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# Coastal cliff monitoring

The British Geological Survey (BGS) uses terrestrial laser (LiDAR) systems and differential GPS for a variety of survey activities. These include the monitoring of cliff erosion and landslides at test sites on the East and South coast of England. These studies improve our understanding of the complex processes taking place at the coast, and their relationship to the geology of the cliff and foreshore.

This understanding should help with the planning and design of defences and location of communities and infrastructure. Illustrations are given here of two Norfolk sites, one at Happisburgh (photo above) and the other at Sidestrand.

Geological systems are complex and difficult to predict. Understanding coastal erosion may appear to be relatively straightforward when compared to other geological systems such as earthquakes and volcanoes. However, to properly understand erosion, we must take into account geology, groundwater, rainfall, wind, wave and tide processes.

**The benefits of terrestrial LiDAR survey techniques**

Satellite-borne techniques, usually invaluable in terrain analysis and ground deformation monitoring, are less useful at the coast, where rapid changes in topography and aspect introduce errors and inconsistencies to data. BGS and others use terrestrial LiDAR as a useful tool to fill this gap. Importantly, LiDAR survey techniques have given BGS scientists a considerable improvement in Health and Safety over previous techniques. The method enables accurate measurement of complex features from a safe distance. The technique is also cheaper to operate and technically simpler than photogrammetry.

**Coastal erosion and accuracy issues**

Carrying out these surveys poses a number of challenges in maintaining accuracy. At most sites, the LiDAR equipment is sited on a soft, sandy beach that may result in subsidence of the instrument as it operates a scan (10-40 minutes). Errors are minimised by the use of specially adapted tripods, and by making regular backsight measurements to fix the position of the point cloud. Accuracy also varies with the complexity and reflectivity of the cliff surface, weather conditions, and ground conditions - occasionally scans are made ankle deep in water!

Although the accuracies achieved using BGS's terrestrial LiDAR methodology, (typically ± 100 mm but within a range of 20-500 mm depending upon site) are poor by engineering or architectural surveying standards, it represents a major step forward for geological applications in what are often hostile environments with no 'fixed' points. Accuracy is also an order of magnitude greater than that achieved by some airborne or satellite borne techniques.

**LIDAR techniques and strategic research approach**

BGS research sites are typically:

- Individual active landslides (or landslide complexes) or
- Cliff and shore platforms that are undergoing active recession.

They have been selected as areas of currently or recently active landsliding considered typical of the coastal unit and the geological materials involved.

Information from the LiDAR / GPS surveys allows accurate digital 3D models of the cliff surface to be generated. The sites are monitored at 6 or 12 monthly intervals, enabling analyses of changes in space and time.

The research programme has been conducting surveys since 2000, with up to 7 epochs to date at each site, and has resulted in some very interesting findings. These include the precise form and cyclicity of landslide activation and embayment formation, quantification of material loss to the sea, and the influence of geotechnical properties upon these factors. The implications for slope stability modelling are also examined.

**It is not only marine erosion and the implications are huge!**

We are re-considering the role of terrestrial processes, such as groundwater flow and geological variation in what have previously been considered to be entirely marine driven coastal erosion systems.

At some sites, notably in ‘soft’ cliffs of low elevation such as those at Happisburgh, Norfolk, we have confirmed that cliff recession is dominated almost entirely by direct erosion by the sea, with some contribution from surface runoff.

However, at other ‘soft’ cliff sites, the amount of erosion and cliff recession is actually dominated by landslide processes. For instance, at Sidestrand, Norfolk, marine erosion has almost continuously eroded 1-5 m of the base of the cliff every year. In most years, the base of the cliff actually moves forward to accommodate this erosion, whilst the cliff top remains stable for several years. As a consequence, however, the cliff top may recede by up to 50 m in a single event that may last only a few minutes. This has implications for national infrastructure, housing and personal safety. It is becoming clear that in cases of very rapid recession, within ‘soft’ cliffs formed in clay-rich formations, for example in the lower cliff at Happisburgh and Sidestrand, soil suction has a major influence on effective stresses, and hence the maintenance of over-steepened cliff profiles in these materials. This is possible because the pore-water held within clays responds very slowly to changes in stress, a phenomenon familiar to rail and road engineers. For the same reason, cliffs may remain unstable for many years after protection from the sea has been put in place.

**BOX 1 – Laser Scanning methodologies**

The scanning methodology has also been applied effectively to engineered structures such as road/rail cuttings, embankments, quarries and other excavations. It has been used by BGS to monitor the Souffriere Hills volcano's newly emerging dome in Montserrat.

Estimation of rock fall volume and the orientation of geological structures such as faults, bedding planes, and joints are particularly effective outputs which can be provided using suitable post-processing and recently available software.

In addition, the recent capability within the BGS of full 3D-immersion visualisation, allowing simulator style 'fly-throughs', represent major enhancements using the same point cloud data described below.  Coastal foreshore studies, in particular sediment budget and beach thickness calculations, have been greatly enhanced with laser scanning technology.  Here, data are acquired from cliff top or dune-top vantage points where available. Greater detail and accuracy is achievable than with aerial LiDAR, or other aerial techniques, though of course much smaller areas are covered.  An attractive feature of the LiDAR method is that terrestrial and aerial data can be easily combined, as can stand-alone GPS data.

**BOX2**

**LIDAR and GPS surveys: 3D recession models for Happisburgh  and Sidestrand**.

The BGS currently operates two terrestrial laser scanners: the long-range (800 m), camera equipped, Riegl LPM-i800HA and the very-long-range (2000 m) Riegl LPM-2K. These scanners offer a compromise between the density and precision of measurement, swathe width, and maximum survey distance. Typically, the scanners are operated 100-600 m from the target, enabling a continuous measurement swathe of 200-600 m.

The result of each laser scan is a 'point cloud' consisting of millions of discrete xyz points all related to the scanner's own location by distance and angles.  The scanner's location is then fixed and the point cloud transformed into grid coordinates using positional data derived by differential GPS. The number of individual scans varies according to the scale and complexity of the site, but a typical campaign results in 5-10 scans that are stitched together to form a single point cloud. The point cloud may be converted to a solid surface model.

The illustrations show a recession model based on six annual scans at Happisburgh (Figure 1) and a recession model for one year's recession at Sidestrand based on vertical movement (Figure 2).

One clear difference between the two sites is that at Happisburgh the erosion is so rapid and the cliff so steep that there is no overlap between successive annual scans, whereas at Sidestrand landslide debris remains on the slope and the progress of individual landslides can be tracked. This is heavily influenced by the scale and slope of the cliffs and the complexity of the geology.

At Happisburgh the geology is simple and the cliff is low (10m) whilst at Sidestrand the geology is very complex and the cliff high (45m).

Figure 1 Cliff recession 3D models (positional difference) from laser scans for cliffs at Happisburgh laser scans (2001 – 2006) [overall recession = 90m]

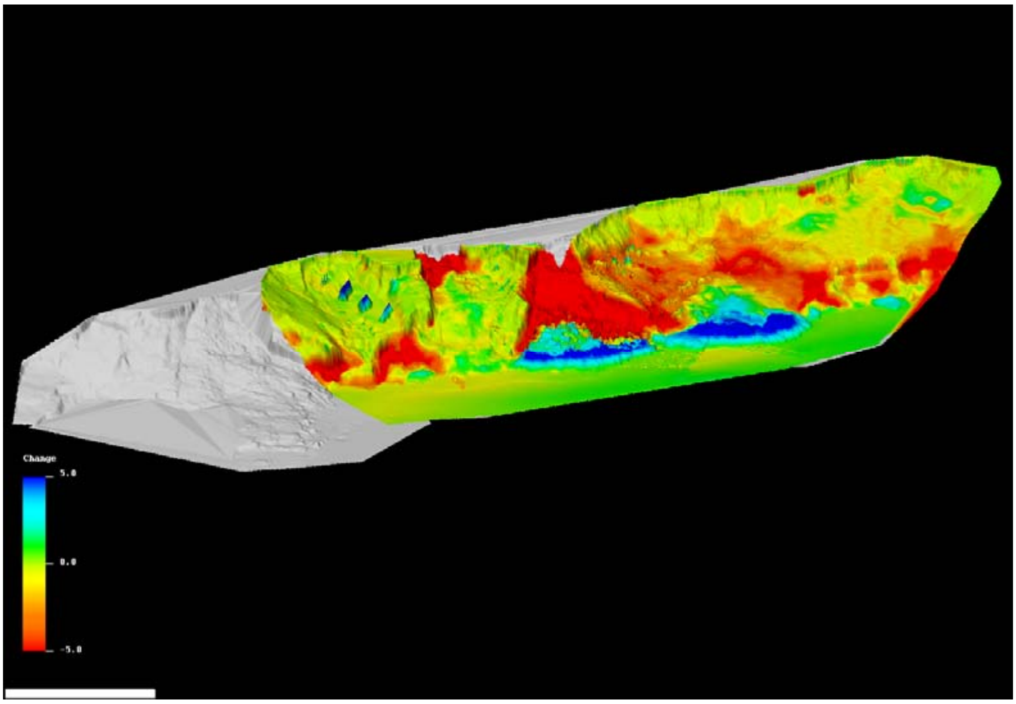


Figure 2 Cliff recession 3D model (elevation difference) from laser scans for cliffs at Sidestrand (2005 to 2006) [red=lower, i.e. material has slipped away; blue=higher, i.e. material has accumulated