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EVALUATION OF LIDAR AND MEDIUM SCALE PHOTOGRAMMETRY FOR DETECTING SOFT-CLIFF COASTAL CHANGE

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Abstract

Lidar and photogrammetry have both been evaluated for detecting short-term coastal change using the Black Ven mudslide, Dorset as a case study. A lidar-generated digital elevation model (DEM) was obtained and initially compared with a DEM generated using available 1:7500 scale aerial photography and automated digital photogrammetry. The quality of these two data sets was assessed using a third DEM, derived using a total station and conventional ground survey methods. The vertical accuracies (rms error) of the lidar and photogrammetry were 0·26 m and 0·43 m respectively, although both data sets displayed a tendency to generate heights slightly lower than the elevation of the terrain surface. The quality of the two data sets was then assessed with respect to local slope angle. The accuracy of photogrammetrically derived elevations varied with slope and more so than in the case of lidar.

From these basic tests, lidar has proved to be more accurate than photogrammetry for soft-cliff monitoring. Further research is required to establish whether this trend is applicable to other data sets and specifically for photogrammetric data acquired using larger scale imagery.

Keywords: airborne laser scanning, Black Ven mudslide, digital photogrammetry, landscape modelling, lidar, normal-angle ($f = 305$ mm) photography

Introduction

There are many contemporary issues concerning the coastal zone. One of the most prevalent is the landward retreat of the cliff line (Bray and Hooke, 1997) associated with potential sea level rise and the implications of this upon the sediment budget within the coastal cell (Bray, 1997). If coastal change is rapid then contemporary monitoring methods using surveying, the global positioning system (GPS) and synthetic aperture radar (SAR) are appropriate (Buckley and Mills, 2000), but in general processes need to operate over many annual cycles before significant change can be detected. Historical maps have been used to unravel the sequential development of a landform (Carr, 1980) but archival aerial photography is one source of truly historical spatial data. Photogrammetric methods have been developed to exploit such sources (Chandler and Cooper, 1989) and used to measure medium- and short-term coastal change (Chandler and Brunsden, 1995; Dixon et al., 1998). Indeed, photogrammetric methods have been widely adopted by geomorphologists interested in landform evolution (Small et al., 1984; Dixon et al., 1998) and notably in monitoring river and flume channel change (Lane et al., 1994; Lane et al., 1998; Stojic et al., 1998; Lane, 2000).

Continual technological and subsequent methodological advances are freeing geomorphologists from the constraints of data supply from National Mapping Agencies, such as the Ordnance Survey (Lane et al., 1998). This provides new opportunities for geomorphological research, as data with greater temporal and spatial resolution becomes readily available. One of the most recent developments has been lidar (light detection and ranging) data which is acquired through airborne laser scanning (ALS). Ackermann (1999) states "airborne laser scanning represents a new and independent technology for the highly automated generation of DTMs and surface models".

Robinson (1994) comments that many users accept DEMs uncritically and that all geomorphologists should assess the quality of any DEM that is used. There is a plethora of potential data-sets available and it is therefore essential to consider the effects of the techniques used to acquire, process and model data, in the context of subsequent geomorphological analysis. Lane et al. (1998) note that "error analysis of this kind is not something to which geomorphologists are accustomed", yet it is paramount that a critical approach is adopted if meaningful geomorphological conclusions are to be drawn.

Consequently, this study focused on comparing DEMs created by photogrammetry and airborne laser scanning, which are two important methods currently available that are compatible, both spatially and temporally, with short-term soft-cliff monitoring. The study was in accord with current objectives of the European Organisation for Experimental Photogrammetric Research (OEEPE), which coordinated comparative tests at the Vaihingen/Enz test site in Germany (Fritsch, 2000) and presented results in Stockholm in March 2001 (Pfeifer and Stadler, 2001). A secondary objective of the study, which is not part of the OEEPE remit, was to assess the validity of using lidar to extend a photogrammetrically generated temporal sequence.

The study area selected for this investigation was the Black Ven mudslide complex in Dorset (Fig. 1). This site was chosen partly because the morphology of the area had been extensively studied qualitatively (Lang, 1953; Arber, 1973; Denness et al., 1975; Brunsden, 1969; Conway, 1979) and quantitatively by Chandler and Cooper (1989), Chandler and Brunsden (1995) and Brunsden and Chandler (1996). The main reason for selecting this site was the ready access to

FIG. 1. Oblique aerial photograph of Black Ven, Dorset.

extensive archival photography dating back to 1946 in the form of contact diapositives. The Environment Agency (EA) was also able to provide lidar coverage of the area at no cost to UK academics. This was in the form of a 2 m DEM originally acquired in 1998.

METHODOLOGY

In a study concerned with comparing data sets it is important to define terms and the conventions adopted by Cooper and Cross (1988) and Cooper (1998) were used. One single epoch of photographic coverage of Black Ven was selected for photogrammetric processing. This consisted of three vertical aerial photographs taken on 28th May 1976, using a conventional Zeiss RMK aerial camera equipped with a 305 mm normal-angle lens. The flying height for the photography was 2375 m, resulting in a photo scale of 1:7500. The photographs were scanned at 20 μm resolution using a Helava DSW100 Digital Scanning Workstation at City University, resulting in a ground pixel size of 0·16 m. No photo control was available from the time that the images were originally acquired but a series of natural features had been coordinated using differential GPS in 1995 (Brunsden and Chandler, 1996). The dynamic nature of the mudslides did make the selection of photo control points quite complex, with the rapidly retreating cliff line and dynamic undercliff prohibiting the use of control points identified within the mudslides. Fortunately, sufficient control points were located well away from the cliff failures and these were coordinated in three dimensions, to a precision of ±0·03 m. All subsequent photogrammetric processing was carried out using the ERDAS Imagine/OrthoMAX package, which included creating a 2 m resolution DEM and orthophoto. The variance factor derived during the bundle adjustment was close to unity, with appropriate standard deviations for the photo coordinates (±4 μm) and the photo control (±0·03 m).

The technical basis of airborne laser scanning (ALS) in general and lidar in particular is well established (Ackermann, 1999; Baltsavias, 1999a, 1999b; Wehr and Lohr, 1999; Lohr, 1998) and will be only reviewed briefly here. An ALS system is composed of a laser range finder, combined with a GPS receiver and a laser inertial navigation system (LINS). The system uses GPS data to compute the absolute position of the sensor at 1 Hz (Lohr, 1998), which is too infrequent to be able to recover accurately the path of the laser space vector. The LINS determines changes in attitude and position at a frequency of 64 Hz, much higher than GPS, but with low absolute accuracy because of gyroscopic drifts. It is the combination of these two data streams that enables the space vector of each laser range estimate to be recovered, although complex data processing algorithms are required. The laser scans the terrain surface perpendicular to the flight direction with a density of up to five measurements per square metre, the density varying with scan angle and localised topography.

The lidar data used in this project was supplied by the EA. The EA processes the LINS, GPS and laser range data using the REALM software package, resulting in output in WGS84. This is transformed into OSGB36 using the OSTN97 and OSGM91 transformations (Ordnance Survey, 2001) for the plan and height coordinates respectively. These coordinates are then processed further using a variety of filters to remove noise, before being rasterised to a 2 m grid through interpolation. There are no statistics available to indicate the number of points used for interpolation when data is sparse, although interpolation is extended no further than 5 m from a measured point. The quoted accuracy of the system is $\pm 0{\cdot}5$ m in plan and $\pm 0{\cdot}1$ m in height (Lohr, 1998) although there is some evidence that the accuracy estimates of service providers are optimistic, and too imprecisely stated (Baltsavias, 1999a).

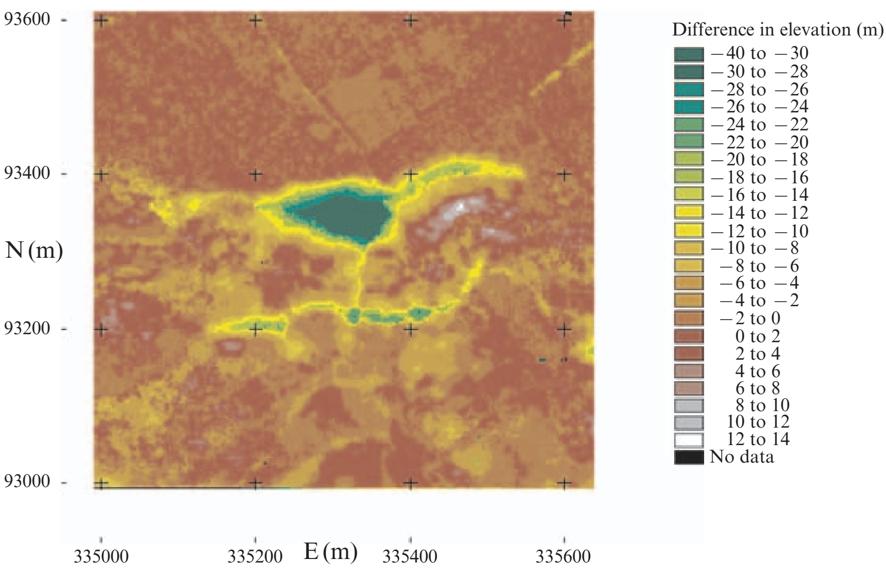

FIG. 2. Initial DEM of difference between lidar and photogrammetry.

The lidar data was captured over two days, 18th March and 2nd April 1998, at a flying height of 1000 m, using an Optech ALTM 1020. It was provided in a simple ASCII file that could be read into the ERDAS Imagine IMG format. The relevant projection and coordinate system data were input into the system to create the lidar DEM.

To assess the accuracy of both the photogrammetry and the lidar data sources, a conventional ground survey using a total station was undertaken in August 1999. The use of conventional survey to provide accepted ground truth was based on the assumption that the ground survey data would be more accurate than the other methods used, therefore allowing the accuracy of those methods to be assessed. However, the dynamic nature of the terrain used in this study created a potential problem. The landslide has been very active through time and it was possible that the 1999 ground survey would not be comparable to the 1976 photogrammetric and 1998 lidar data. The Black Ven landslip is a complex series of slumps and flows, yet its primary mode of morphological change is through rotational failure (Arber, 1973; Brunsden, 1969; Conway, 1979). A change in elevation of the cliff top would be accompanied by fracturing of the surface prior to slumping (Brunsden and Chandler, 1996). Consequently, field analysis of the processes operating at Black Ven was undertaken and it was evident that there was no fracturing of the cliff top surface either within or surrounding the area of interest. Thus the flat cliff top was considered stable, providing an area where direct comparison between the 1976 photogrammetry, 1998 lidar and 1999 field survey would be valid. The survey area consisted of relatively flat uniform terrain, with grass cover and was within a 20 m elevation range. The site was broken down into a series of small sections (Areas) based upon physical boundaries in the field such as hedge lines or lines of break of slope. Area 1 was convex in nature, although the general slope characteristics were less than 3° along a SW–NE axis. Areas 3 and 4 were planar areas with slopes of 4° and 6° respectively, with a NE aspect. Area 5 also had a NE aspect with a slope of between 9° and 16°. With the exception of Area 1, all areas were bounded along at least one side by hedges.

RESULTS AND ANALYSIS

The initial analysis of the DEM of difference between the photogrammetry and lidar (Fig. 2) reveals two primary patterns. First, regions of very significant change are apparent, due to geomorphological activity over time (for example 335300, 93350). Secondly, there are areas where minor differences or "discrepancies" between the photogrammetric DEM and lidar DEM are apparent. The cliff top (area north of Northing 93400) is one such area despite being geomorphologically stable during this period, suggesting that the difference is a consequence of the differing data acquisition and processing methods.

In order to assess the accuracies of the lidar and photogrammetrically generated DEMs, the two surfaces were compared with the ground survey DEM which is assumed to be more accurate than the other two techniques. The map of difference between lidar and the ground survey (Fig. 3) suggests higher accuracy compared with the photogrammetric comparison (Fig. 4). A series of cross sections was extracted from the lidar, photogrammetric and survey DEMs and Table I summarises the statistics derived by comparing these cross sections for each Area. A number

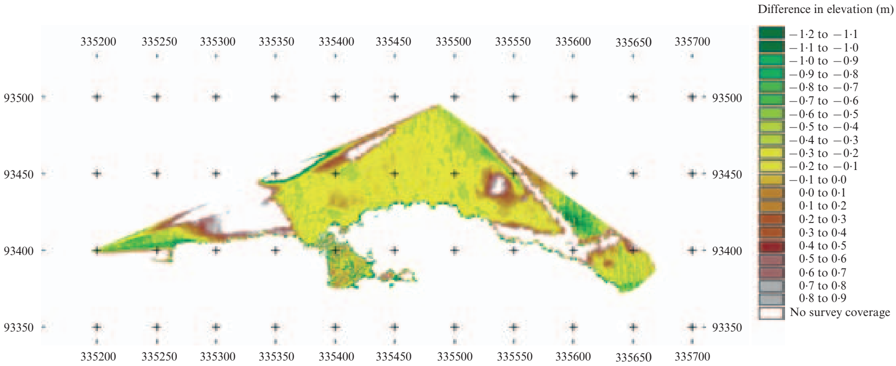

FIG. 3. Accuracy of lidar (discrepancies between lidar and ground survey).

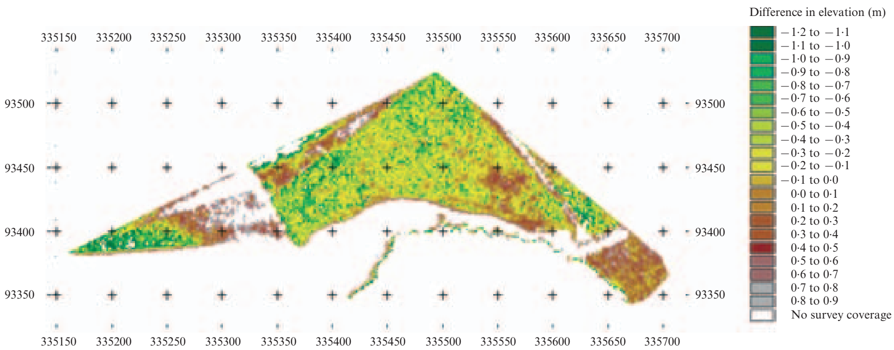

FIG. 4. Accuracy of photogrammetry (discrepancies between photogrammetry and ground survey).

TABLE I. Summary of cross sections through DEMs of difference for lidar minus ground survey and photogrammetry minus ground survey.

Datasets	*Area*	*Discrepancy range (m)*	*Mean discrepancies (m)*	*Standard deviation of discrepancies (m)*	*Rms error (m)*
Photo-Survey	1	1·152	−0·290	0·259	0·388
Lidar-Survey	1	0·393	−0·162	0·082	0·182
Photo-Survey	3	1·077	−0·349	0·307	0·460
Lidar-Survey	3	0·720	−0·078	0·182	0·212
Photo-Survey	4	1·219	−0·399	0·301	0·522
Lidar-Survey	4	0·922	−0·158	0·226	0·304
Photo-Survey	5	0·936	−0·112	0·237	0·347
Lidar-Survey	5	0·652	0·021	0·182	0·327

of trends are evident. First, simple visual analysis of the cross sections revealed that all three data-sets produced similar elevation data for the areas examined (see Fig. 5). The photogrammetrically generated data varied significantly relative to the survey, while the lidar remained more consistent. These trends are confirmed by the mean, standard deviation and rms error values in Table I displayed by Area, with an overall rms error of 0·26 m for lidar and 0·43 m for photogrammetry and a standard deviation of 0·15 m and 0·26 m respectively.

The vertical discrepancies in the cross sections for the individual areas were combined to generate an overall frequency distribution of vertical discrepancies. Visual inspection of Fig. 6 revealed that both data sets had a negative skew, and that lidar, relative to the photogrammetry, had a higher kurtosis and lower skew.

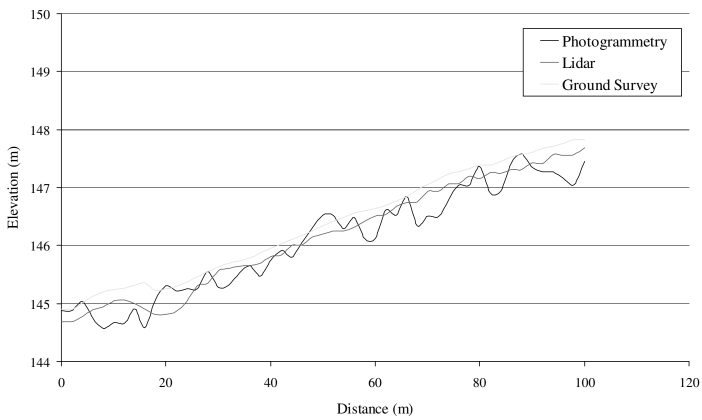

FIG. 5. Sample cross section displaying variation in elevation with technique.

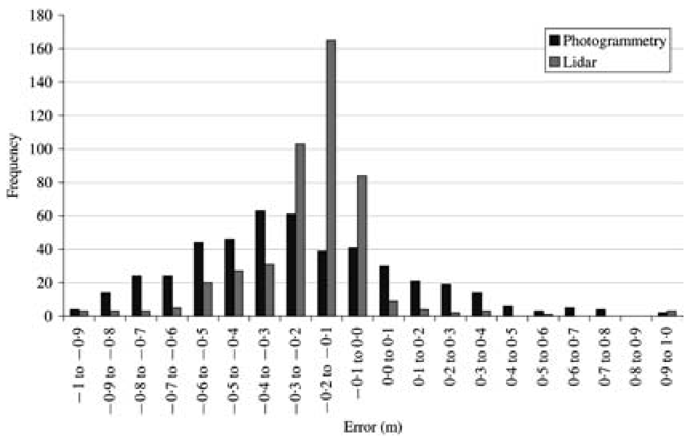

FIG. 6. Frequency distribution of lidar and photogrammetric error.

The greater spread of the photogrammetric data is indicative of greater variability in the accuracy of individual data points. In addition, the average discrepancies of the photogrammetric points are greater than the average discrepancies of lidar. These trends are similar to those in Table I. However, the degree to which lidar and photogrammetry vary with the ground survey changes from area to area. Among the primary differences between the surveyed areas were the general slope characteristics. However, the relationship between general slope characteristics and the results given in Table I do not fully explain the differences evident between lidar and photogrammetry for these areas.

Wood and Fisher (1993) suggest that accuracy is not only dependent upon the algorithms used to process the data and the subsequent terrain model, but also the nature of the topography. Terrain roughness and slope are cited as critical factors that influence data quality. In this instance, the land cover of tussocky grass results in a large variety of local slopes and aspects, rendering general slope values invalid for examining the relationship between slope and data quality. Consequently the *local* slope (the points adjacent to the point in question) of the ground survey data was used to assess the influence of slope upon accuracy (Figs. 7 and 8).

Both data sets suggest a general association between point accuracy and slope, with lidar negatively correlated. It would appear that, as slope increases, the lidar data tends increasingly to underestimate terrain elevation. Photogrammetry also displays decreasing accuracy with increased slope; however, this trend is offset by the negative intercept.

The low values for the R^2 test in Figs. 7 and 8 indicate that the residuals are high. The high occurrence of low slope angles ($<4°$) and the relatively low frequency of higher slope angles ($>4°$) limits the validity of any statistical tests. However, although there is insufficient data to statistically quantify any trend, the figures do hint that the data may follow the suggested lines. Further research is

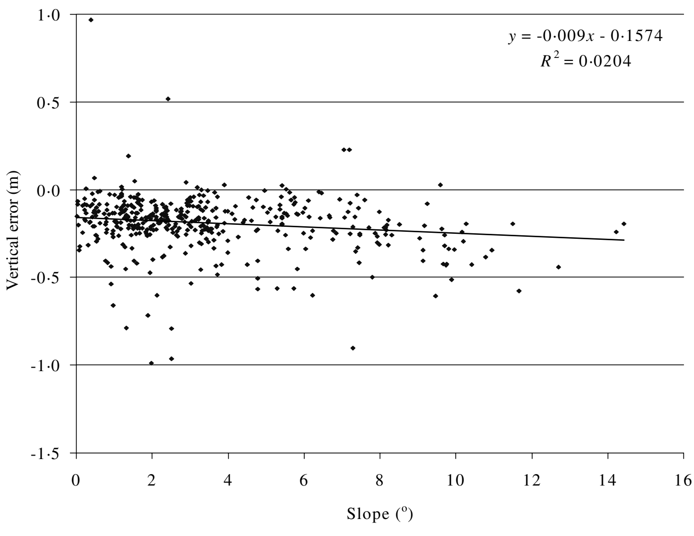

FIG. 7. Relationship between slope and lidar error.

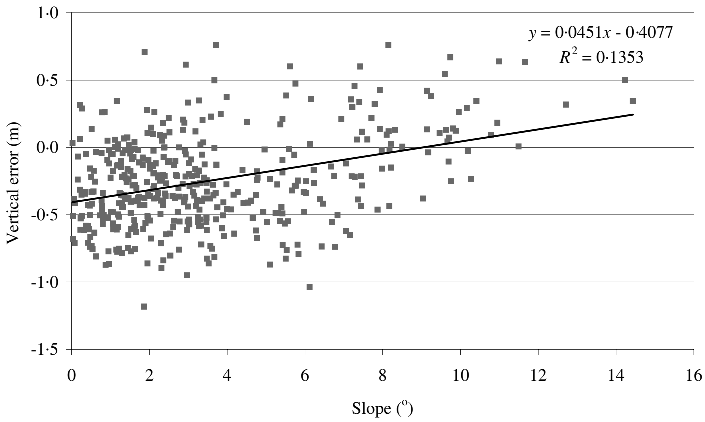

FIG. 8. Relationship between slope and photogrammetric error.

necessary to investigate whether a statistically significant trend can be identified beyond the site conditions used in this test.

DISCUSSION

Data Accuracy

The vertical accuracy of lidar and photogrammetry data sets has been examined and reveals that the rms error of lidar and photogrammetry is 0·26 m and 0·43 m respectively, for an area of relatively flat terrain, with an elevation range of 20 m and land cover of grass. This would imply that the lidar is of a higher quality than the photogrammetry, although lidar does not approach the expected quality of the system of ±0·10 m (Lohr, 1998). In contrast, the OEEPE test in the Vaihingen region (Pfeifer and Stadler, 2001) suggests a rms error for lidar of 0·08 m for soft landscape features on flat terrain. This rises to 0·11 m on sloping grassland, and to 0·48 m for hard inclined features, although it is suggested that this result was partly a consequence of the grid structure of the DEM (Pfeifer and Stadler, 2001). These figures are comparable to the quality of the data examined at Black Ven.

It is important to note that the photography used in this instance was not acquired for this particular purpose and method of use. The precision of photogrammetrically acquired data is highly dependent on the geometry and particularly the scale of the aerial photographs. The scale is dependent upon the focal length of the camera and the flying height, which in this case was 2375 m. The lidar sensor was flown at the markedly lower altitude of 1000 m, highlighting one of the main limitations of this study. An equivalent flying height would have increased the precision of the photogrammetrically derived data by a factor approaching 2·4, assuming the same camera lens was adopted. Thus as image scale increases, precision estimates of photogrammetrically acquired data should improve. However, should a comparison be based upon imagery acquired using a 300 mm normal angle lens or would a 150 mm wide angle lens have been more appropriate? It is interesting to note that if a wide-angle lens had been adopted, the flying height would have been 1188 m for the same ground coverage, which is comparable to the altitude of the lidar sensor. Although there is always a danger of extrapolating results beyond test conditions, it is worth estimating height accuracies at the same lower flying height using the research conducted by Fryer et al. (1994), in which a general rule based upon many studies was developed. This was carried out and suggests that optimum height accuracies using a wide-angle lens at a flying height of 1188 m would then have been 0·18 m, which is slightly better than the lidar estimate and is supported also by the findings of Baltsavias, (1999a). It should be stated that this simple approach does assume equal success in stereo matching and feature representation, and also that error is independent of surface characteristics, as scale changes.

Airborne laser scanning (ALS) has a higher degree of automation than photogrammetry (Baltsavias, 1999a) but although the latter requires many manual stages to be performed, these are well established and known. In contrast, the EA is reluctant to reveal the detailed processes involved in generating lidar data. This is not unusual; Baltsavias (1999a) declares that "the proprietary processing algorithms of service providers are kept in darkness". Consequently, it is not possible to determine the precise effects of the various filters and any interpolation applied to maintain the accuracy of the data over changing terrain slope, roughness and vegetation coverage. However, it is important to note that any gross errors will have been filtered out of the lidar data set, whilst the photogrammetric data-set received only the very basic post-processing common to most digital photogrammetric systems.

The primary concern in the study so far has been vertical accuracy. Horizontal accuracy plays an equally significant role, as this determines whether a comparison of elevation is appropriate. Examination of the lidar "cliff line" with the surveyed "cliff line" revealed high planimetric accuracy. Baltsavias (1999a) indicates that structures generated from ALS may not be well defined as the lidar system averages out the elevation over a 2 m footprint, which may lead to mis-registration of a feature by ± 2 m. The distance between the lidar and survey "cliff lines" did not exceed 2 m, indicating reasonable planimetric accuracy. A comparison of this sort with photogrammetry was not possible due to the date of photography used and the obvious changes that have occurred. Examination of other features such as buildings resulted in too short a length of fixed object to facilitate a meaningful comparison. However, the resolution of the photogrammetry was an order of magnitude higher than the lidar, with pixels of only 0·15 m, and so the planimetric accuracy of the photogrammetry should be better than that of lidar.

Despite the poorer heighting accuracy of photogrammetry when compared to lidar, it is valid to state that both lidar and photogrammetry are accurate methods applicable to short-term soft-cliff monitoring. As already indicated, the rms error of lidar and photogrammetry for the terrain conditions examined are 0·26 m and 0·43 m respectively. When applied at the 95% confidence level, 95% of the lidar data is accurate to within $\pm 0{\cdot}51$ m and 95% of the photogrammetry data is accurate to within $\pm 0{\cdot}84$ m.

Change Detection

Once accuracy measures have been established, it is possible to identify change that is statistically significant, provided that it is assumed that there are no systematic or gross errors in the two data sets. Individual discrepancies are compared with a critical value at a particular level of statistical significance (Shearer, 1990; Cooper, 1987); those which are greater are attributable to genuine geomorphological change, whilst lower discrepancies are associated with measurement uncertainty. The initial DEM of difference between the two data sets (Fig. 5) did not take into account such uncertainty. It is normal practice to derive the critical value from precision estimates, but a more conservative value may be obtained using the accuracy assessments, making the critical assumption that the surface data is free from systematic error. It is extremely difficult ever to state with certainty that all systematic errors have been eradicated and indeed the small negative mean discrepancies in Table I suggest that some minor systematic effects remain. However, this approach was adopted in this study, and a critical value of 0·98 m (95% confidence level) was applied to the discrepancy data derived by lidar and photogrammetry. Fig. 9 portrays those discrepancies that exceed this critical value and should therefore represent genuine change (for example 335300, 93350). However, it is apparent that change is not necessarily attributable to geomorphological processes because growth and removal of vegetation can cause significant morphological differences, as is the case with the hedgerows on the cliff top (for example 335230, 93570) and this alone could explain the small negative mean discrepancies exhibited in Table I.

CONCLUSION

The suitability of lidar and photogrammetry for short-term monitoring of soft-cliffs has been assessed. The interest in short-term changes requires a technique sufficient to determine small changes in morphological form, which may be a

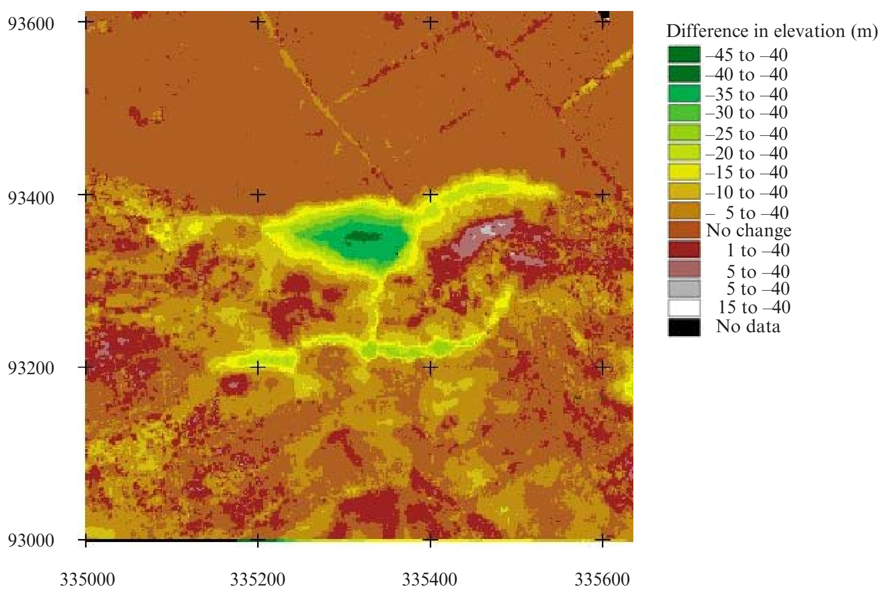

FIG. 9. Geomorphological change over time (with tolerances applied).

prelude to larger scale changes. Both lidar and photogrammetry displayed strong correlation with the accepted ground truth data. Analysis based upon comparing cross sections through the generated DEMs revealed that both techniques slightly underestimated the elevation of the terrain. In this trial lidar was consistently more accurate than photogrammetry using the normal-angle, medium-scale photography which was available here, with overall rms errors of 0·26 m and 0·43 m respectively.

It was established that accuracy of the data sets was also dependent upon slope angle. Lidar displayed a minor tendency to increasingly underestimate the elevation of the terrain as slope increased. However, the influence of slope upon photogrammetry was more marked. At low slope angles, elevation was underestimated. At higher slope angles, elevation was over estimated, indicating that the accuracy of the photogrammetric data-set was influenced more than lidar by the slope of the terrain. Further tests are necessary to establish whether these findings apply on slopes greater than those tested in this investigation, such as those which may be found on steep cliff faces. This would require simultaneous photogrammetric and lidar data capture, which was not possible in this instance.

Whilst both techniques have proved themselves to be accurate, further tests are required, using different scales of photography, to establish the scale of photography that is comparable to lidar in terms of accuracy.

REFERENCES

ACKERMANN, F., 1999. Airborne laser scanning—present status and future expectations. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54(2/3): 64–67.

ARBER, M. A., 1973. Landslips near Lyme Regis. *Proceedings of the Geologists' Association*, 84(2): 121–133.

BALTSAVIAS, E. P., 1999a. A comparison between photogrammetry and laser scanning. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54(2/3): 83–94.

BALTSAVIAS, E. P., 1999b. Airborne laser scanning: basic relations and formulas. *Ibid.*: 199–214.

BRAY, M. J., 1997. Episodic shingle supply and the modified development of Chesil Beach, England. *Journal of Coastal Research,* 13(4): 1035–1049.

BRAY, M. J. and HOOKE, J. M, 1997. Prediction of soft-cliff retreat with sea-level rise. *Ibid.*, 13(2): 453–467.

BRUNDSEN, D., 1969. The moving cliffs of Black Ven. *Geographical Magazine*, 41(5): 372–374.

BRUNSDEN, D. and CHANDLER, J. H., 1996. Development of an episodic landform change model based upon the Black Ven mudslide, 1946–1995. Chapter 40 in *Advances in Hillslope Processes* (Eds. M. G. Anderson and S. M. Brooks). Wiley, Chichester. 1306 pages: 869–896.

BUCKLEY, S. and MILLS, J., 2000. GPS and the wheel—how integrating the world's greatest inventions is helping to monitor coastal erosion. *Surveying World*, 9(1): 41.

CARR, A. P., 1980. The significance of cartographic sources in determining coastal change. In *Timescales in Geomorphology* (Eds. R. A. Cullingford, D. A. Davidson and J. Lewin). John Wiley, Chichester. 360 pages.

CHANDLER, J. H. and COOPER, M. A. R., 1989. The extraction of positional data from historical photographs and their application to geomorphology. *Photogrammetric Record,* 13(73): 69–78.

CHANDLER, J. H. and BRUNSDEN, D., 1995. Steady state behaviour of the Black Ven mudslide: the application of archival analytical photogrammetry to studies of landform change. *Earth Surface Processes and Landforms*, 20(3): 255–275.

CONWAY, B. W., 1979. The contribution made to cliff instability by head deposits in the east Dorset coastal area. *Quarterly Journal of Engineering Geology*, 12: 267–279.

COOPER, M. A. R., 1987. *Control Surveys in Civil Engineering*. Blackwell, Oxford. 381 pages.

COOPER, M. A. R., 1998. Datums, coordinates and differences. Chapter 2 in *Landform Monitoring, Modelling and Analysis* (Eds. S. N. Lane, K. S. Richards and J. H. Chandler). Wiley, Chichester. 454 pages: 21–36.

COOPER, M. A. R. and CROSS, P. A., 1988. Statistical concepts and their application in photogrammetry and surveying. *Photogrammetric Record,* 12(71): 637–663.

DENNESS, B., CONWAY, B. W., MCCANN, D. M. and GRAINGER, P. 1975. Investigation of a coastal landslip at Charmouth, Dorset. *Quarterly Journal of Engineering Geology*, 8: 119–140.

DIXON, L. F. J., BARKER, R., BRAY, M., FARRES, P., HOOKE, J., INKPEN, R., MEREL, A., PAYNE, D. and SHELFORD, A., 1998. Analytical photogrammetry for geomorphological research. Chapter 4 in *Landform Monitoring, Modelling and Analysis* (Eds. S. N. Lane, K. S. Richards and J. H. Chandler). Wiley, Chichester. 454 pages: 63–94.

FRYER, J. G., CHANDLER, J. H. and COOPER, M. A. R., 1994. On the accuracy of heighting from aerial photographs and maps: implications to process modellers. *Earth Surface Processes and Landforms*, 19(6): 577–583.

FRITSCH, D., 2000. Personal communication.

LANE, S. N., 2000. The measurement of river channel morphology using digital photogrammetry. *Photogrammetric Record,* 16(96): 937–961.

LANE, S. N., CHANDLER, J. H. and RICHARDS, K. S., 1994. Developments in monitoring and modelling small-scale river bed topography. *Earth Surface Processes and Landforms*, 19(4): 349–368.

LANE, S. N., RICHARDS, K. S. and CHANDLER, J. H., 1998. *Landform Monitoring, Modelling and Analysis*. Wiley, Chichester. 454 pages.

LANG, W. D., 1953. Mud flows at Charmouth. *Proceedings of the Dorset Natural History and Archaeological Society*, 75: 151–156.

LOHR, U., 1998. Digital elevation models by laser scanning. *Photogrammetric Record*, 16(91): 105–109.

ORDNANCE SURVEY, 2001. http://www.gps.gov.uk [Accessed: 6th December 2001].

PFEIFER, N. and STADLER, P., 2001. Derivation of digital terrain models in the SCOP++ environment. *Proceedings of OEEPE Workshop on Airborne Laserscanning and Interferometric SAR for Detailed Digital Terrain Models*, Stockholm, Sweden. Paper 4. 10 pages.

ROBINSON, G. J., 1994. The accuracy of digital elevation models derived from digitised contour data. *Photogrammetric Record*, 14(83): 805–814.

SHEARER, J. W., 1990. The accuracy of digital terrain models. Chapter 24 in *Terrain Modelling in Surveying and Civil Engineering* (Eds. G. Petrie and T. J. M. Kennie). Whittles Publishing and Thomas Telford, London, 1990. 351 pages: 315–336.

SMALL, R. J., BEECROFT, I. R. and STIRLING, D. M., 1984. Rates of deposition on lateral moraine embankments, Glacier de Tsidjoure Nouve, Valais, Switzerland. *Journal of Glaciology,* 30(106): 275–281.

STOJIC, M., CHANDLER, J., ASHMORE, P. and LUCE, J., 1998. The assessment of sediment transport rates by automated digital photogrammetry. *Photogrammetric Engineering & Remote Sensing,* 64(5): 387–395.

WEHR, A. and LOHR, U., 1999. Airborne laser scanning—an introduction and overview. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54(2/3): 68–82.

WOOD, J. D. and FISHER, P. F., 1993. Assessing interpolation accuracy in elevation models. *IEEE Computer Graphics and Applications*, 13(2): 48–56.

Résumé

On a évalué à la fois le lidar et la photogrammétrie pour la détection des changements littoraux à court terme, en utilisant comme cas d'étude le glissement de terrain et de boue du Black Ven (Dorset). On a d'abord comparé le modèle numérique des altitudes (MNA) issu de déterminations au lidar, au MNA obtenu par photogrammétrie numérique automatisée à partir des photographies aériennes au 1:7500 existantes. Puis on a évalué ces deux jeux de données en utilisant un troisième MNA, réalisé par les méthodes classiques de levé direct sur le terrain avec un théodolite station totale. Les précisions verticales (erreurs moyennes quadratiques) obtenues au lidar et par photogrammétrie ont été respectivement de 0,26 m et 0,43 m, tandis que s'affirmait dans les deux jeux de données une tendance à fournir des altitudes *légèrement inférieures à celles de la surface réelle du terrain. On a enfin évalué la qualité des deux jeux de données en ce qui concerne les angles de pente locale du terrain. Il est apparu que la précision des altitudes obtenues par photogrammétrie variait avec la pente et cela davantage que dans le cas du lidar. On peut conclure de ces essais que le lidar est plus précis que la photogrammétrie pour suivre l'évolution des falaises en terrain tendre. Il conviendra de poursuivre les études pour savoir si cette tendance se confirme sur d'autres jeux de données et notamment lorsqu'on utilise la photogrammétrie pour dériver des données provenant d'images à plus grande échelle.*

Zusammenfassung

Sowohl die Lidar Datenerfassung als auch die Photogrammetrie wurden hinsichtlich einer Erkennung von kurzfristigen Veränderungen in Küstenzonen am Beispiel des Black Ven Murenabgangs in Dorset untersucht. Es wurde ein Lidar Höhenmodell (DEM) erzeugt und mit einem DEM verglichen, das aus verfügbaren Luftbildern im Massstab 1:7500 mittels automatisierter, digitaler Photogrammetrie erzeugt wurde. Die Qualität dieser beiden Datensätze wurde mit einem dritten DEM überprüft, das mit Hilfe klassischer geodätischer Messungen mittels einer Totalstation abgeleitet wurde. Die Höhengenauigkeiten (Quadratischer Mittelwert) für Lidar und Photogrammetrie waren 0·26 m bzw. 0·43 m, obwohl in beiden Datensätzen eine Tendenz zur Erzeugung von Höhen leicht unterhalb der Geländeoberfläche zu beobachten war. Die Qualität beider Datensätze wurde dann noch hinsichtlich des lokalen Neigungswinkels überprüft. Die Genauigkeit der aus der Photogrammetrie abgeleiteten Höhen war von der Geländeneigung abhängig, und dies stärker als im Falle der Lidar Anwendung. Aus diesen ersten Untersuchungen hat sich gezeigt, dass für die Überwachung von gerundeten Klippen, Lidar eine höhere Genauigkeit liefert als die Photogrammetrie. Es sind weitere Untersuchungen erforderlich, um zu verifizieren, ob dieser Trend auch für andere Datensätze gilt, insbesondere auch für den Fall, dass die photogrammetrischen Daten aus grossmassstäbigen Luftbildern abgeleitet wurden.