Reprocessing the EUREF GB 2001 GPS campaign

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1 Introduction

This paper details the analysis of the *reprocessing* of the EUREF GB 2001 GPS campaign. The original campaign, carried out by Ordnance Survey, the National Mapping Agency of Great Britain, was ratified by the EUREF 2002 symposium. The reprocessing was necessary due to an error being discovered in the antenna phase centre offsets used in the original campaign.

The GPS data used and the processing methodology employed are unchanged from the original campaign with the exception of the correction to the antenna phase centre offsets. Full details of the original campaign are in the paper presented to EUREF 2002 – [Greaves, Fane 2003], which is available at http://www.euref-iag.net/symposia/book2002/168-184.pdf.

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- The Institute of Engineering Surveying & Space Geodesy (IESSG) at the University of Nottingham, especially Dr. Richard Bingley and Mohammed Alsubaie for invaluable help in isolating the phase centre offset error and in checking the set up of Bernese Software.
- Carine Bruyninx of the EUREF Permanent Network Central Bureau (EPNCB) and Heinz Habrich EPN Analysis Coordinator for advice on which antenna phase centre offsets should be applied.

2 Observations

The EUREF GB 2001 GPS Campaign was based on observations at 30 permanent GPS stations which comprise the Ordnance Survey Active GPS Network, four additional stations and six IGS stations in Europe. In all, data from 40 stations were processed, of which 20 became EUREF GB 2001 stations. A list of the stations included in the processing is given in Table 1 and Figure 1 shows their distribution.

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. 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.

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Table 1. List of stations.

Stn. ID	Station	DOMES No.	Station Description
CARL	Carlisle	13205S001	EUREF GB 2001 COGR station
CARM	Carmarthen	13206S001	EUREF GB 2001 COGR station
COLC	Colchester	13207S001	EUREF GB 2001 COGR station
DARE	Daresbury	13208S001	EUREF GB 2001 COGR station
DROI	Droitwich	13209S001	EUREF GB 2001 COGR station
EDIN	Edinburgh	13217S001	EUREF GB 2001 COGR station
GLAS	Glasgow	13219S001	EUREF GB 2001 COGR station
IESG	IESSG Nottingham	13220S001	Existing EUREF COGR station
INVE	Inverness	13221S001	EUREF GB 2001 COGR station
IOMN	Isle of Man North	13222S001	EUREF GB 2001 COGR station
IOMS	Isle of Man South	13224S001	EUREF GB 2001 COGR station
KING	Kings Lynn	13225S001	EUREF GB 2001 COGR station
LEED	Leeds	13215S001	EUREF GB 2001 COGR station
MALG	Mallaig	13226S001	EUREF GB 2001 COGR station
NEWC	Newcastle	13227S001	EUREF GB 2001 COGR station
NORT	Northampton	13228S001	EUREF GB 2001 COGR station
NOTT	Nottingham	13220S002	EUREF GB 2001 COGR station
OSHQ	Ordnance Survey HQ	13274S002	EUREF GB 2001 COGR station
PLYM	Plymouth	13229S001	EUREF GB 2001 COGR station
THUR	Thurso	13230S001	EUREF GB 2001 COGR station
OS01	Buddon	13296M002	Existing EUREF ground marker station
OS08	Kirkby Stephen	N/A	Existing EUREF ground marker station
OS12	Solar Pillar Herstmonceux	N/A	Existing EUREF ground marker station
GRAS	Observatoire de Calern	10002M006	IGS Reference Station
KOSG	Kootwijk Observatory	13504M003	IGS Reference Station
ONSA	Onsala	10402M004	IGS Reference Station
REYK	Reykjavik	10202M001	IGS Reference Station
VILL	Villafranca	13406M001	IGS Reference Station
WTZR	Wettzell	14201M010	IGS Reference Station
BLAC	Blackpool	N/A	Non EUREF COGR station
BUT1	Butt of Lewis	N/A	Non EUREF COGR station (GLA site)
FLA1	Flamborough Head	N/A	Non EUREF COGR station (GLA site)
LIZ1	Lizard Point	N/A	Non EUREF COGR station (GLA site)
LYN1	Point Lynas	N/A	Non EUREF COGR station (GLA site)
NAS1	Nash Point	N/A	Non EUREF COGR station (GLA site)
NFO1	North Foreland	N/A	Non EUREF COGR station (GLA site)
SCP1	Saint Catherine's Point	N/A	Non EUREF COGR station (GLA site)
SUM1	Sumburgh Head	N/A	Non EUREF COGR station (GLA site)

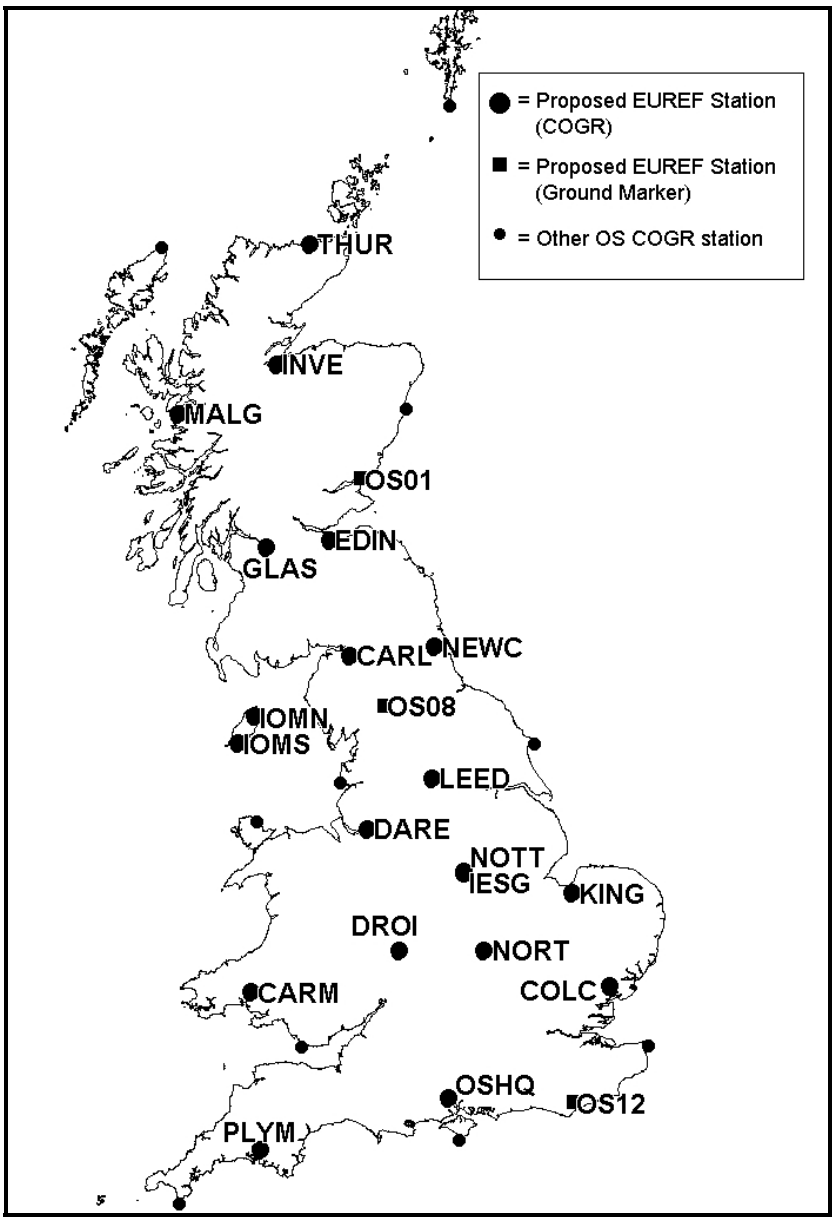

Figure 1. The EUREF GB 2001 campaign map of GB stations

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 2022	00:00:00 12:05:00	12:00:00 23:59:30
22-July-2001	11240	2031 2032	00:00:00 12:05:00	12:00:00 23:59:30
23-July-2001	11241	2041 2042	00:00:00 12:05:00	12:00:00 23:59:30
24-July-2001	11242	2051 2052	00:00:00 12:05:00	12:00:00 23:59:30
25-July-2001	11243	2061 2062	00:00:00 12:05:00	12:00:00 23:59:30

26-July-2001	11244	2071 2072	00:00:00 12:05:00	12:00:00 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

A full list of the GPS receivers and antennas used is given in Table 3.

Table 3. Receiver and 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	NONE
OS08	Kirkby Stephen	LEICA SR520	LEIAT504	NONE
OS12	Solar Pillar	ASHTECH UZ-12	ASH700936E	NONE
GRAS	Observatoire de Calern	ROGUE SNR-12 RM	AOAD/M_T	NONE
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	NONE
VILL	Villafranca	ASHTECH Z-XII3	AOAD/M_T	NONE
WTZR	Wettzell	AOA SNR-8000 ACT	AOAD/M_T	NONE
BLAC	Blackpool	LEICA CRS1000	LEIAT504	LEIS
BUT1	Butt of Lewis	Trimble 4000SSI	TRM33429.00+GP	TCWD
FLA1	Flamborough Head	Trimble 4000SSI	TRM33429.00+GP	TCWD
LIZ1	Lizard Point	Trimble 4000SSI	TRM33429.00+GP	TCWD
LYN1	Point Lynas	Trimble 4000SSI	TRM33429.00+GP	TCWD
NAS1	Nash Point	Trimble 4000SSI	TRM33429.00+GP	TCWD
NFO1	North Foreland	Trimble 4000SSI	TRM33429.00+GP	TCWD
SCP1	Saint Catherine's Point	Trimble 4000SSI	TRM33429.00+GP	TCWD
SUM1	Sumburgh Head	Trimble 4000SSI	TRM33429.00+GP	TCWD

3 The phase centre offset error

The heights of some of the Active stations were first questioned when the IESSG did some analysis on GPS data on behalf of the Environment Agency (EA).

The Active stations initially questioned are not EUREF stations but were included in the EUREF 2001 campaign. These stations are located at lighthouses and run by the General Lighthouse Authority (GLA). They are shown as “Other OS COGR station” on the map at Figure 1 and as “Non EUREF COGR station (GLA site)” in Table 1.

After extensive investigation by both IESSG and Ordnance Survey the cause of the error was traced to the elevation dependant antenna phase centre offset corrections that had been applied to the Trimble antennas at the GLA sites. In the process, it was also discovered that the same problem affected all the other Active stations.

The error in the elevation dependant phase centre offsets occurred when they were transferred from the format in which they are supplied by the IGS and NGS to the format used by Bernese Software.

An example of the IGS / NGS format (from the *igs_01.pcv* file) is shown in Figure 2 and an example of the (correct) Bernese format is shown in Figure 3.

```
123456789112345678921234567893123456789412345678951234567896123456789712345678 98
         0         0         0         0         0         0         0         0
VENDOR          MODEL #               DESCRIPTION                    (AVE) YR/MO/DY
                                                                    |AVE = # in average
 [north]  [ east]  [  up ]                                          | L1 Offset (mm)
 [90]  [85]  [80]  [75]  [70]  [65]  [60]  [55]  [50]  [45]        | L1 Phase at
 [40]  [35]  [30]  [25]  [20]  [15]  [10]  [ 5]  [ 0]              | Elevation (mm)
 [north]  [ east]  [  up ]                                          | L2 Offset (mm)
 [90]  [85]  [80]  [75]  [70]  [65]  [60]  [55]  [50]  [45]        | L2 Phase at
 [40]  [35]  [30]  [25]  [20]  [15]  [10]  [ 5]  [ 0]              | Elevation (mm)

TRIMBLE         TRM33429.00+GP                                      NGS (  8) 97/10/27
       -.2        1.2       74.0
    .0   3.9   7.6  11.1  14.1  16.5  18.3  19.2  19.5  19.1
  18.1  16.6  14.9  13.0  11.5  10.4  10.2    .0    .0
        .6         .9       70.3
    .0    .6   1.4   2.4   3.4   4.4   5.1   5.6   5.8   5.7
   5.3   4.7   3.9   3.0   2.1   1.4    .9    .0    .0
```

Figure 2. Example of igs_01.pcv file format for elevation dependant antenna phase centre offsets.

```
RECEIVER TYPE         ANTENNA TYPE          FROM   TO      TYP   D(Z) D(A)
******************** ******************** ****** ******  ***    ***  ***
TRIMBLE 4000SSI       TRM33429.00+GP             0 999999    1      5  360

    A\Z     0      5     10     15     20     25     30     35     40     45     50     55 ……
L1   0   0.00   3.90   7.60  11.10  14.10  16.50  18.30  19.20  19.50  19.10  18.10  16.60 ……
L2   0   0.00   0.60   1.40   2.40   3.40   4.40   5.10   5.60   5.80   5.70   5.30   4.70 ……
```

Figure 3. Example of the Bernese format for elevation dependant antenna phase centre offsets.

When the Bernese phase centre offset file was being created for the original EUREF GB 2001 processing the order of the elevation dependant corrections was mistakenly reversed. This is because as it was incorrectly assumed that the steps in the Bernese format were in degrees elevation like the *igs_01.pcv* file, but just given in the reverse order. The error was discovered when it was realised that the Bernese angles were in degrees zenith, where 0 degrees zenith = 90 degrees elevation. Therefore, the values in the Bernese format should be in the same order as those in the *igs_01.pcv* file format.

4 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. The reprocessing used the exact same processing strategy as in the original EUREF GB 2001 processing. A full description of the processing strategy is in [Greaves, Fane 2003] so only a summary will be given here. Full details of the phase centre offsets used, reference frame coordinates and transformation to ETRS89 are given after the summary.

4.1 Summary of processing strategy

- Site displacements.
  Ocean tide loading corrections applied. Model FES95 parameters from the AIUB automated service [Schaer 2001]. Solid Earth tides and polar tides according to IERS 1996 standards.
- Orbits.
  Precise IGS orbits (.sp3) and corresponding Earth rotation parameters (.erp) used throughout the processing. Bernese orbit model "B" [Beutler et al 2001] applied – JGM3 gravity model, DE200 planetary ephemeris, elastic Earth tidal corrections to IERS 1996 standards, CSR Texas ocean tide model, general relativistic corrections.
- Data pre-processing.
  Zero difference L_3 code processing to give receiver clock offsets. Single differences formed using the SHORTEST strategy. Data cleaned by removing data < 10° elevation, unpaired observations and small (<5 minutes) data periods. Check for cycle slips and fix is possible using residuals from triple difference solution.
- Troposphere modelling.
  Elevation angle of 10° with elevation dependant weighting used throughout the processing. No a priori troposphere model used – full delay estimated every 2 hours with dry Neill function. Except at IGS stations where computed troposphere parameters from Centre for Orbit Determination in Europe (CODE) were used (*CODyyddd.TRP* files).
- Ionosphere modelling
  Ionosphere effects removed by processing the L_3 linear combination whenever possible. Except at ambiguity resolution stage of processing where the CODE final ionosphere product (*CODwwwwd.ION* files) was used.
- Ambiguity free processing.
  Baseline by baseline processing at the double difference level, L_3 observable. Residuals used to detect outliers.
- Ambiguity resolution.
  Baseline by baseline processing at the double difference level, QIF (Quasi-Ionosphere-Free) algorithm.
- Final network processing.
  Entire network processed in a single run at the double difference level, L_3 observable. Previously resolved ambiguities introduced as integers, unresolved ambiguities pre-eliminated. Minimal constraint to one IGS station (KOSG) and normal equations (*.NEQ* files) saved.
- Normal equation stacking.
  Daily *.NEQ* files combined to produce solution based on whole two weeks of data. First a minimal constraint solution produced (only KOSG fixed) and analysed. Once outliers removed solution constrained to IGS stations to give final ITRF97 solution.

4.2 Antenna phase centre offsets

For obvious reasons particular attention was paid to the antenna phase centre offsets used in the reprocessing! Most of the antenna types used in the network do not have specific offsets in the *igs_01.pcv* file by the IGS and EPN. E.g. there is no specific offset entry in *igs_01.pcv* for the ASH700936E SNOW antenna but there is one for a generic 700936 RADOM which, incidentally, has the same values as all the other ASH700936 variants. Similarly there is no entry for the LEIAT504 LEIS antenna but there is one for the LEIAT504 NONE (without a radome). However a calibration for LEIAT504 LEIS is now available from the NGS (http://www.ngs.noaa.gov/ANTCAL/).

The original EUREF GB 2001 campaign used a mixture of calibrations from the IGS and the NGS. For the reprocessing advice was taken from the EPNCB about which calibration values should be applied and particularly if the radome should be accounted for. The advice of the EPNCB was that the IGS values should be used to ensure the highest possible consistency between EUREF and IGS.

Table 4 shows which offset values from the *igs_01.pcv* file were applied to the various antenna types in the network. Great care was taken to ensure that the offsets from *igs_01.pcv* were correctly transferred to the Bernese format!

Table 4. Antenna phase centre and elevation dependant offsets used in the reprocessing.

Antenna (IGS Code)		Offsets used from *igs_01.pcv* file		
LEIAT504	LEIS	LEICA	LEIAT504	
LEIAT504	NONE	LEICA	LEIAT504	
ASH700936D_M	SNOW	ASHTECH	700936 RADOM	
ASH700936E	SNOW	ASHTECH	700936 RADOM	*
ASH700936E	NONE	ASHTECH	ASH700936E	*
AOAD/M_T	NONE	TURBOROGUE	AOAD/M_T	
AOAD/M_B	DUTD	ROGUE	AOAD/M_B	
AOAD/M_B	OSOD	ROGUE	AOAD/M_B	
TRM33429.00+GP	TCWD	TRIMBLE	TRM33429.00+GP	

* these offsets are identical

4.3 Reference Frame Coordinates

The ITRF97, epoch 1997.00 coordinates of the 6 IGS stations and their corresponding velocities were used 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.

Table 5. ITRF97 coordinates of IGS stations.

IGS Station Coordinates in the ITRF97 at Epoch 1997.00				
Station	**DOMES No.**	**X (m)**	**Y (m)**	**Z (m)**
GRAS	10002M006	4581691.0258	556114.6863	4389360.6849
KOSG	13504M003	3899225.2583	396731.8151	5015078.3414
ONSA	10402M004	3370658.6756	711877.0294	5349786.8684
REYK	10202M001	2587384.5001	-1043033.5002	5716563.9689
VILL	13406M001	4849833.7962	-335049.1807	4116014.8247
WTZR	14201M010	4075580.6968	931853.6663	4801568.0423

IGS Station Velocities from the ITRF97 (Epoch 1997.00) Velocity Field				
Station	**Plate**	**Vx (m/yr)**	**Vy (m/yr)**	**Vz (m/yr)**
GRAS	EURA	-0.0118	0.0185	0.0090
KOSG	EURA	-0.0130	0.0158	0.0092
ONSA	EURA	-0.0136	0.0147	0.0084

REYK	NOAM	-0.0201	-0.0035	0.0083
VILL	EURA	-0.0071	0.0187	0.0110
WTZR	EURA	-0.0158	0.0171	0.0071

IGS Station Coordinates in the ITRF97 at Epoch 2001.55				
Station	**DOMES No.**	**X (m)**	**Y (m)**	**Z (m)**
GRAS	10002M006	4581690.9721	556114.7705	4389360.7259
KOSG	13504M003	3899225.1991	396731.8870	5015078.3833
ONSA	10402M004	3370658.6137	711877.0963	5349786.9066
REYK	10202M001	2587384.4086	-1043033.5161	5716564.0067
VILL	13406M001	4849833.7639	-335049.0956	4116014.8748
WTZR	14201M010	4075580.6249	931853.7442	4801568.0746

4.4 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 $X^E(89) = X^E(t_c)$

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	+ 0.0020 ”
$\dot{R}2_{97}$, rotation in Y	+ 0.0050 ”
$\dot{R}3_{97}$, rotation in Z	- 0.0065 ”
$\dot{X}^E$, estimation of velocity of station in ETRS89	0 (for stable part of Eurasian plate)

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.

5 Processing Results

The mean percentage of resolved ambiguities per session is shown in Figure 4 along with the maximum and minimum percentages. The average overall ambiguity resolution was 78.9%.

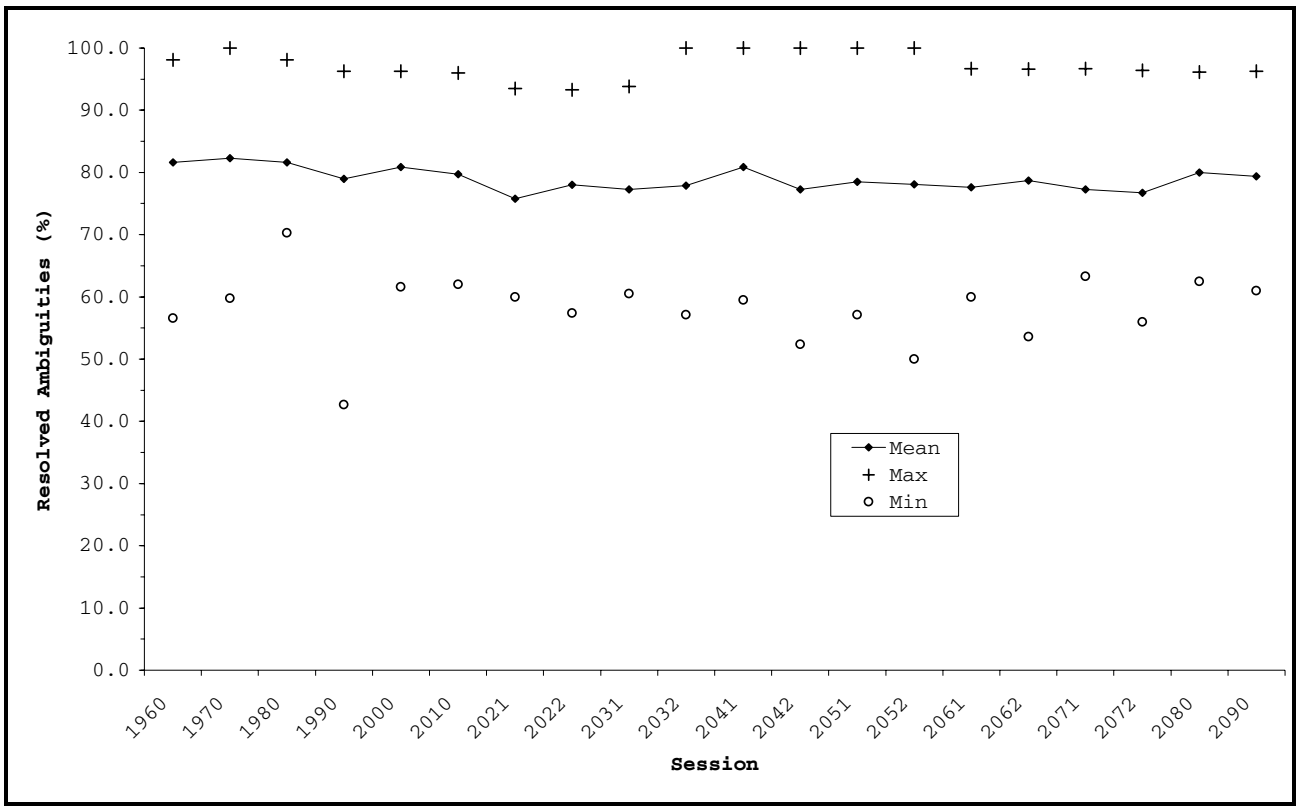

Figure 4. Graph of percentage of ambiguities resolved per session.

The unit weight errors of the individual daily solutions varied between 1.2 mm and 1.3 mm.

5.1 Minimally constrained solution

The unit weight error of the minimally constrained solution was 1.3 mm.

Figure 5 shows the repeatability of all the processed baselines. The increased height RMS of some of the shorter baselines could possibly be due to the fact that the RMS's come from baselines involving the non EUREF GLA stations. These stations are located at lighthouses and the antennas are of regular survey ground plane design, rather than geodetic choke rings.

Outlier detection showed that session 2062 contained more noise than the other sessions and this was causing a large number of stations to be flagged as outliers on this day. Session 2062 was therefore removed from the combined solution. The RMS repeatabilities of the EUREF GB 2001 stations and the IGS fiducial stations from the final accepted minimally constrained solution are shown in Figure 6 and Table 7. The North and East repeatabilities range from 1.3 mm to 3.2 mm with overall RMS's of 1.8 mm and 2.1 mm respectively. The height repeatabilities range from 3.2 mm to 7.6 mm with an overall RMS of 5.1 mm. The figures in Table 7 also indicate the good precision of the minimally constrained solution.

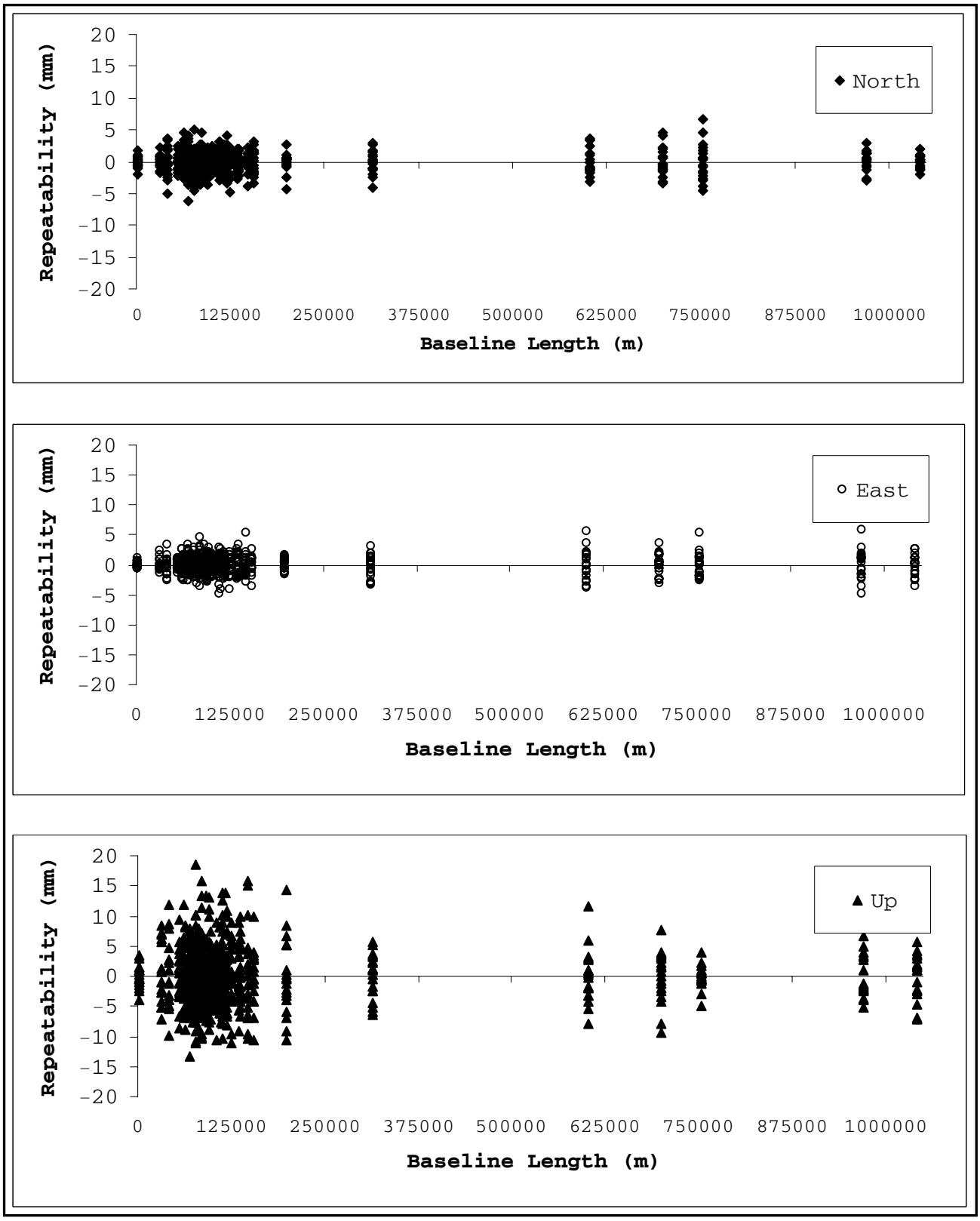

Figure 5. Minimally constrained solution baseline repeatability.

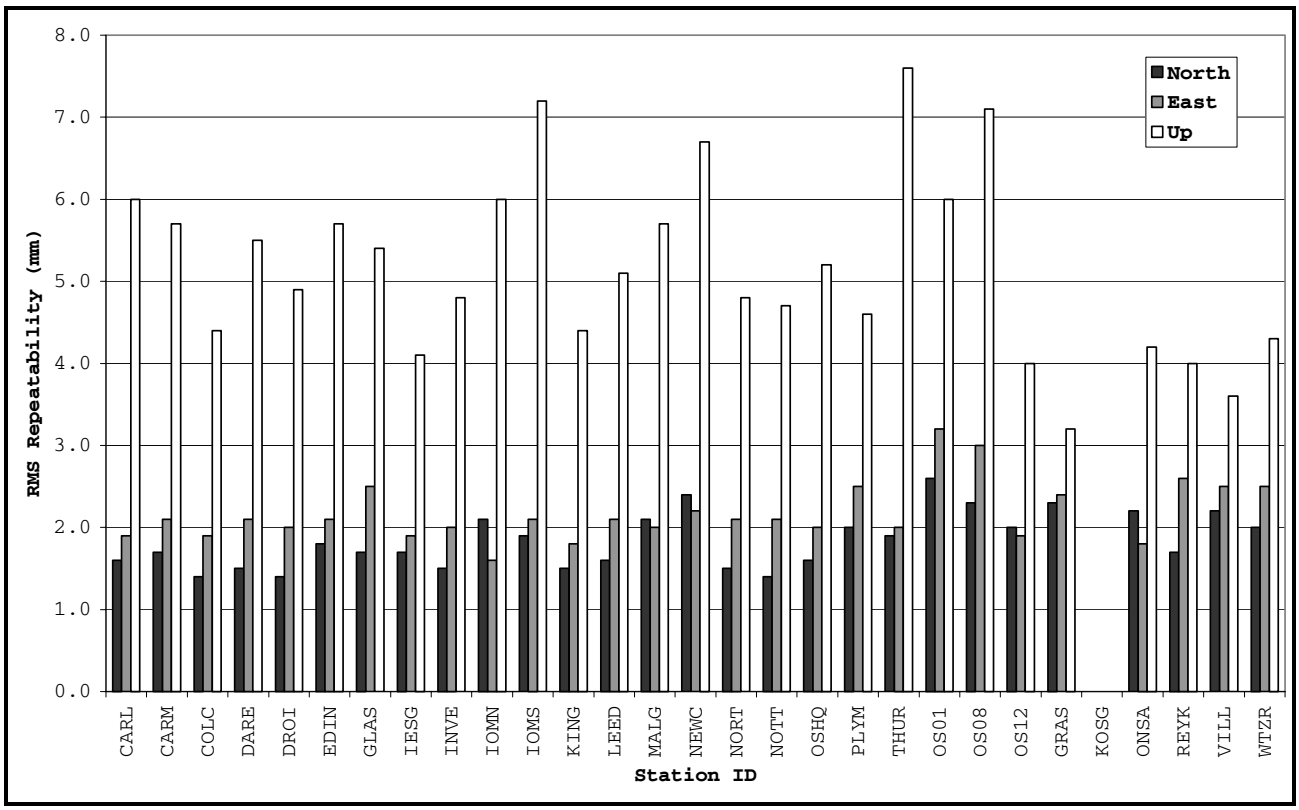

Figure 6. Graph of minimally constrained solution RMS repeatabilities for each station.

Table 7. Minimally constrained solution. Session-to-session RMS coordinate repeatabilities.

Station	North (mm)	East (mm)	Up (mm)
CARL	1.6	1.9	6.0
CARM	1.7	2.1	5.7
COLC	1.4	1.9	4.4
DARE	1.5	2.1	5.5
DROI	1.4	2.0	4.9
EDIN	1.8	2.1	5.7
GLAS	1.7	2.5	5.4
IESG	1.7	1.9	4.1
INVE	1.5	2.0	4.8
IOMN	2.1	1.6	6.0
IOMS	1.9	2.1	7.2
KING	1.5	1.8	4.4
LEED	1.6	2.1	5.1
MALG	2.1	2.0	5.7
NEWC	2.4	2.2	6.7
NORT	1.5	2.1	4.8
NOTT	1.4	2.1	4.7
OSHQ	1.6	2.0	5.2
PLYM	2.0	2.5	4.6
THUR	1.9	2.0	7.6
OS01	2.6	3.2	6.0
OS08	2.3	3.0	7.1
OS12	2.0	1.9	4.0
GRAS	2.3	2.4	3.2
KOSG	Fixed	Fixed	Fixed
ONSA	2.2	1.8	4.2
REYK	1.7	2.6	4.0
VILL	2.2	2.5	3.6

WTZR	2.0	2.5	4.3
Overall RMS	**1.8**	**2.1**	**5.1**

A further test on the quality of the minimally constrained 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 minimally constrained 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.

Table 8. Coordinate recoveries of IGS fiducial stations.

Accepted coordinates. ITRF97 e2001.55. Computed from velocity field.				
Station	**DOMES No.**	**X (m)**	**Y (m)**	**Z (m)**
GRAS	10002M006	4581690.9721	556114.7705	4389360.7259
KOSG	13504M003	3899225.1991	396731.8870	5015078.3833
ONSA	10402M004	3370658.6137	711877.0963	5349786.9066
REYK	10202M001	2587384.4086	-1043033.5161	5716564.0067
VILL	13406M001	4849833.7639	-335049.0956	4116014.8748
WTZR	14201M010	4075580.6249	931853.7442	4801568.0746
Estimated coordinates. ITRF97 e2001.55. Minimally constrained solution.				
Station	**DOMES No.**	**X (m)**	**Y (m)**	**Z (m)**
GRAS	10002M006	4581690.9693	556114.7685	4389360.7319
KOSG	13504M003	3899225.2010	396731.8865	5015078.3823
ONSA	10402M004	3370658.6170	711877.0891	5349786.9005
REYK	10202M001	2587384.4098	-1043033.5086	5716563.9943
VILL	13406M001	4849833.7508	-335049.0885	4116014.8770
WTZR	14201M010	4075580.6343	931853.7391	4801568.0857
Transformation residuals between accepted and estimated coordinates.				
Station	**DOMES No.**	**North (m)**	**East (m)**	**Up (m)**
GRAS	10002M006	0.0064	-0.0016	0.0020
KOSG	13504M003	-0.0021	-0.0007	0.0003
ONSA	10402M004	-0.0048	-0.0077	-0.0042
REYK	10202M001	-0.0039	0.0074	-0.0119
VILL	13406M001	0.0105	0.0062	-0.0089
WTZR	14201M010	0.0012	-0.0071	0.0136

5.2 Constrained Solution

The unit weight error of the constrained solution was 1.3 mm.

The RMS repeatabilities for the constrained solution are shown in Figure 7 and Table 9. The figures in Table 9 are a further indication of the good quality of the solution.

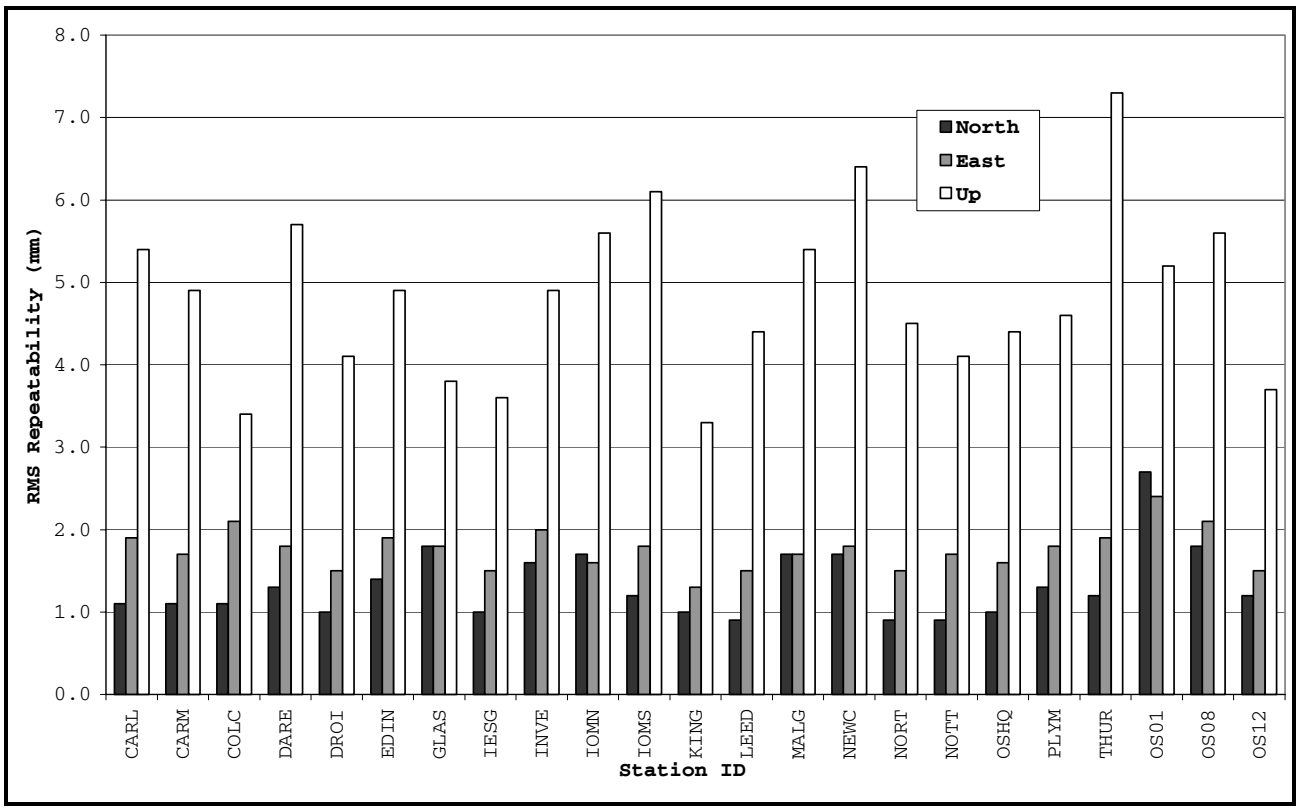

Figure 7. Graph of Constrained Solution RMS Repeatabilities for each station.

Table 9. Constrained network solution. Session-to-session RMS coordinate repeatabilities.

Station	North (mm)	East (mm)	Up (mm)
CARL	1.1	1.9	5.4
CARM	1.1	1.7	4.9
COLC	1.1	2.1	3.4
DARE	1.3	1.8	5.7
DROI	1.0	1.5	4.1
EDIN	1.4	1.9	4.9
GLAS	1.8	1.8	3.8
IESG	1.0	1.5	3.6
INVE	1.6	2.0	4.9
IOMN	1.7	1.6	5.6
IOMS	1.2	1.8	6.1
KING	1.0	1.3	3.3
LEED	0.9	1.5	4.4
MALG	1.7	1.7	5.4
NEWC	1.7	1.8	6.4
NORT	0.9	1.5	4.5
NOTT	0.9	1.7	4.1
OSHQ	1.0	1.6	4.4
PLYM	1.3	1.8	4.6
THUR	1.2	1.9	7.3
OS01	2.7	2.4	5.2
OS08	1.8	2.1	5.6
OS12	1.2	1.5	3.7
Overall RMS	**1.3**	**1.6**	**4.4**

The coordinates of the EUREF GB 2001 stations from the constrained solution were compared with the coordinates from the minimally constrained solution. The results of this comparison are in Table 10. The effect of fixing the 6 IGS fiducial stations has been to systematically shift the unconstrained solution coordinates by -0.3 mm in North, 0.4 mm in East and 0.7 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.

Table 10. Comparison of coordinates between constrained & minimally constrained solutions.

Station	North (mm)	East (mm)	Up (mm)
CARL	-0.4	0.4	0.8
CARM	-0.2	0.3	0.5
COLC	-0.2	0.2	0.4
DARE	-0.2	0.3	0.5
DROI	-0.3	0.2	0.5
EDIN	-0.4	0.5	0.8
GLAS	-0.5	0.7	1.0
IESG	-0.3	0.2	0.5
INVE	-0.4	1.1	1.4
IOMN	-0.3	0.5	0.7
IOMS	-0.4	0.4	0.6
KING	-0.2	0.3	0.5
LEED	-0.2	0.3	0.5
MALG	-0.4	0.7	1.0
NEWC	-0.4	0.3	0.6
NORT	-0.2	0.3	0.5
NOTT	-0.2	0.3	0.5
OSHQ	-0.2	0.2	0.4
PLYM	0.0	0.4	0.5
THUR	-0.8	0.7	1.2
OS01	-0.7	0.7	1.2
OS08	-0.3	0.4	0.7
OS12	-0.3	0.2	0.5
Overall RMS	-0.3	0.4	0.7

The coordinates from the constrained solution were accepted as the final coordinates. A full list of final ITRF97, epoch 2001.55, coordinates (including the non EUREF stations) is given in Annex A.

5.3 Comparison with previous EUREF 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 4.4 above. A full list of final ETRS89, epoch 2001.55 coordinates is given in Annex 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 11.

Table 11. 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.			
Station	**X (m)**	**Y (m)**	**Z (m)**
IESG	3851174.4854	-80151.8556	5066646.9851
OS01	3526416.4844	-171421.1909	5294098.6650
OS08	3713868.6619	-154772.6370	5166095.4537
OS12	4033459.2080	23626.3089	4924303.0718

FBM Project (1999) coordinates and differences. ETRS89.			
Station	**X (m)**	**Y (m)**	**Z (m)**
IESG	3851174.4949	-80151.8583	5066647.0157
OS01	3526416.4889	-171421.1923	5294098.6824
OS08	3713868.6750	-154772.6392	5166095.4810
	North (m)	**East (m)**	**Up (m)**
IESG	0.0108	-0.0025	0.0301
OS01	0.0058	-0.0011	0.0170
OS08	0.0051	-0.0017	0.0299

EUVN97 coordinates and differences. ETRS89.			
Station	**X (m)**	**Y (m)**	**Z (m)**
IESG	3851174.4950	-80151.8500	5066647.0170
OS01	3526416.4860	-171421.1890	5294098.6750
OS08	3713868.6620	-154772.6170	5166095.4440
OS12	4033459.2080	23626.3160	4924303.0820
	North (m)	**East (m)**	**Up (m)**
IESG	0.0116	0.0058	0.0311
OS01	0.0043	0.0020	0.0092
OS08	-0.0051	0.0200	-0.0083
OS12	0.0064	0.0071	0.0080

IESSG daily analysis coordinates. ITRF97 (e2001.46) transformed to ETRS89.			
Station	**X (m)**	**Y (m)**	**Z (m)**
IESG	3851174.4862	-80151.8603	5066646.9922
	North (m)	**East (m)**	**Up (m)**
IESG	0.0035	-0.0047	0.0062

UKGauge96 coordinates and differences. ETRS89.			
Station	**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	0.0031	0.0023	-0.0025
OS12	0.0025	0.0031	0.0111

EUREF EIR/GB 95 coordinates and differences. ETRS89.			
Station	**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	0.0234	-0.0007	0.0165
OS08	0.0213	-0.0020	0.0126

UKGauge93 coordinates and differences. ETRS89.			
Station	**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	0.0039	-0.0078	0.0164
OS12	0.0135	0.0050	0.0101

UKGauge92 coordinates and differences. ETRS89.			
Station	**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	0.0447	-0.0004	0.0090
OS12	0.0349	0.0049	0.0157

EUREF GB92 coordinates and differences. ETRS89.			
Station	**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	0.0181	0.0131	0.0708
OS08	0.0077	0.0081	0.0551
OS12	0.0121	-0.0208	-0.0043

UKGauge91 coordinates and differences. ETRS89.			
Station	**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	0.0285	0.0034	-0.0230
OS12	0.0082	0.0024	0.0173

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 its 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) were 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 (6 mm or better) at stations OS01 and OS12. OS01 also has a recovery generally better than 10 mm in all components with the FBM Project and OS12 recovers to better than 3 mm in plan and 11 mm in height when compared with the UKGauge96 campaign.

Coordinate recovery at station OS08 is not as consistent as at OS01 and OS12. There is a 20 mm discrepancy in the East component when compared to EUVN97 and a 29 mm discrepancy in height when compared to the FBM Project. However the recoveries compared to UKGauge96 are improved – less than 4 mm in all components. The North and East recoveries compared to the FBM Project are good and the 30 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 20 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 an 11 mm difference in North and a 30 mm difference in height. IESG is a permanent geodetic station operated by IESSG at the University of 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. 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 of 6 mm or better 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 discrepancy may be due to differences between the two software packages used to process the observations – Bernese for EUREF GB 2001 and GAS for the FBM Project – and possibly in different antenna calibrations used.

Moving down the comparisons in Table 11 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 22 mm and 14 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 15 mm where as for UKGauge92 the East and Up recoveries are good but the North recoveries are up to 44 mm. Coordinate recoveries from the EUREF GB 92 campaign are better than 20 mm in plan but go up to 70 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. Calculating the RMS of all the differences shows the general level of agreement is around 17 mm in North, 8 mm in East and 25 mm in Up. Calculating the RMS of the more recent campaigns up to and including UKGauge96 gives 6 mm in North, 7 mm in East and 19 mm in Up.

5.4 Comparison with original EUREF GB 2001 campaign

The final ETRS89 coordinates from the reprocessing were compared with the previous EUREF GB 2001 results [Greaves, Fane 2003]. This was to determine the effect of both the correction of the error in the antenna phase center offsets and also the standardisation of the offsets used to those supplied by the IGS.

Table 12 shows the differences in North, East and Up between the two campaigns. In Table 12 the sense of the differences is *from* the reprocessing *to* the original campaign. E.g. a negative Up difference implies the original published station was too low.

Table 12. NEU differences between reprocessing and original campaign, grouped by antenna type.

Station	Antenna		North (mm)	East (mm)	Up (mm)	Mean North (mm)	Mean East (mm)	Mean Up (mm)
KOSG	AOAD/M_B	DUTD	0.0	0.0	-0.1	0.0	0.0	0.0
ONSA	AOAD/M_B	OSOD	-0.1	-0.3	0.0			
GRAS	AOAD/M_T	NONE	0.1	0.0	0.0			
REYK	AOAD/M_T	NONE	0.0	0.3	-0.1			
VILL	AOAD/M_T	NONE	0.2	0.2	-0.1			
WTZR	AOAD/M_T	NONE	-0.1	-0.3	0.0			
IESG	ASH700936D_M	SNOW	0.8	1.2	10.8	0.6	1.4	11.2
DROI	ASH700936E	SNOW	0.2	1.1	11.7			
INVE	ASH700936E	SNOW	-0.1	2.2	12.8			
KING	ASH700936E	SNOW	0.7	1.2	9.6			
LEED	ASH700936E	SNOW	0.5	1.3	11.8			
NEWC	ASH700936E	SNOW	0.4	1.4	12.5			
NORT	ASH700936E	SNOW	0.5	1.1	9.8			
NOTT	ASH700936E	SNOW	0.6	1.1	11.0			
OSHQ	ASH700936E	SNOW	1.0	1.6	13.0			
OS12	ASH700936E	NONE	1.1	1.4	9.2			
BLAC	LEIAT504	LEIS	0.1	0.3	4.9	-0.2	0.6	6.2
CARL	LEIAT504	LEIS	-0.2	0.4	5.3			
CARM	LEIAT504	LEIS	0.1	0.5	6.2			
COLC	LEIAT504	LEIS	-0.3	0.1	4.7			
DARE	LEIAT504	LEIS	0.0	0.3	6.1			
EDIN	LEIAT504	LEIS	-0.3	0.5	5.7			
GLAS	LEIAT504	LEIS	-0.5	0.9	6.5			
IOMN	LEIAT504	LEIS	-0.2	0.4	5.2			
IOMS	LEIAT504	LEIS	-0.1	0.2	5.6			
MALG	LEIAT504	LEIS	-1.0	0.6	7.3			
PLYM	LEIAT504	LEIS	0.3	0.5	5.7			
THUR	LEIAT504	LEIS	-1.0	0.6	7.9			
OS01	LEIAT504	NONE	-1.1	1.0	8.3			
OS08	LEIAT504	NONE	-0.2	0.9	4.9			
BUT1	TRM33429.00+GP	TCWD	-0.2	1.3	-21.3	0.7	0.4	-23.3
FLA1	TRM33429.00+GP	TCWD	1.0	0.0	-26.0			
GIR1	TRM33429.00+GP	TCWD	0.5	0.1	-22.8			
LIZ1	TRM33429.00+GP	TCWD	1.1	1.0	-18.1			
LYN1	TRM33429.00+GP	TCWD	0.8	0.2	-24.1			
NAS1	TRM33429.00+GP	TCWD	0.9	0.3	-24.9			
NFO1	TRM33429.00+GP	TCWD	1.0	0.1	-28.7			
SCP1	TRM33429.00+GP	TCWD	1.1	-0.2	-26.5			
SUM1	TRM33429.00+GP	TCWD	0.0	0.4	-17.2			

As is to be expected, the effect of the antenna phase center offset error on the plan position (North and East) of the stations is negligible and all the major differences are in height.

6 Conclusions

The results in 5.1 (Table 7) show the high level of internal quality of the solution to be 2 mm in North and East and 5 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 small differences between the minimally constrained and the constrained solutions (Table 10) 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 better than 7 mm in North and East and 19 mm in Up. This is despite some larger than expected differences that are explained. Comparison to older campaigns up to 1995 (and up to ITRF93) generally agrees to around 20 to 30 mm.

Comparison with the original EUREF GB 2001 campaign shows that the effect of correcting the error in the antenna phase center offsets has resulted in changes to the station heights. The changes vary from +23 mm for the non EUREF stations with `TRM33429.00+GP  TCWD` antenna to -11 mm for the stations with the `ASH700936` type antennas.

References

Ashkenazi, V., Bingley, R., Codd, B., Cory, M. (1996), 'Results and Analysis of the EUREF EIR/GB 95 GPS Campaign', in Gubler, E. & Hornik, H. (eds), Subcommission for Europe (EUREF), Publication No. 5, Report on the Symposium of the IAG Subcommission for Europe (EUREF) held in Ankara, 22 – 25 May, 1996, Bayerische Kommission für die Internationale Erdmessung, München, Germany.

Beutler, G., Bock, H., Brockmann, E., Dach, R., Fridez, P., Gurtner, W., Hugentobler, U., Ineichen, D., Johnson, J., Meindl, M., Mervart, L., Rothacher, M., Schaer, S., Springer, T., Weber, R. (2001), Bernese GPS Software Version 4.2, Astronomical Institute of the University of Berne, Switzerland.

Boucher, C. & Altamimi, Z. (2001), Specifications for reference frame fixing in the analysis of a EUREF GPS campaign, available from http://lareg.ensg.ign.fr/EUREF/memo.pdf.

Denys, P., Cross, P., Calvert, C. (1995), 'EUREF GB 92 SciNet92 to ETRS transformation redefinition', in Gubler, E. & Hornik, H. (eds), Subcommission for Europe (EUREF), Publication No. 4, Report on the Symposium of the IAG Subcommission for Europe (EUREF) held in Helsinki, 3 – 6 May, 1995, Bayerische Kommission für die Internationale Erdmessung, München, Germany.

Greaves, M., Fane, C. (2003), 'The British EUREF GB 2001 GPS Campaign', in Torres, J. A., Hornik, H. (eds), Subcommission for Europe (EUREF) Publication No. 12, Report on the Symposium of the IAG Subcommision for Europe (EUREF) held in Ponta Delgada, 5 – 8 June 2002, Verlag des Bundesamt für Kartographie und Geodäsie, Frankfurt, Germany.

IESSG (2000), Ordnance Survey FBM Positioning Project: Analysis of GPS Observations, Final Report to Ordnance Survey (OS Contract Number 14305, University of Nottingham, Nottingham, UK.

Ineichen, D., Gurtner, W., Springer, T., Engelhardt, G., Luthardt, J., Ihde, J. (1999), 'EUVN97 Combined Solution', in Gubler, E. & Hornik, H. (eds), Subcommission for Europe (EUREF), Publication No. 7, Volume 2 - Report on the Symposium of the IAG Subcommission for Europe (EUREF) held in Bad Neuenahr-Ahrweiler, June 10 –13, 1998, Bundesamtes für Kartographie und Geodäsie, Frankfurt, Germany.

Schaer, S. (2001), Automatic service for computing BLQ tables, Bernese Software Mail message number 0134, available from ftp://ftp.unibe.ch/aiub/bswmail/bswmail.0134.

A Final ITRF97 Coordinates

EUREF GB 2001 final ITRF97, epoch 2001.55, coordinates. GRS80 Ellipsoid. SE's based on coordinate repeatabilities.																	
Station Name	**Station 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	3671344.433	-188441.209	5194774.075	N	54	53	43.532342		W	2	56	17.789830		93.548		
		0.002	0.002	0.005				0.001					0.002		0.005		
Carmarthen	CARM	3936213.908	-296554.215	4993187.221	N	51	51	32.080550		W	4	18	30.680634		81.355		
		0.002	0.002	0.005				0.001					0.002		0.005		
Colchester	COLC	3943778.283	61764.205	4995618.041	N	51	53	39.727125		E	0	53	50.085304		75.274		
		0.001	0.002	0.003				0.001					0.002		0.003		
Daresbury	DARE	3811965.411	-175799.882	5093615.643	N	53	20	41.298278		W	2	38	25.766691		88.418		
		0.002	0.002	0.005				0.001					0.002		0.006		
Droitwich	DROI	3909832.823	-147096.962	5020322.631	N	52	15	19.065925		W	2	9	16.501284		101.524		
		0.002	0.001	0.004				0.001					0.002		0.004		
Edinburgh	EDIN	3575928.278	-205860.465	5259853.304	N	55	55	29.225651		W	3	17	41.242979		119.043		
		0.002	0.002	0.005				0.001					0.002		0.005		
Glasgow	GLAS	3578263.285	-268830.381	5255394.388	N	55	51	14.406485		W	4	17	47.355947		71.627		
		0.001	0.002	0.004				0.002					0.002		0.004		
IESSG Nottingham	IESG	3851174.293	-80151.683	5066647.152	N	52	56	26.484318		W	1	11	32.219366		98.449		
		0.001	0.001	0.003				0.001					0.002		0.004		
Inverness	INVE	3427172.198	-252834.174	5355255.647	N	57	29	10.508071		W	4	13	9.341602		66.183		
		0.001	0.002	0.005				0.002					0.002		0.005		
Isle of Man North	IOMN	3716635.515	-285228.402	5158273.175	N	54	19	45.111680		W	4	23	18.559531		94.521		
		0.002	0.001	0.006				0.002					0.002		0.006		
Isle of Man South	IOMS	3737196.910	-302953.978	5142476.262	N	54	5	11.995636		W	4	38	4.269422		84.382		
		0.003	0.002	0.006				0.001					0.002		0.006		
Kings Lynn	KING	3868685.875	27112.819	5053897.099	N	52	45	4.928878		E	0	24	5.537059		66.429		
		0.001	0.001	0.003				0.001					0.001		0.003		
Leeds	LEED	3773717.603	-109614.287	5123816.241	N	53	48	0.782813		W	1	39	49.641115		215.610		
		0.002	0.001	0.004				0.001					0.002		0.004		
Mallaig	MALG	3463462.974	-353538.122	5326325.628	N	57	0	21.849238		W	5	49	42.112391		68.500		
		0.002	0.002	0.005				0.002					0.002		0.005		
Newcastle	NEWC	3667109.023	-103493.274	5200153.346	N	54	58	44.849966		W	1	36	59.667539		125.882		
		0.002	0.002	0.006				0.002					0.002		0.006		
Northampton	NORT	3912445.272	-62314.495	5020095.438	N	52	15	5.802401		W	0	54	44.953446		131.594		
		0.002	0.001	0.004				0.001					0.002		0.005		
Nottingham	NOTT	3849254.708	-80460.619	5068085.248	N	52	57	43.896092		W	1	11	50.906574		93.829		
		0.002	0.002	0.004				0.001					0.002		0.004		
Ordnance Survey HQ	OSHQ	4026741.407	-101963.607	4928808.009	N	50	55	52.613924		W	1	27	1.842742		100.399		
		0.002	0.002	0.004				0.001					0.002		0.004		
Plymouth	PLYM	4060025.020	-291641.836	4894189.719	N	50	26	19.897990		W	4	6	31.115837		215.252		
		0.002	0.002	0.004				0.001					0.002		0.005		
Thurso	THUR	3325995.755	-216616.082	5419847.946	N	58	34	52.344692		W	3	43	34.707849		98.650		
		0.003	0.002	0.007				0.001					0.002		0.007		
Buddon	OS01	3526416.289	-171421.028	5294098.823	N	56	28	42.593095		W	2	46	58.758821		57.789		
		0.001	0.002	0.006				0.003					0.002		0.005		
Kirkby Stephen	OS08	3713868.470	-154772.468	5166095.618	N	54	26	47.753202		W	2	23	10.948059		356.138		
		0.002	0.002	0.006				0.002					0.002		0.006		
Solar Pillar Herstmonceux	OS12	4033459.016	23626.487	4924303.243	N	50	52	2.654291		E	0	20	8.207915		70.813		
		0.001	0.002	0.004				0.001					0.002		0.004		
Observatoire de Calern	GRAS	4581690.972	556114.771	4389360.726	N	43	45	17.053090		E	6	55	14.060350		1319.309		
		0.000	0.000	0.000				0.000					0.000		0.000		
Kootwijk Observatory	KOSG	3899225.199	396731.887	5015078.383	N	52	10	42.333765		E	5	48	34.715040		96.855		
		0.000	0.000	0.000				0.000					0.000		0.000		
Onsala	ONSA	3370658.614	711877.096	5349786.907	N	57	23	43.073541		E	11	55	31.859141		45.573		
		0.000	0.000	0.000				0.000					0.000		0.000		
Reykjavik	REYK	2587384.409	-1043033.516	5716564.007	N	64	8	19.619964		W	21	57	19.745585		93.046		
		0.000	0.000	0.000				0.000					0.000		0.000		
Villafranca	VILL	4849833.764	-335049.096	4116014.875	N	40	26	36.932897		W	3	57	7.127957		647.362		
		0.000	0.000	0.000				0.000					0.000		0.000		
Wettzell	WTZR	4075580.625	931853.744	4801568.075	N	49	8	39.111736		E	12	52	44.071794		666.020		
		0.000	0.000	0.000				0.000					0.000		0.000		
Blackpool	BLAC	3771798.664	-200342.006	5122306.981	N	53	46	44.805185		W	3	2	25.629010		64.956		
		0.002	0.001	0.005				0.001					0.002		0.005		
Butt of Lewis	BUT1	3319367.561	-364169.656	5416049.201	N	58	30	56.181070		W	6	15	39.284056		115.075		
		0.001	0.002	0.004				0.002					0.002		0.004		
Flamborough Head	FLA1	3746732.229	-5082.905	5144448.486	N	54	7	0.673217		W	0	4	39.823534		86.825		
		0.002	0.002	0.004				0.001					0.002		0.005		
Girdle Ness	GIR1	3466836.855	-124006.403	5334407.848	N	57	8	20.498814		W	2	2	54.808084		108.658		
		0.002	0.002	0.006				0.002					0.002		0.007		
Lizard Point	LIZ1	4094405.417	-372839.398	4860027.712	N	49	57	36.229270		W	5	12	10.957683		124.300		
		0.003	0.002	0.006				0.002					0.002		0.007		
Point Lynas	LYN1	3798969.365	-284924.369	5098371.112	N	53	24	58.634726		W	4	17	21.041947		100.821		
		0.002	0.002	0.005				0.002					0.002		0.006		
Nash Point	NAS1	3979694.776	-246984.003	4961571.265	N	51	24	2.824263		W	3	33	4.611936		112.411		

		0.001	0.002	0.004				0.002				0.002		0.004
North Foreland	NFO1	3988362.875	100576.526	4959734.319	N	51	22	28.101156	E	1	26	40.379823	99.481	
		0.001	0.002	0.003				0.002				0.002		0.003
St. Catherines Point	SCP1	4057626.639	-91926.021	4903773.343	N	50	34	32.297054	W	1	17	52.154859	94.694	
		0.001	0.002	0.005				0.002				0.002		0.005
Sumburgh Head	SUM1	3210451.629	-71446.323	5492461.518	N	59	51	14.764887	W	1	16	29.519335	149.937	
		0.002	0.002	0.005				0.001				0.002		0.006

B Final ETRS89 Coordinates

EUREF GB 2001 final ETRS89, epoch 2001.55, coordinates. GRS80 Ellipsoid. SE's based on coordinate repeatabilities.																			
Station Name	**Station 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	3671344.624 0.002	-188441.377 0.002	5194773.912 0.005	N	54	53	43.524020 0.001				W	2	56	17.798663 0.002				93.530 0.005
Carmarthen	CARM	3936214.089 0.002	-296554.390 0.002	4993187.048 0.005	N	51	51	32.072171 0.001				W	4	18	30.689067 0.002				81.339 0.005
Colchester	COLC	3943778.479 0.001	61764.029 0.002	4995617.873 0.003	N	51	53	39.718861 0.001				E	0	53	50.075951 0.002				75.260 0.003
Daresbury	DARE	3811965.600 0.002	-175800.054 0.002	5093615.476 0.005	N	53	20	41.289945 0.001				W	2	38	25.775496 0.002				88.401 0.006
Droitwich	DROI	3909833.011 0.002	-147097.137 0.001	5020322.461 0.004	N	52	15	19.057590 0.001				W	2	9	16.510119 0.002				101.508 0.004
Edinburgh	EDIN	3575928.470 0.002	-205860.629 0.002	5259853.143 0.005	N	55	55	29.217336 0.001				W	3	17	41.251797 0.002				119.024 0.005
Glasgow	GLAS	3578263.475 0.001	-268830.545 0.002	5255394.226 0.004	N	55	51	14.398153 0.002				W	4	17	47.364557 0.002				71.607 0.004
IESSG Nottingham	IESG	3851174.485 0.001	-80151.856 0.001	5066646.985 0.003	N	52	56	26.476011 0.001				W	1	11	32.228415 0.002				98.434 0.004
Inverness	INVE	3427172.392 0.001	-252834.334 0.002	5355255.490 0.005	N	57	29	10.499761 0.002				W	4	13	9.350308 0.002				66.162 0.005
Isle of Man North	IOMN	3716635.702 0.002	-285228.571 0.001	5158273.010 0.006	N	54	19	45.103328 0.002				W	4	23	18.568055 0.002				94.502 0.006
Isle of Man South	IOMS	3737197.096 0.003	-302954.147 0.002	5142476.095 0.006	N	54	5	11.987277 0.001				W	4	38	4.277888 0.002				84.364 0.006
Kings Lynn	KING	3868686.071 0.001	27112.645 0.001	5053896.933 0.003	N	52	45	4.920607 0.001				E	0	24	5.527733 0.001				66.414 0.003
Leeds	LEED	3773717.795 0.002	-109614.457 0.001	5123816.075 0.004	N	53	48	0.774504 0.001				W	1	39	49.650129 0.002				215.593 0.004
Mallaig	MALG	3463463.163 0.002	-353538.283 0.002	5326325.469 0.005	N	57	0	21.840901 0.002				W	5	49	42.120734 0.002				68.479 0.005
Newcastle	NEWC	3667109.218 0.002	-103493.442 0.002	5200153.184 0.006	N	54	58	44.841672 0.002				W	1	36	59.676635 0.002				125.864 0.006
Northampton	NORT	3912445.464 0.002	-62314.670 0.001	5020095.269 0.004	N	52	15	5.794093 0.001				W	0	54	44.962503 0.002				131.580 0.005
Nottingham	NOTT	3849254.900 0.002	-80460.792 0.002	5068085.081 0.004	N	52	57	43.887785 0.001				W	1	11	50.915623 0.002				93.813 0.004
Ordnance Survey HQ	OSHQ	4026741.594 0.002	-101963.785 0.002	4928807.836 0.004	N	50	55	52.605591 0.001				W	1	27	1.851626 0.002				100.386 0.004
Plymouth	PLYM	4060025.199 0.002	-291642.015 0.002	4894189.543 0.004	N	50	26	19.889601 0.001				W	4	6	31.124246 0.002				215.238 0.005
Thurso	THUR	3325995.952 0.003	-216616.239 0.002	5419847.793 0.007	N	58	34	52.336405 0.001				W	3	43	34.716723 0.002				98.628 0.007
Buddon	OS01	3526416.484 0.001	-171421.191 0.002	5294098.665 0.006	N	56	28	42.584796 0.003				W	2	46	58.767775 0.002				57.769 0.005
Kirkby Stephen	OS08	3713868.662 0.002	-154772.637 0.002	5166095.454 0.006	N	54	26	47.744886 0.002				W	2	23	10.956974 0.002				356.121 0.006
Solar Pillar Herstmonceux	OS12	4033459.208 0.001	23626.309 0.002	4924303.072 0.004	N	50	52	2.646002 0.001				E	0	20	8.198730 0.002				70.801 0.004
Observatoire de Calern	GRAS	4581691.169 0.000	556114.577 0.000	4389360.544 0.000	N	43	45	17.044991 0.000				E	6	55	14.050700 0.000				1319.308 0.000
Kootwijk Observatory	KOSG	3899225.408 0.000	396731.713 0.000	5015078.220 0.000	N	52	10	42.325665 0.000				E	5	48	34.704800 0.000				96.843 0.000
Onsala	ONSA	3370658.846 0.000	711876.939 0.000	5349786.764 0.000	N	57	23	43.065758 0.000				E	11	55	31.847048 0.000				45.557 0.000
Reykjavik	REYK	2587384.582 0.000	-1043033.647 0.000	5716563.866 0.000	N	64	8	19.611882 0.000				W	21	57	19.749762 0.000				93.011 0.000
Villafranca	VILL	4849833.917 0.000	-335049.296 0.000	4116014.674 0.000	N	40	26	36.924446 0.000				W	3	57	7.136015 0.000				647.359 0.000
Wettzell	WTZR	4075580.849 0.000	931853.565 0.000	4801567.913 0.000	N	49	8	39.103942 0.000				E	12	52	44.060738 0.000				666.014 0.000
Blackpool	BLAC	3771798.853 0.002	-200342.176 0.001	5122306.815 0.005	N	53	46	44.796849 0.001				W	3	2	25.637763 0.002				64.939 0.005
Butt of Lewis	BUT1	3319367.753 0.001	-364169.812 0.002	5416049.046 0.004	N	58	30	56.172750 0.002				W	6	15	39.292359 0.002				115.052 0.004
Flamborough Head	FLA1	3746732.426 0.002	-5083.075 0.002	5144448.323 0.004	N	54	7	0.664948 0.001				W	0	4	39.832869 0.002				86.809 0.005
Girdle Ness	GIR1	3466837.054 0.002	-124006.564 0.002	5334407.692 0.006	N	57	8	20.490537 0.002				W	2	2	54.817233 0.002				108.637 0.007
Lizard Point	LIZ1	4094405.591 0.003	-372839.578 0.002	4860027.534 0.006	N	49	57	36.220859 0.002				W	5	12	10.965890 0.002				124.285 0.007
Point Lynas	LYN1	3798969.550 0.002	-284924.540 0.002	5098370.944 0.005	N	53	24	58.626365 0.002				W	4	17	21.050449 0.002				100.803 0.006
Nash Point	NAS1	3979694.959	-246984.180	4961571.091	N	51	24	2.815893				W	3	33	4.620481				112.396

		0.001	0.002	0.004				0.002				0.002		0.004
North Foreland	NFO1	3988363.070 0.001	100576.349 0.002	4959734.150 0.003	N	51	22	28.092902 0.002	E	1	26	40.370412 0.002		99.469 0.003
St. Catherines Point	SCP1	4057626.825 0.001	-91926.200 0.002	4903773.170 0.005	N	50	34	32.288722 0.002	W	1	17	52.163749 0.002		94.681 0.005
Sumburgh Head	SUM1	3210451.834 0.002	-71446.476 0.002	5492461.370 0.005	N	59	51	14.756662 0.001	W	1	16	29.528858 0.002		149.914 0.006