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Assessment of interferometric SAR DEM for UK National mapping

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Abstract

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High resolution DEMs at 10m and 30m have been created from SAR interferometric tandem pairs over 3 areas in the UK to assess the potential of this technology for UK National Mapping as part of an Applications Demonstration Programme (ADP) funded by the Ordnance Survey R (OS) and the BNSC. The UCL 3D Image Maker (IfSAR) for DEM generation has been employed (described by Muller, Mandanayake, Upton - Fringe 96) and OS National Mapping products have been used to provide a quantitative assessment of accuracy as well as for phase flattening.
The 3 areas include the city of St Albans, Herts and the M25/M1 motorway junctions; Mablethorpe, Lincolnshire and an area within the Lake District. These areas have been selected for studying the effects of urban buildings and topography (St Albans); for assessment of the potential of IfSAR-DEMs for coastal flat regions (Mablethorpe); for studying the effects of topography (Lake District) and for studying the potential of IfSAR-DEMs to measure topography over narrow cuttings associated with new road developments. System effects studied include the effect of winter vs summer; day vs night; atmospheric effects as well as baseline (Bperp) separation. Results of the quantitative assessment for St Albans are presented here.
Keywords: SAR Interferometry, DEM, UK National mapping

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Introduction

The UK is one, if not the most, well mapped countries in the world with primary digital mapping coverage from maps of scale 1:1250 up to 1:10 000 including a National Height dataset based on photogrammetric contour surveys of the underlying terrain surface with 5m and 10m contour interval and a derived gridpoint interpolated 10m DEM both known as the Land-Form PROFILE **(TM)** data-set. PROFILE **(TM)** contours are at 10m intervals in mountainous areas and 5m in all other areas.

Murray et al., 1996 recently described a number of studies which are being conducted as part of a BNSC Application Demonstrator Programme under OS and BNSC sponsorship at UCL and for land use only at the University of Southampton. The LANDMASS project is evaluating remote sensing data sources for applications in topographic mapping, Digital Elevation Models, Building and 3D Urban modelling and land use.

Specifically for DEMs, the ERS tandem IfSAR data is being evaluated as part of the following investigations:

automatic detection of changes in the terrain surface
remodelling the surface following major engineering works (e.g. highways)
improving the surface elevation resolution where 5m and 10m contours are inappropriate, especially flat regions which may be sensitive to flooding

Existing topographic data (50m OS Land-Form PANORAMA **(TM)**) is used in order to phase flatten the ERS interferograms and so concentrate on evaluating where and why there are differences between the IfSAR-DEM and existing OS DEM products derived from the digitised 1:10 000 map contours.

In order to extend this study to a general study of DEM densification, a 100m degraded version of the 50m DEM has also been used for phase flattening in an attempt to evaluate what the effect of using medium scale resolution grids such as those used by the US National Intelligence Mapping Agency (NIMA, part of which was formerly known as the Defence Mapping Agency) for DTED DMA, 1990 could have on automating higher resolution DEM production using ERS tandem interferometry if and when these data may become available globally (see Muller, this workshop).

SAR interferometry is now gaining increasing acceptance as a spaceborne technique for rapid and potentially accurate determination of topographic information. As the use of such SAR sensors increases and systems to extract IfSAR-DEMs become more automated and reliable, it is likely that their use will become more widespread.

Therefore, it is important to evaluate such systems and understand their limitations and strengths in order to get the best final DEM product quality. In this paper, we make a quantitative quality assessment of the accuracy which can be achieved by terrain densification using IfSAR pairs from the ERS tandem mission. Qualitative remarks will also be made concerning the potential use of ERS SAR from detecting narrow cutting and it 's use for updating existing low resolution DEM to produce high resolution DEMs.

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Methods

Muller, Mandanayake, Upton (this workshop) describe the UCL- 3DIM (IfSAR) processing system developed at UCL. IfSAR-DEMs can be produced using either the WGS84 ellipsoid, a coarse DEM or a fine DEM resampled all of which can be resampled to the spacing required for the final output IfSAR-DEM. Currently, nearest neighbour interpolation is used for terrain densification which can cause small artifacts.

All phase unwrapping (loc.cit.) and phase-to-height conversion operations are done in ground range which is considerably different to previous approaches. Precision state vectors from the German D-PAF have been used to provide accurate planimetric geocoding whose accuracy from our experiments appears to be well within the final 30m DEM spacing.

The final IfSAR-DEM produced at either 10m or 30m grid-spacing is compared statistically at each and every elevation gridpoint with the OS 10m grid using the techniques described in Day and Muller, 1989 . A example of the phase coherence is shown and statistics are given.

Data set description

The SAR data used in this study are all night-time passes of two ERS1/2 tandem and two ERS2 35-day repeat passes over St Albans. The location of the frames are shown in Figure 1 over a coarser DEM and basic parameters given for each data-set are shown in Table 1. This test area covers a part of the M25 motorway and large parts of the built-up area in St Albans and North London.

Accurate determination of the SAR acquisition geometry is required for several of the interferometric processing steps of the UCL-3DIM (IfSAR) such as phase flattening using coarser DEM and geocoding. Precision state orbital vectors from the D-PAF were used for geocoding and phase flattening.

Phase flattening for each image pair was done using three different resolution coarser DEMs (based on the supplied 50m OS DEM) to produce higher resolution IfSAR DEMs. Resolution of the coarser DEMs used are:

50m OS dem resampled to 1/10000 deg (~10m) to produce IfSAR DEM at 1/10 000 deg
50m OS dem resampled to 1 arc-second (~30m) to produce IfSAR DEM at 1 second
50m OS degraded resampled to 3 arc-seconds (~100m)

Satellite	Orbit of	Frame	Date	Latitude extent/deg	Longitude extent/deg	Bperp/m	Day/Night	MODE
ERS1	23006	1035	08/12/95	51.30 - 52.38	-1.56 - 0.16	217	Night	Tandem
ERS2	3333	1035	09/12/95	51.30 - 52.38	-1.56 - 0.16	217	Night	Tandem
ERS1	22505	1035	03/11/95	51.30 - 52.38	-1.56 - 0.16	-141	Night	Tandem
ERS2	2832	1035	04/11/95	51.30 - 52.38	-1.56 - 0.16	-141	Night	Tandem
ERS2	2832	1035	04/11/95	51.30 - 52.38	-1.56 - 0.16	206	Night	35 day
ERS2	3333	1035	09/12/95	51.30 - 52.38	-1.56 - 0.16	206	Night	35 day

Table 1. ERS Image details

Figure 2. St Albans, SAR Geocoded Amplitude images
Four tiled image, DEM used to geocode is OS 50m at 1/10000 deg grid

Top Left: ERS1 Orbit:22505 Date: 03/11/95 time: Night

Top Right: ERS1 Orbit:23006 Date: 08/11/95 time: Night

Bottom Left: ERS2 Orbit:2832 Date: 04/11/95 time: Night

Bottom Right: ERS2 Orbit:3333 Date: 09/11/95 time: Night

Figure 3(a-d). St Albans, Input DEMs for phase flattening and DEM comparison

(a) 10m OS DEM (used for comparison)

(b) 50m OS DEM 10m gird(used for flattening)

(c) 50m OS DEM 30m gird(used for flattening)

(d) 100m OS DEM 30m gird (used for flattening)

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Results

Figure 2 shows 4 SAR amplitude images for 2 of the ERS tandem pairs. Notice the distinct dark linear feature associated with the M25 motorway in this figure which goes from West to East and the bright urban ribbon development along the M1 from South to North.

The ground truth OS DEMs are shown in Figure 3. The reduction in resolution between the 10m Land-Form PROFILE and 50m Land- Form PANORAMA products is easily visible as are the artifacts associated with grid-point interpolation of contours.

Figure 4a shows the flattened interferometric phase, Figure 4b the phase coherence and Figure 4c the unwrapped phase for the tandem image pair (orbits 23006 and 3333) using the UCL-3DIM (IfSAR) system. Figure 4c also includes the digital map vector data taken from the 1:1250 map scale series which clearly shows the motorway features as well as the built-up areas. The 50m DEM interpolated to 10m was used to flatten the interferogram. Figures 4a-4c all clearly shows the M25 Motorway Junction with the M1 as bright features as well as the underpass. Neither of these features in visible in any of the OS DEMs (see Figure 3). Pixels that cannot be unwrapped or have too low a phase coherence are shown in black (figure 4b) and are not used in the unwrapped phase to DEM transformation. They are filled by the input 10m (derived from 50m interpolated) DEM although the 10m DEM could have been used instead.

Figure 5a shows the 10m IfSAR DEM that was produced from the ground-range unflattened interferogram. It should be closely compared with the OS 10m DEM (Figure 3a). The overall morphological structure is maintained but there are a great deal more details present aside from the aforementioned roads. Some of these details may be the result of phase noise.

Three IfSAR DEM were produced for this tandem image pair and compared against the 10m OS DEM and their statistics are shown in tables 2-3 with a histogram plot comparison of elevations in Graph 1.

Table 4 shows the elevation difference statistics for all 9 DEMs created from the 3 pairs. Notice how the error sharply goes up for the second pair (23006/3333) when degraded 100m DEMs are used for phase flattening and the much poorer accuracy and coverage of the 35-day repeat ERS-2 derived IfSAR-DEM (2832/3333). However, even for the 35-day repeat the overall elevation rms is around 12m which is comparable to SPOT (Muller, Mandanayake, Upton) for a vegetated area.

Figure 5b shows an example DEM elevation difference image between the IfSAR-DEM and the OS 10m DEMs. Note the apparent tilt across the data-set. This may be due to residual errors in the orbital state vectors. It may be possible to reduce these systematic errors in future through the use of Ground Control Points. Differences in elevation may be due to buildings, deciduous tree-trunks and coniferous tree canopies (the DEMs were produced from late Autumn data, see Table 1).

DEM	**Number of Points**	**Min.**	**Mean**	**Max.**	**RMS**	**SD**
OS 10m	260000	57.890	85.258	136.580	86.516	14.697
OS 50m in 10m grid	260000	58.000	85.158	134.000	86.429	14.768
OS 50m in 30m grid	29078	58.000	85.221	134.000	86.464	14.608
OS 100m in 30m grid	29078	58.000	85.080	134.000	86.342	14.707

Table 2. St Albans, OS DEM Elevation statistics coarse DEMs and 10m DEM

Input DEM Resolution/m	**Output DEM DEM Resolution/m**	**Number of Points**	**Min.**	Mean	Max.	RMS	SD
50	10	260000	-12.030	0.100	7.710	1.806	1.804
50	30	29078	-25.950	0.087	29.800	6.098	6.097
100	30	29078	-24.950	0.227	39.590	6.301	6.297

Table 3. St Albans, Input DEM - 10M OS DEM Elevation difference statistics for coarser DEM used for phase flattening

Image Pair	**Flatten DEM / output DEM Resolution/m**	**Number of Points**	**Min.**	Mean	Max.	RMS	SD
22505/2832	50m/10m	260000	27.085	72.848	161.638	74.857	17.224
22505/2832	50m/30m	29078	28.638	72.896	163.362	74.918	17.288
22505/2832	100m/30m	29078	26.723	73.055	163.362	75.044	17.167
23006/3333	50m/10m	260000	36.392	81.501	153.155	82.521	12.934
23006/3333	50m/30m	29078	36.392	80.916	142.155	81.925	12.817
23006/3333	100m/30m	29078	36.297	86.985	151.182	88.130	14.162
2832/3333	50m/10m	260000	35.845	80.889	156.608	82.706	17.237
2832/3333	50m/30m	29078	35.845	80.812	156.608	82.577	16.982
2832/3333	100m/30m	29078	35.845	81.104	156.155	82.779	16.570

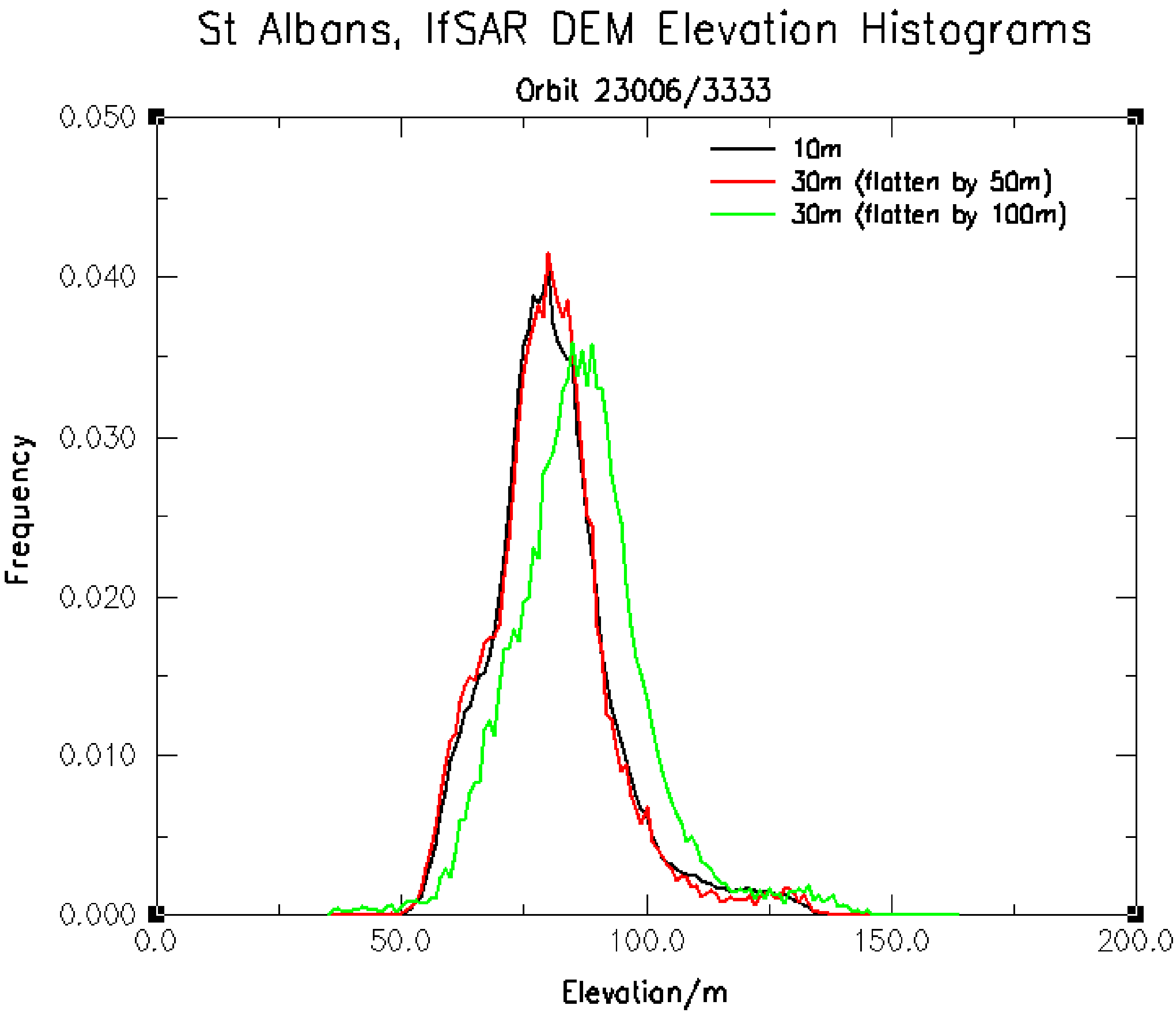
Table 4. St Albans, IfSAR DEM Elevation statistics

Image Pair	**Flatten DEM / output DEM Resolution/m**	**Number of Points**	**Min.**	Mean	Max.	RMS	SD	% of points filled
22505/2832	50m/10m	255133	-24.267	-0.639	49.628	7.192	7.164	1.87
22505/2832	50m/10m	28516	-33.302	-0.661	56.832	8.687	8.662	1.93
22505/2832	100m/30m	27801	-57.527	-0.831	56.832	8.454	8.414	4.39
23006/3333	50m/10m	257802	-23.295	-0.786	31.223	5.759	5.705	0.85
23006/3333	50m/30m	28794	-46.548	-1.436	42.073	7.812	7.679	0.98
23006/3333	100m/30m	28225	-57.223	4.745	39.635	10.036	8.843	2.93
2832/3333	50m/10m	223789	-24.108	-0.050	32.941	10.617	10.617	13.93
2832.3333	50m/30m	25021	-45.599	-0.206	49.505	12.153	12.152	13.95
2832/3333	100m/30m	20911	-54.047	-0.763	45.423	11.859	11.835	28.09

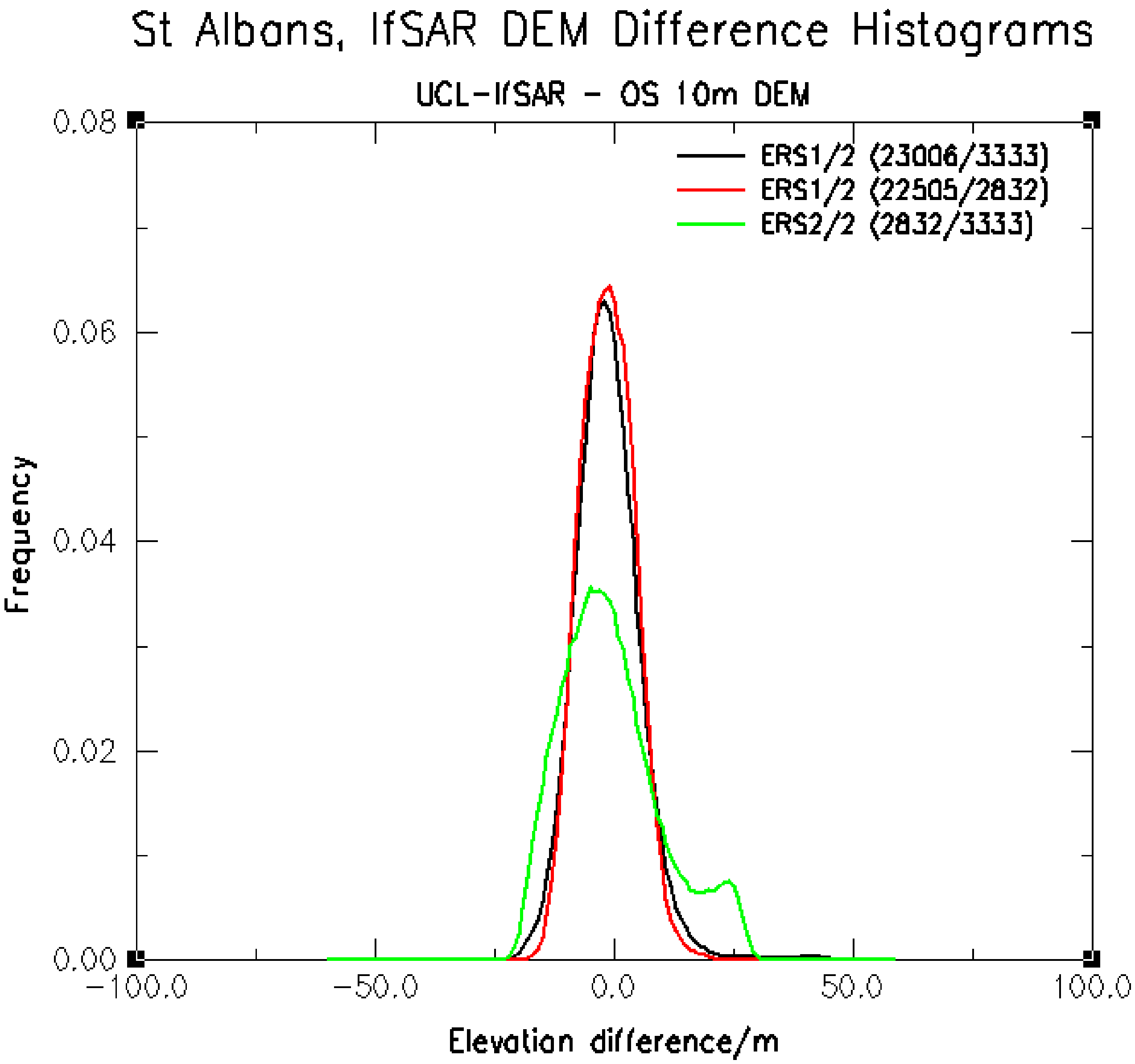
Table 5. St Albans, IfSAR - OS 10M DEM Elevation difference statistics

Image Pair	Number of Points	Min.	Mean	Max.	RMS	SD
22505/2832	260000	0.00	54.37	94.00	56.80	16.45
23006/3333	260000	0.00	44.99	92.00	47.07	13.85
2832/3333	260000	0.00	33.25	93.00	37.27	16.85

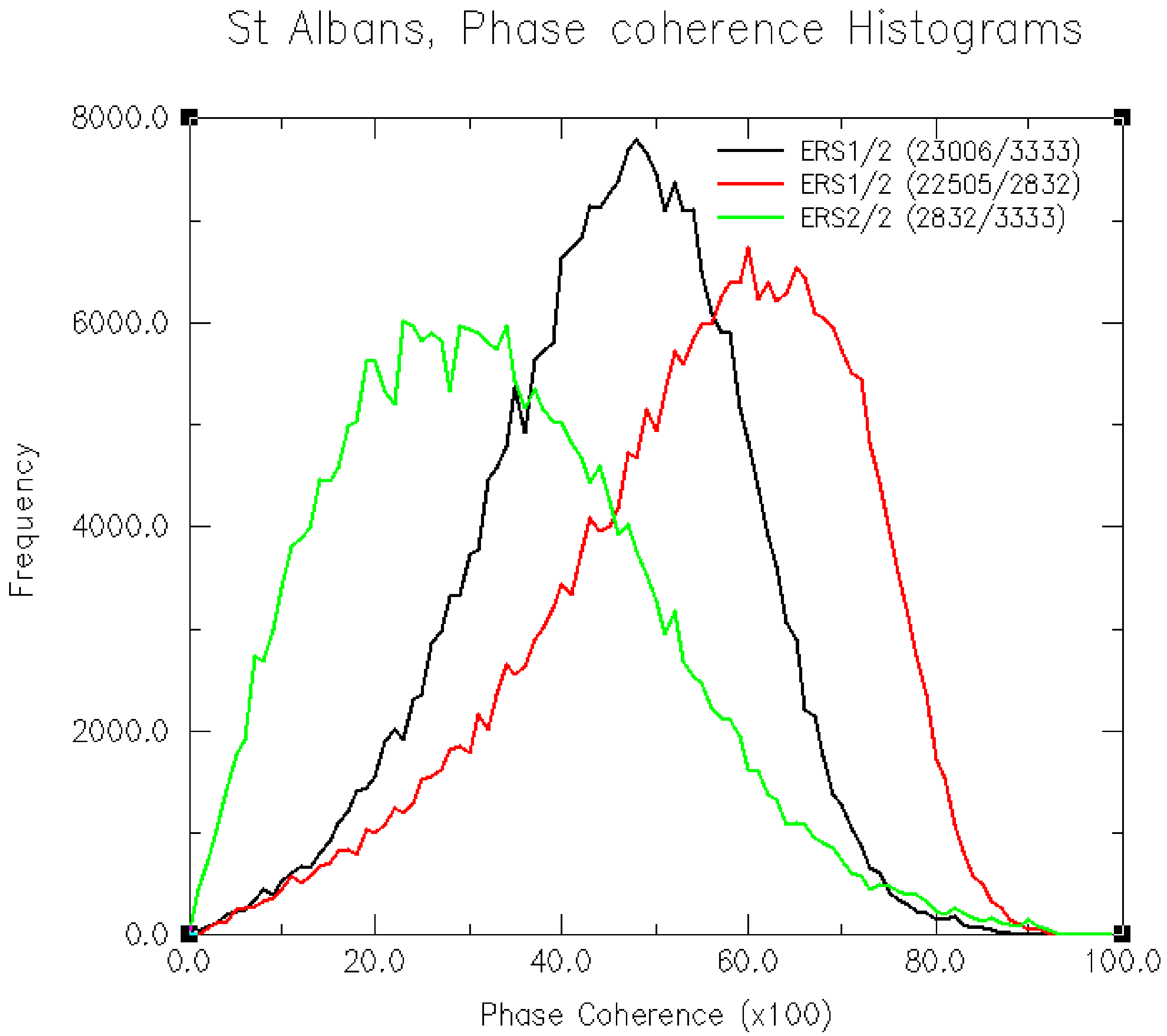
Table 6. St Albans, Phase coherence statistics



Graph 1. St Albans, DEM Elevation Histogram for Orbit 23006/3333



Graph 2. St Albans, 10m DEM Elevation difference Histogram Orbit 23006/3333,22505/2832 and 2832/3333



Graph 3. St Albans, Phase coherence Histogram

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Conclusions and Future work

IfSAR-DEMs using densification of existing UK National Mapping data have been shown to produce DEMs of elevation accuracy between 7 and 12 m rms which is comparable to SPOT.

It was possible to detect in the IfSAR-DEM, a narrow cutting of the M25 motorway which is not present in the highest resolution OS product. It was also possible to produce DEMs over a highly vegetated and cluttered scene with even a 35-day repeat. No atmospheric effects were detected and no detectable difference in accuracy even with Bperps differing by one-third.

Further work is required to look at the effects of different baselines and to try to understand what the elevation differences refer to, particularly regarding detailed land cover. Processing is being extended to the other 2 regions currently and results will be reported in the upcoming Florence Symposium.

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