
Carlisle	CARL	1.5	0.6	3.2
Carmarthen	CARM	1.8	0.7	3.0
Colchester	COLC	1.8	0.6	3.3
Daresbury	DARE	1.7	0.7	3.2
Droitwich	DROI	1.8	0.7	2.9
Edinburgh	EDIN	1.4	0.7	3.3
Glasgow	GLAS	1.5	0.6	3.2
IESSG Nottingham	IESG	1.7	0.7	3.1
Inverness	INVE	1.2	0.7	3.4
Isle of Man North	IOMN	1.7	0.7	3.2
Isle of Man South	IOMS	1.6	0.7	3.2
Kings Lynn	KING	1.6	0.6	3.1

Station Name	Comp ID	North (mm)	East (mm)	Up (mm)
Leeds	LEED	1.5	0.6	3.1
Mallaig	MALG	1.5	0.8	3.2
Newcastle	NEWC	1.5	0.7	3.1
Northampton	NORT	1.8	0.8	2.9
Nottingham	NOTT	1.7	0.6	2.7
Ordnance Survey HQ	OSHQ	1.8	0.7	2.9
Plymouth	PLYM	2.0	0.8	2.9
Thurso	THUR	1.2	0.9	3.4
Buddon	OS01	1.3	0.6	3.3
Kirkby Stephen	OS08	1.5	0.6	3.5
Solar Pillar	OS12	1.9	0.5	2.7
Overall RMS		*1.7*	*0.7*	*3.2*

4.4 Comparison with Previous Campaigns

The final accepted coordinates from the constrained solution were transformed to the ETRS89, epoch 2001.55 using the method from [BOUCHER and ALTAMIMI 2001] see 3.10 above. A full list of final ETRS89, epoch 2001.55 coordinates is given in Appendix B.

Stations OS01 (Buddon), IESG (IESSG Nottingham), OS08 (Kirkby Stephen) and OS12 (Solar Pillar) were included in the network because they have been coordinated in previous geodetic GPS campaigns. These previous ETRS89 coordinates were compared with the coordinates from the constrained solution as an external measure of accuracy. The results of these comparisons are shown in Table 12.

The FBM Project [IESSG 2000] was a GPS campaign carried out in early 1999 to provide accurate GRS80 ellipsoidal heights for all fundamental bench marks (FBMs) in Great Britain. The coordinates for OS01 and OS08 from this campaign are based on two 4 hour GPS sessions on the same day (or on consecutive days). Station IESG was a reference station in the FBM Project and it's coordinates are based on 77 days of GPS data. The processing and analysis for the FBM Project was carried out by IESSG using similar techniques and models as those used in the EUREF GB 2001 campaign.

The EUVN97 campaign [INEICHEN 1999] is well known and was a Europe wide fiducial GPS campaign with observations lasting 7 days in May 1997. The UKGauge campaigns (91, 92, 93 & 96) was a series of fiducial GPS campaigns to determine the heights of tide gauge bench marks. Coordinates from UKGauge were kindly provided by IESSG.

Two previous EUREF campaigns were also used in comparisons. EUREF EIR/GB 95 [Ashkenazi et al 1996] was a campaign to realise an ETRS89 network in Northern Ireland and the Republic of Ireland, that also included some stations in Great Britain. EUREF GB 92 [DENYS et al 1995] was the first EUREF network in Great Britain.

Comparison with the EUVN97 campaign shows good coordinate recovery (5 mm or better) at stations OS01 and OS12. OS01 also has a recovery better than 9 mm in all components with the FBM Project and OS12 recovers to better than 2 mm when compared with the UKGauge96 campaign.

Coordinate recovery at station OS08 is not as consistent as at OS01 and OS12. There is a 19 mm discrepancy in the East component when compared to EUVN97 and a 25 mm discrepancy in height when compared to the FBM Project. However the recoveries compared to UKGauge96 are improved – less than 8 mm in all components. The plan North and East recoveries compared to the FBM Project are good and the 25 mm height difference may be due to the fact that it is based on just two 4 hour session as opposed to a continuous week of data in EUREF GB 2001. However, there is no readily available reason for the 19 mm East difference when compared to EUVN97. OS08 is not a permanent station and requires a tripod set up which could be a factor in this difference, as is the four year time period between the two observations.

The coordinate recoveries at IESG were more of a concern. Compared to both EUVN97 and the FBM Project there is a 10 mm difference in North and a 20 mm difference in height, the East component is always <4.6mm. IESG is a permanent geodetic station operated by IESSG at Nottingham, so the differences are unlikely to be due to set up. IESSG confirmed that IESG has not been moved, re-sited or changed in any significant way since it was first established. There is obviously close agreement at IESG between EUVN97 and the FBM Project, so, as an additional check, IESSG kindly provided coordinates from their most recent daily analysis of the IESG data. These coordinates stem from highly accurate processing similar to that carried out for the weekly European Permanent Network analysis.

Table 12. Comparison with Previous Campaigns. (NB: the sense of all differences is from EUREF GB 2001 to the previous campaign.)

Final Estimated Coordinates from Constrained Solution. ETRS89			
	X (m)	Y (m)	Z (m)
OS01	3526416.4899	-171421.1902	5294098.6713
IESG	3851174.4913	-80151.8545	5066646.9942
OS08	3713868.6649	-154772.6362	5166095.4576
OS12	4033459.2129	23626.3103	4924303.0796

FBM Project (1999) Coordinates and differences. ETRS89			
	X (m)	Y (m)	Z (m)
OS01	3526416.4889	-171421.1923	5294098.6824
IESG	3851174.4949	-80151.8583	5066647.0157
OS08	3713868.6750	-154772.6392	5166095.4810
	North (m)	East (m)	Up (m)
OS01	0.0069	-0.0021	0.0088
IESG	0.0100	-0.0037	0.0194
OS08	0.0053	-0.0026	0.0250

EUVN97 Coordinates and differences. ETRS89			
	X (m)	Y (m)	Z (m)
OS01	3526416.4860	-171421.1890	5294098.6750
IESG	3851174.4950	-80151.8500	5066647.0170
OS08	3713868.6620	-154772.6170	5166095.4440
OS12	4033459.2080	23626.3160	4924303.0820
	North (m)	East (m)	Up (m)
OS01	0.0053	0.0010	0.0009
IESG	0.0109	0.0046	0.0204
OS08	-0.0049	0.0191	-0.0132
OS12	0.0053	0.0057	-0.0012

IESSG Coordinates from daily analysis. ITRF97 (e2001.46) transformed to ETRS89			
	X (m)	Y (m)	Z (m)
IESG	3851174.4862	-80151.8603	5066646.9922
	North (m)	East (m)	Up (m)
IESG	0.0028	-0.0059	-0.0046

UKGauge96 Coordinates and differences. ETRS89			
	X (m)	Y (m)	Z (m)
OS08	3713868.6580	-154772.6345	5166095.4535
OS12	4033459.2130	23626.3120	4924303.0819
	North (m)	East (m)	Up (m)
OS08	0.0033	0.0014	-0.0074
OS12	0.0014	0.0017	0.0019

EUREF EIR/GB 95. Coordinates and differences. ETRS89			
	X (m)	Y (m)	Z (m)
OS01	3526416.4740	-171421.1911	5294098.6917
OS08	3713868.6518	-154772.6386	5166095.4763
	North (m)	East (m)	Up (m)
OS01	0.0248	0.0003	0.0097
OS08	0.0217	-0.0009	0.0102

UKGauge93 Coordinates and differences. ETRS89			
	X (m)	Y (m)	Z (m)
OS01	3526416.4898	-171421.1990	5294098.6808
OS12	4033459.2039	23626.3139	4924303.0881
	North (m)	East (m)	Up (m)
OS01	0.0053	-0.0069	0.0095
OS12	0.0123	0.0063	0.0025

UKGauge92. Coordinates and differences. ETRS89			
	X (m)	Y (m)	Z (m)
OS01	3526416.4521	-171421.1898	5294098.6972
OS12	4033459.1908	23626.3137	4924303.1059
	North (m)	East (m)	Up (m)
OS01	0.0461	0.0005	0.0022
OS12	0.0337	0.0062	0.0080

EUREF GB92. Coordinates and differences. ETRS89			
	X (m)	Y (m)	Z (m)
OS01	3526416.5090	-171421.1790	5294098.7340
OS08	3713868.6880	-154772.6300	5166095.5030
OS12	4033459.1960	23626.2880	4924303.0760
	North (m)	East (m)	Up (m)
OS01	0.0195	0.0140	0.0640
OS08	0.0081	0.0092	0.0527
OS12	0.0109	-0.0195	-0.0120

UKGauge91. Coordinates and differences. ETRS89			
	X (m)	Y (m)	Z (m)
OS01	3526416.4482	-171421.1858	5294098.6616
OS12	4033459.2125	23626.3113	4924303.0903
	North (m)	East (m)	Up (m)
OS01	0.0299	0.0043	-0.0298
OS12	0.0070	0.0037	0.0096

Mean coordinates from the latest 7 days of analysis were computed and transformed to ETRS89. The coordinate recovery between the EUREF GB 2001 solution and these coordinates confirms the EUREF GB 2001 position for station IESG with recoveries better than 6 mm in all components. This result also indicates that there is perhaps a change occurring at IESG. IESSG are aware that the building on which IESG sits is settling at a rate of about 2 mm per year which would account for approximately 5 mm difference between the FBM Project and now. IESSG have also found periodic height variations in their time series analysis which have an annual signal and maximise early in the year and minimise in the middle of the year. The amplitude of this signal is about 5 mm so from peak (FBM Project observations) to trough (EUREF GB 2001 observations) could account for another 10 mm of height difference. A further small discrepancy may be due to the bias between the two software packages used to process the observations – Bernese for EUREF GB 2001 and GAS for the FBM Project.

Moving down the comparisons in Table 12 the campaigns get older and the coordinate recoveries less consistent and generally of a lower precision. From the EUREF EIR/GB 95 campaign OS01 and OS08 exhibit similar differences of approximately 20 mm and 10 mm in North and Up respectively and very small differences in East. From the older UKGauge campaigns the differences vary. UKGauge93 has coordinate recoveries generally better than 10 mm where as for UKGauge92 the East and Up recoveries are good but the North recoveries are up to 46 mm. Coordinate recoveries from the EUREF GB 92 campaign are better than 20 mm in plan but go up to 64 mm in height.

It is perhaps to be expected that coordinate recoveries from older campaigns will not be as good when the time span between them and the differences in the underlying ITRF's are taken into account. The general level of agreement is around 20 to 30 mm.

5. Conclusions

The results in 4.1 above (Table 7) show the high level of internal quality of the solution to be generally better than 3 mm in North and East and 7 mm in height.

The coordinate recoveries of the IGS fiducial stations (Table 8) show that the ITRF is being realised at the 10 mm level.

The differences between the unconstrained and the constrained solutions (Table 11) show the high level of internal consistency between the IGS stations.

Comparison with previous campaigns has shown that the ETRS89, coordinates agree with previous (recent) campaigns to generally 10 mm or better. This is despite some larger than expected differences that are explained. Comparison to older campaigns up to 1995 (and up to ITRF93) generally agree to around 20 to 30 mm.

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A. Final ITRF97 Coordinates

EUREF GB 2001 Final ITRF97, epoch 2001.55, coordinates. GRS80 Ellipsoid. SE's based on coordinate repeatabilities.

Station Name	Comp ID	X (m) ±se (m)	Y (m) ±se (m)	Z (m) ±se (m)	Lat (dms) ±se (m)	Long (dms) ±se (m)	Height (m) ±se (m)
Carlisle	CARL	3671344.436 0.004	-188441.209 0.001	5194774.079 0.005	N 54 53 43.532333 0.002	W 002 56 17.789806 0.002	93.554 0.006
Carmarthen	CARM	3936213.912 0.004	-296554.215 0.001	4993187.226 0.004	N 51 51 32.080552 0.002	W 004 18 30.680608 0.002	81.361 0.006
Colchester	COLC	3943778.286 0.003	61764.205 0.001	4995618.045 0.004	N 51 53 39.727115 0.002	E 000 53 50.085308 0.002	75.278 0.005
Daresbury	DARE	3811965.414 0.003	-175799.882 0.001	5093615.648 0.004	N 53 20 41.298279 0.001	W 002 38 25.766675 0.002	88.424 0.005
Droitwich	DROI	3909832.830 0.003	-147096.961 0.001	5020322.640 0.003	N 52 15 19.065933 0.002	W 002 09 16.501225 0.002	101.535 0.006
Edinburgh	EDIN	3575928.281 0.005	-205860.465 0.001	5259853.308 0.006	N 55 55 29.225638 0.002	W 003 17 41.242952 0.002	119.049 0.008
Glasgow	GLAS	3578263.289 0.004	-268830.380 0.001	5255394.393 0.004	N 55 51 14.406470 0.002	W 004 17 47.355896 0.002	71.633 0.007
IESSG Nottingham	IESG	3851174.299 0.003	-80151.682 0.001	5066647.161 0.003	N 52 56 26.484343 0.002	W 001 11 32.219300 0.002	98.460 0.005
Inverness	INVE	3427172.205 0.004	-252834.173 0.002	5355255.657 0.005	N 57 29 10.508066 0.001	W 004 13 09.341472 0.002	66.196 0.008
Isle of Man North	IOMN	3716635.519 0.005	-285228.402 0.002	5158273.179 0.005	N 54 19 45.111673 0.002	W 004 23 18.559512 0.002	94.526 0.007
Isle of Man South	IOMS	3737196.914 0.005	-302953.978 0.002	5142476.266 0.004	N 54 05 11.995631 0.002	W 004 38 04.269410 0.002	84.388 0.007
Kings Lynn	KING	3868685.880 0.003	27112.820 0.001	5053897.107 0.003	N 52 45 04.928899 0.002	E 000 24 05.537124 0.002	66.438 0.006
Leeds	LEED	3773717.609 0.003	-109614.285 0.001	5123816.250 0.004	N 53 48 00.782826 0.002	W 001 39 49.641047 0.002	215.622 0.006
Mallaig	MALG	3463462.979 0.005	-353538.122 0.002	5326325.633 0.005	N 57 00 21.849207 0.002	W 005 49 42.112354 0.002	68.508 0.008
Newcastle	NEWC	3667109.030 0.005	-103493.273 0.002	5200153.357 0.005	N 54 58 44.849982 0.002	W 001 36 59.667461 0.002	125.895 0.007
Northampton	NORT	3912445.278 0.004	-62314.494 0.001	5020095.446 0.004	N 52 15 05.802416 0.002	W 000 54 44.953386 0.002	131.604 0.008
Nottingham	NOTT	3849254.714 0.004	-80460.618 0.002	5068085.2571 0.004	N 52 57 43.896108 0.002	W 001 11 50.906514 0.002	93.840 0.006
Ordnance Survey HQ	OSHQ	4026741.414 0.004	-101963.606 0.001	4928808.0192 0.004	N 50 55 52.613955 0.002	W 001 27 01.842662 0.002	100.412 0.005
Plymouth	PLYM	4060025.024 0.004	-291641.836 0.001	4894189.724 0.004	N 50 26 19.898000 0.002	W 004 06 31.115807 0.002	215.258 0.005
Thurso	THUR	3325995.760 0.005	-216616.082 0.002	5419847.952 0.007	N 58 34 52.344659 0.002	W 003 43 34.707818 0.002	98.658 0.008
Buddon	OS01	3526416.2946 0.003	-171421.0273 0.002	5294098.8297 0.004	N 56 28 42.593057 0.003	W 002 46 58.758763 0.003	57.7976 0.007
Kirkby Stephen	OS08	3713868.4728 0.004	-154772.4674 0.002	5166095.6215 0.005	N 54 26 47.753196 0.002	W 002 23 10.948010 0.002	356.1431 0.008
Solar Pillar Herstmonceux	OS12	4033459.0211 0.003	23626.4888 0.002	4924303.2511 0.005	N 50 52 02.654328 0.001	E 000 20 08.207983 0.002	70.8225 0.006
Observatoire de Calern	GRAS	4581690.9720 0.0000	556114.7705 0.0000	4389360.7260 0.0000	N 43 45 17.053093 0.0000	E 006 55 14.060349 0.0000	1319.3093 0.0000
Kootwijk Observatory	KOSG	3899225.1991 0.0000	396731.8870 0.0000	5015078.3832 0.0000	N 52 10 42.333763 0.0000	E 005 48 34.715041 0.0000	96.8546 0.0000
Onsala	ONSA	3370658.6138 0.0000	711877.0960 0.0000	5349786.9065 0.0000	N 57 23 43.073537 0.0000	E 011 55 31.859128 0.0000	45.5726 0.0000
Reykjavik	REYK	2587384.4087 0.0000	-1043033.5158 0.0000	5716564.0066 0.0000	N 64 08 19.619963 0.0000	W 021 57 19.745568 0.0000	93.0461 0.0000
Villafranca	VILL	4849833.7637 0.0000	-335049.0953 0.0000	4116014.8749 0.0000	N 40 26 36.932901 0.0000	W 003 57 07.127950 0.0000	647.3621 0.0000
Wettzell	WTZR	4075580.6250 0.0000	931853.7439 0.0000	4801568.0746 0.0000	N 49 08 39.111734 0.0000	E 012 52 44.071785 0.0000	666.0197 0.0000

B. Final ETRS89 Coordinates

EUREF GB 2001 Final ETRS89, epoch 2001.55, coordinates. GRS80 Ellipsoid. SE's based on coordinate repeatabilities.

Station Name	Comp ID	X (m) ±se (m)	Y (m) ±se (m)	Z (m) ±se (m)	Lat (dms) ±se (m)	Long (dms) ±se (m)	Height (m) ±se (m)
Carlisle	CARL	3671344.628 0.004	-188441.376 0.001	5194773.916 0.005	N 54 53 43.524012 0.002	W 002 56 17.798639 0.002	93.535 0.006
Carmarthen	CARM	3936214.093 0.004	-296554.390 0.001	4993187.053 0.004	N 51 51 32.072175 0.002	W 004 18 30.689042 0.002	81.345 0.006
Colchester	COLC	3943778.482 0.003	61764.029 0.001	4995617.876 0.004	N 51 53 39.718849 0.002	E 000 53 50.075954 0.002	75.265 0.005
Daresbury	DARE	3811965.603 0.003	-175800.054 0.001	5093615.481 0.004	N 53 20 41.289946 0.001	W 002 38 25.775482 0.002	88.407 0.005
Droitwich	DROI	3909833.018 0.003	-147097.136 0.001	5020322.470 0.003	N 52 15 19.057596 0.002	W 002 09 16.510059 0.002	101.520 0.006
Edinburgh	EDIN	3575928.474 0.005	-205860.629 0.001	5259853.148 0.006	N 55 55 29.217325 0.002	W 003 17 41.251769 0.002	119.030 0.008
Glasgow	GLAS	3578263.479 0.004	-268830.545 0.001	5255394.231 0.004	N 55 51 14.398136 0.002	W 004 17 47.364504 0.002	71.613 0.007
IESSG Nottingham	IESG	3851174.491 0.003	-80151.854 0.001	5066646.994 0.003	N 52 56 26.476036 0.002	W 001 11 32.228349 0.002	98.445 0.005
Inverness	INVE	3427172.399 0.004	-252834.332 0.002	5355255.501 0.005	N 57 29 10.499757 0.001	W 004 13 09.350178 0.002	66.175 0.008
Isle of Man North	IOMN	3716635.705 0.005	-285228.571 0.002	5158273.014 0.005	N 54 19 45.103320 0.002	W 004 23 18.568035 0.002	94.508 0.007
Isle of Man South	IOMS	3737197.099 0.005	-302954.147 0.002	5142476.100 0.004	N 54 05 11.987274 0.002	W 004 38 04.277877 0.002	84.370 0.007
Kings Lynn	KING	3868686.076 0.003	27112.647 0.001	5053896.941 0.003	N 52 45 04.920631 0.002	E 000 24 05.527798 0.002	66.424 0.006
Leeds	LEED	3773717.802 0.003	-109614.456 0.001	5123816.085 0.004	N 53 48 00.774519 0.002	W 001 39 49.650056 0.002	215.605 0.006
Mallaig	MALG	3463463.168 0.005	-353538.282 0.002	5326325.474 0.005	N 57 00 21.840870 0.002	W 005 49 42.120696 0.002	68.486 0.008
Newcastle	NEWC	3667109.225 0.005	-103493.440 0.002	5200153.195 0.005	N 54 58 44.841685 0.002	W 001 36 59.676559 0.002	125.877 0.007
Northampton	NORT	3912445.469 0.004	-62314.669 0.001	5020095.277 0.004	N 52 15 05.794109 0.002	W 000 54 44.962447 0.002	131.589 0.008
Nottingham	NOTT	3849254.906 0.004	-80460.791 0.002	5068085.090 0.004	N 52 57 43.887803 0.002	W 001 11 50.915565 0.002	93.824 0.006
Ordnance Survey HQ	OSHQ	4026741.601 0.004	-101963.784 0.001	4928807.846 0.004	N 50 55 52.605623 0.002	W 001 27 01.851545 0.002	100.399 0.005
Plymouth	PLYM	4060025.202 0.004	-291642.015 0.001	4894189.548 0.004	N 50 26 19.889611 0.002	W 004 06 31.124219 0.002	215.243 0.005
Thurso	THUR	3325995.957 0.005	-216616.238 0.002	5419847.799 0.007	N 58 34 52.336371 0.002	W 003 43 34.716688 0.002	98.636 0.008
Buddon	OS01	3526416.490 0.003	-171421.190 0.002	5294098.671 0.004	N 56 28 42.584761 0.003	W 002 46 58.767716 0.003	57.778 0.007
Kirkby Stephen	OS08	3713868.665 0.004	-154772.636 0.002	5166095.458 0.005	N 54 26 47.744880 0.002	W 002 23 10.956923 0.003	356.126 0.008
Solar Pillar Herstmonceux	OS12	4033459.213 0.003	23626.310 0.002	4924303.080 0.005	N 50 52 02.646038 0.001	E 000 20 08.198800 0.002	70.810 0.006
Observatoire de Calern	GRAS	4581691.1686 0.000	556114.5768 0.000	4389360.5443 0.000	N 43 45 17.044993 0.000	E 006 55 14.050699 0.000	1319.3078 0.000
Kootwijk Observatory	KOSG	3899225.4084 0.000	396731.7127 0.000	5015078.2204 0.000	N 52 10 42.325663 0.000	E 005 48 34.704800 0.000	96.8428 0.000
Onsala	ONSA	3370658.8458 0.000	711876.9385 0.000	5349786.7636 0.000	N 57 23 43.065754 0.000	E 011 55 31.847032 0.000	45.5571 0.000
Reykjavik	REYK	2587384.5824 0.000	-1043033.6467 0.000	5716563.8662 0.000	N 64 08 19.611881 0.000	W 021 57 19.749743 0.000	93.0114 0.000
Villafranca	VILL	4849833.9167 0.000	-335049.2962 0.000	4116014.6742 0.000	N 40 26 36.924451 0.000	W 003 57 07.136005 0.000	647.3586 0.000
Wettzell	WTZR	4075580.8490 0.000	931853.5652 0.000	4801567.9129 0.000	N 49 08 39.103940 0.000	E 012 52 44.060726 0.000	666.0142 0.000