A Dual-frequency GPS survey to test medium-scale DTM data quality and to generate precise DTM data for sea-level rise prediction in protected habitat areas.

Seamus Coveney[1], Stewart Fotheringham[2], Martin Charlton[3], John Sweeney[4]

[1]National Centre for Geocomputation NUIM, Ireland & Department of Geography, NUIM, Ireland.
Telephone: (00353-1-7086196)
Fax: (00353-1-7086456)
Email: seamus.j.coveney@nuim.ie
[2 & 3] National Centre for Geocomputation NUIM, Ireland.
[4] Department of Geography, NUIM, Ireland.

1. Introduction

Global average temperatures have increased by about 0.6°C (± 0.2°C) during the 20th century, and are projected to increase by between 1.4°C and 5.8°C by 2100 (IPCC, 2001a). This is predicted to lead to worldwide sea-level rise (SLR) of up to 1m by 2100 (IPCC, 2001b), which will have an impact on coastal environments protected under the Natura 2000 Habitats and Birds Directives (EU, 1992 & 1979).

Estuaries are predominantly sedimentary environments, and are characterised by shallow slope gradients, which make them particularly sensitive to changes in sea-level. The Shannon estuary is the largest river estuary in Ireland and it is designated as a Special Area of Conservation (SAC) under the Habitats Directive providing protection for coastal salt marsh habitats within the estuary.

Sea-level rise (SLR) predictions will be carried out for a portion of the estuary, based on Intergovernmental Panel on Climate Change (IPCC) predictions for best case, median case and worst case SLR up to 2100. IPCC predictions range from a best case minimum of 0.1m, to a median case prediction of 0.48m, through to a worst case of 0.88m.

Regional geological phenomena can add significantly to these trends. A north-south gradient of post-glacial land-surface rebound has been observed in Ireland on a geological timescale, with greater rebound in the north relative to the south resulting in land-surface submergence in the south of Ireland (Devoy, 2000), adding an additional trend to climate-induced SLR.

Historical trends in tidal records provide a useful indicator of changing sea-level. Data provided The Shannon Foynes Port Company (SFPC) for periods from 1877 – 1902, 1949 – 1965, 1970 – 2000 & 2002 – 2004 suggested an average upward trend of 4-4.5mm/yr for the period from 1877 - 2004. Continuation of this trend (in the absence of any acceleration for SLR) suggests local SLR of between 40cm to 45cm by 2100.

2. DTM data and sea-level rise

The generation of meaningful SLR prediction maps in a Geographic Information System (GIS) presupposes the existence of reliable Digital Terrain Model (DTM) data. Ordnance Survey Ireland (OSi) 1:50,000-scale data is the best national coverage dataset that is currently available in Ireland. Vertical errors in this dataset are quoted at ±5m. Highly precise DTM data can be derived from LIDAR (LIght Detection And Ranging) survey data, with height errors of ±15cm typically quoted for LIDAR DTM data. LIDAR-derived DTM data is starting to become available for major urban areas in Ireland, but there are as yet no immediate plans to extend this to non-urban areas. The lack of accurate DTM data for the Shannon estuary has created a need for the generation of DTM data from first principles.

Rasterised DTM data is often classified according to its spatial resolution. While this is often valid as a general indicator of the spatial resolution of the measured data from which a raster is derived, it cannot be relied upon as such. The density of the spot heights on the OSi 1:50,000-scale spot heights for the area around Shannon averages one per 30 hectares. In addition, these spot heights are not all from field measurements, but are more typically derived from photogrammetric interpretation. Contours interpolated from the spot heights are issued by OSi as part of the overall base DTM dataset, and these are typically used as base data for the generation of a raster DTM. The coastline at a scale of 1:10,000 is often used to extend the DTM model to the coast. The use of a relatively sparse set of data, most of which are interpolated values suggests that vertical accuracies will indeed be subject to significant errors.

SLR prediction modelling in a GIS typically involves a simple reclassification of a DTM by subtracting a given SLR height value from every cell in the DTM raster dataset. This creates a new model of terrain height. While error ranges of ±5m are acceptable for mapping purposes, they are beyond the level of accuracy needed for SLR prediction. However, vertical errors can be expected to be largest in mountainous regions, where vertical gradients are greatest. The range of possible error in the coastal region was assessed to determine whether the elevation data was of sufficient quality for SLR modelling, and to provide a high-quality dataset for the generation of a local DTM.

3. Methods

Dual-frequency (survey-grade) GPS (Global Positioning Systems) survey equipment is capable of measuring elevation to a precision range of 1 – 2cm relative to the local geoid. A Dual-frequency GPS survey was carried out in an area to the south of Shannon town, where habitat mapping from the National Parks and Wildlife Service (NPWS) confirmed the presence of protected salt marsh habitat within the Shannon estuary SAC. The results of the GPS survey were compared with the national coverage DTM to quantify the error ranges encountered within the OSi 1:50,000 dataset, and to provide the basis of a high-quality local DTM for use in SLR predictions in GIS.

The spatial extent of the GPS survey area was chosen to cover a range of spot height and contour elevation values (table 3) in order to facilitate accuracy testing. A raster

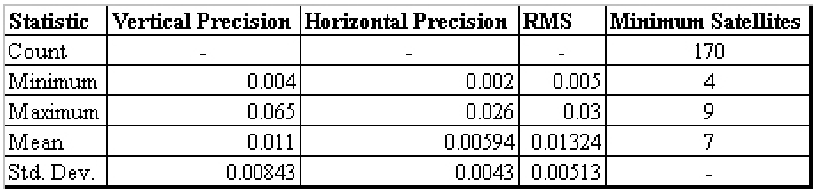
DTM grid was derived from the 1:50,000-scale spot height and contour data to provide the basis for a simple SLR inundation model, which could be used to guide the GPS point survey. This area was sub-divided into an initial network of twenty six 500x500m blocks and 310 sub-blocks measuring 100x100m providing a sampling framework for the GPS survey.

The first GPS survey was carried out over a 7-day period in September 2006. A Trimble R8 dual-frequency differential GPS receiver was used to capture 170 x,y,z points at an average spacing of 80m. GPS points were recorded in WGS84 / ERTS89 coordinates relative to the Irish OSGM02 GEOID model.

4 Analysis and Discussion

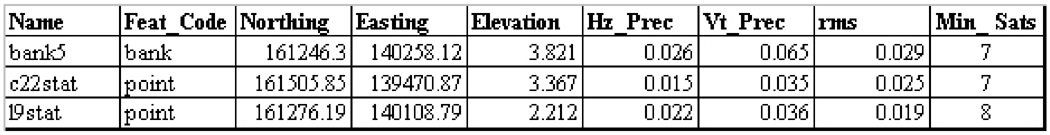
The density of the survey points is roughly 45 times that of the OSi 1:50,000-scale spot heights for the area. The GPS point data was recorded in fast-static mode, which measures position over a period of at least 8 minutes for each point. Elevation values derivable from this method are currently more accurate than Real Time Kinematic (RTK) in Ireland, which defines position over a much shorter time-span by reference to a national network of 13 OSi GPS correction stations.

Trimble Geomatics Office (TGO) software v.1.62 was used to post-process the 170 points captured. The data was post-processed against RINEX data from the OSi GPS reference station at Limerick University. The baseline to this station from the centre of the survey area is well within the recommended range of 30km, being located at approximately 22km from the survey site. The locations of these OSi GPS reference stations are updated daily, and are known in the x,y, & z planes to an accuracy of <1mm (OSi Geodetic site: http://www.osi.ie/gps/index.asp). The TGO software enabled each point in the survey network to be referenced against the known location of the station at Limerick, returning an estimate of the accuracy of each surveyed point in the x,y, & z planes. The average vertical error in the 170 points captured after post-processing was 11mm, with a maximum vertical error of 6.5cm, and a minimum error of 4mm (table 1). The point that returned the worst accuracy (6.5cm) turned out to be in a location where it was not needed, and was excluded from subsequent analysis (table 2). The next two low accuracy results were within the region of 3cm, and were deemed more than acceptable for the purposes required.



Statistic	Vertical Precision	Horizontal Precision	RMS	Minimum Satellites
Count	-	-	-	170
Minimum	0.004	0.002	0.005	4
Maximum	0.065	0.026	0.03	9
Mean	0.011	0.00594	0.01324	7
Std. Dev.	0.00843	0.0043	0.00513	-

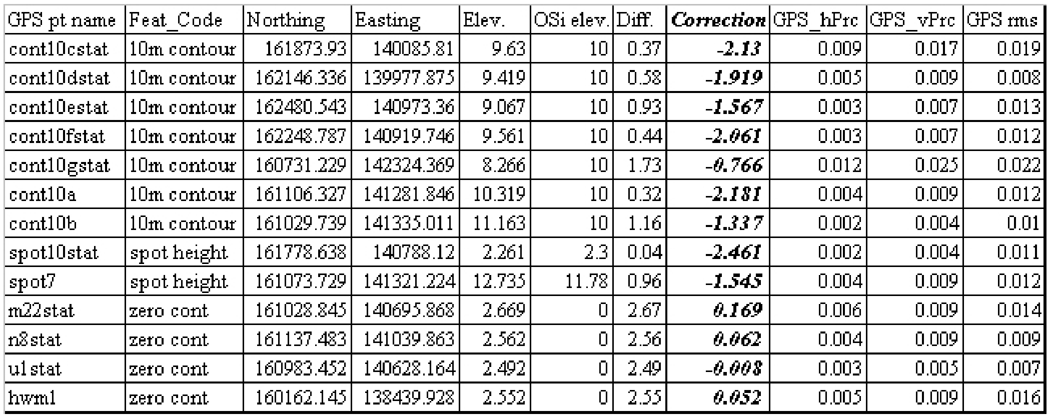
Table 1: Minimum, maximum and mean vertical RMS errors in the 170 points surveyed.



Name	Feat_Code	Northing	Easting	Elevation	Hz_Prec	Vt_Prec	rms	Min_ Sats
bank5	bank	161246.3	140258.12	3.821	0.026	0.065	0.029	7
c22stat	point	161505.85	139470.87	3.367	0.015	0.035	0.025	7
19stat	point	161276.19	140108.79	2.212	0.022	0.036	0.019	8

Table 2: The three low-accuracy, maximum and mean vertical RMS errors in the 170 points surveyed.

The results observed suggest that the errors observed in the OSI base data were smallest at the coastline itself (table 3) and were greater inland. Locations that corresponded with points and contours on the OSi spot height and contour data were identified and surveyed with the Trimble R8. Only two spot heights (out of a planned 4) could be located in the field. One was no longer in existence, due to construction activity, and the other was inaccessible and was set aside for capture in a next planned survey. The difference between the elevations as defined by the OSi spot height data and the GPS suggested an OSi underestimation error of 1.545m and .461m respectively (table 3). Seven points on OSi 10m contours were identified, visited and surveyed by GPS, revealing vertical errors of between -2.181m and -0.766m. Four points on the OSi 1:10,000-scale zero contour were identified, visited and surveyed by GPS, indicating vertical errors of between -0.008m and 0.169m (table 3). These results suggested that zero contour data may be the most accurately defined in the OSi base DTM data. All these results will be compared to extended analysis from a contiguous survey planned for March 2007.



GPS pt name	Feat_Code	Northing	Easting	Elev.	OSi elev.	Diff.	***Correction***	GPS_hPrc	GPS_vPrc	GPS rms
cont10cstat	10m contour	161873.93	140085.81	9.63	10	0.37	***-2.13***	0.009	0.017	0.019
cont10dstat	10m contour	162146.336	139977.875	9.419	10	0.58	***-1.919***	0.005	0.009	0.008
cont10estat	10m contour	162480.543	140973.36	9.067	10	0.93	***-1.567***	0.003	0.007	0.013
cont10fstat	10m contour	162248.787	140919.746	9.561	10	0.44	***-2.061***	0.003	0.007	0.012
cont10gstat	10m contour	160731.229	142324.369	8.266	10	1.73	***-0.766***	0.012	0.025	0.022
cont10a	10m contour	161106.327	141281.846	10.319	10	0.32	***-2.181***	0.004	0.009	0.012
cont10b	10m contour	161029.739	141335.011	11.163	10	1.16	***-1.337***	0.002	0.004	0.01
spot10stat	spot height	161778.638	140788.12	2.261	2.3	0.04	***-2.461***	0.002	0.004	0.011
spot7	spot height	161073.729	141321.224	12.735	11.78	0.96	***-1.545***	0.004	0.009	0.012
m22stat	zero cont	161028.845	140695.868	2.669	0	2.67	***0.169***	0.006	0.009	0.014
n8stat	zero cont	161137.483	141039.863	2.562	0	2.56	***0.062***	0.004	0.009	0.009
u1stat	zero cont	160983.452	140628.164	2.492	0	2.49	***-0.008***	0.003	0.005	0.007
hwm1	zero cont	160162.145	138439.928	2.552	0	2.55	***0.052***	0.005	0.009	0.016

Table 3: The three low-accuracy, maximum and mean vertical RMS errors in the 170 points surveyed.

5. Initial conclusions

Based on the trend observed in the historical tidal data for Limerick Docks, the minimum IPCC SLR prediction for 2100 appears to be very unlikely in the Shannon estuary. SLR of 0.4 – 0.45m can be expected in the absence of any acceleration in the trend observed between 1877 and 2004.

The vertical accuracies achieved across the entire GPS survey area suggests that dual-frequency GPS is a reliable source of base data for generation of a DTM of sufficient quality for use in SLR prediction mapping.

The error ranges encountered in the initial survey suggest that errors in the OSi base data are within the published ranges, with the smallest errors occurring at the coastline. The classification of error in the OSi data as discussed here will be subject to revision as further GPS surveys are carried out in adjoining areas long the coast.

The impact of sedimentation is also being assessed, and appraisal of various interpolation methods will be assessed in addition to modelling salt marsh change based on DTM-derived variables and local coastal energy gradients.

References

Devoy, R.J.N. (2000). "Implications of SLR for Ireland." in, R. J. Nichol and A. de la Vega (eds), Vulnerability and Adaptation to Impacts of Accelerated Sea-level Rise, pp. 33-46. Proceedings of the SURVAS Expert Workshop, ZMK University of Hamburg, 19-21 June 2000. EU Concerted Action Programme, Brussels.

EU (1979). "Council Directive (79/409/EEC), on the conservation of wild birds." Office for Official Publications of the European Communities.

EU (1992). "Council Directive 92/43/EEC; on the conservation of natural habitats and of wild fauna and flora." Office for Official Publications of the European Communities.

IPCC (2001a). "Climate change 2001: Impacts, Adaptation and Vulnerability." in McCarthy. J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (eds.), Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate change. Cambridge University Press.

IPCC (2001b). "Changes in Sea Level." in, Climate change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate change. Cambridge University Press.