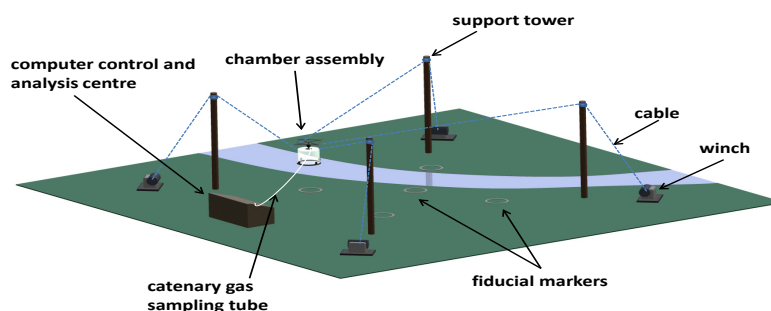


daily and seasonal variability, making the task of attempting to produce meaningful integrated gas flux data for terrestrial and freshwater systems very difficult. A major reason for the paucity of accurate flux data is the difficulty of making frequent measurements in complex and heterogeneous environments. We increasingly need measurements at smaller 'field' scales, enabling flux comparisons across heterogeneous landscapes or gradients (e.g. pastures, wetlands) and across field manipulations (e.g. fertilizer additions, crop trials) with an urgent need for new measurement approaches. Existing automated flux chambers frequently present problems of power supply, centralised gas analysis, expensive multiplexing, and cannot be easily applied to tall vegetation. Also, establishment of automated chambers in large numbers across spatially separated plots is prohibitively expensive. The overall aim of the current NERC-funded project was to develop a new type of automated GHG flux equipment.

In order to acquire high-frequency trace gas measurements at the field scale, we have designed a novel automated trace gas measurement system which is a flexible and cost-effective alternative to current manual or automated chambers. This new automated system 'flies' a chamber to any X-Y-Z co-ordinate within the field site by transporting it through the air using cables and winches between four towers in the corners of the site (see Fig. 1).

Fig. 1. The SkyGas chamber system, showing the tower and wire system which enables the chamber to be moved to any point over the experimental area, under the winch control system.



The basic 3D flying system mirrors the more expensive technologies used in camera and stage work, but we deploy a gas flux chamber in the head configuration. The system operates automatically under computer control, enabling different measuring cycles to be pre-programmed including specific sampling points, pathways or protocols across the field site. All mechanical and software development associated with SkyGas has been carried out by University of York staff and has involved a number of key areas for development, including electronic flight control, mechanical engineering, atmospheric gas analysis, chamber design, high frequency data analysis, etc.

Site location. The recently constructed Heslington East campus at the University of York includes specific wildlife 'reserve' areas containing natural vegetation and a complex of freshwater pools and rivers, and an area has been made available for use by the Biology, Physics and Chemistry Departments for construction of an Open-Air Atmospheric Chemistry Facility (53°56'41.59"N; 1°01'40.28"W). The site is only a few minutes walk away from the Departments of Biology and Chemistry, providing ease of access and security (Fig. 2); it was

solely within this defined area where the loaned GEF equipment was deployed.



Fig. 2. Showing the location of the SkyGas prototype system on the York campus, with a photograph of the moving chamber head (foreground) and one of the supporting posts and winches in the background.

Role of GPS. One core requirement for the SkyGas system was a control system which required knowledge of the real-time location of the head in 3-D, to cm (X, Y, Z) accuracy, within the SkyGas arena. These data need to be relayed to the control centre (CC) and the four winches then individually instructed to move the head, under automatic control, through a specific series of X-Y-Z co-ordinates. This kind of problem is routinely encountered in aeronautical control systems and the necessary open loop algorithms are well proven and an area of expertise for which the Electronics Department at York is internationally recognised. Initial project design discussions led to the adoption of a simple index system on the winch feeds to inform the CC of the position of each winch rope in real time; this was considered a secure and inexpensive approach, although it was recognised that later developments could, ideally, utilise high specification GPS. Given current equipment limits within NERC grants, it was not possible to develop the more expensive GPS solution within the existing proof of concept grant, but the NERC GEF was an ideal opportunity to investigate the potential of GPS for the control aspects of the project. We predicted that incorporating differential GPS feedback would improve precision, flexibility of control and the ability to increase scale without loss of accuracy.

Survey procedure and data quality (including any recommendations for future borrowers). We deployed the differential GPS system i) to accurately locate 'landing points' in the X,Y and Z planes within the arena, ii) by attaching to the moving chamber to investigate the feasibility of real-time dynamic location control and iii) attached to the moving chamber to test the precision and accuracy of repeated landings. In order to achieve this we established a 'base station' on the CC roof and used the second GPS system in 'roving' mode. The GPS data were compared with fixed point 'calibrated plates' in fixed positions on the ground with pre-marked 2D mm grids. These comparisons showed that consecutive landings resulted in a cluster of GPS points for each landing area, with the majority of landing points being within ca. 9 mm of each other for the GPS and 3 mm for the fixed calibration plates. The GPS was indicating an accuracy of between 9 mm and 15 mm in terms of landing accuracy of the chamber but the points were in fact closer to each other, as

indicated by the calibrated landing plates. Similar errors were found when using the GPS to locate fixed positions using repeated measurements. We found the equipment to be easy to use after appropriate training, was sufficiently robust for extensive field use and had the capability of providing real-time feedback positional data to the CC under all weather conditions.

Findings and Interpretation to date. It appears that, for a 30 m x 30 m SkyGas arena, the use of differential GPS as part of the control system offers no advantages over simple indexing of the winches and is 'over-kill'. However, we have no measurements of comparative GPS and winch accuracy over a much larger arena (e.g. football field scale) and suspect that an independent and absolute indexing system, such as that provided by differential GPS (or laser tracking), would be an important technical development at the next stage of scale increase.

Conclusions and recommendations. The prototype SkyGas system at the University currently uses indexed coders on the winches to locate the position of the ropes and, hence the moving head. Although acceptable at the prototype stage, such a system cannot compensate for dynamic changes in rope stretch and supporting post movement and also requires extensive initial manual and labour-intensive positioning of the head for each sampling point. Any future larger scale SkyGas system would benefit greatly from the incorporation of some form of real-time X,Y Z positioning to, firstly, accurately locate the positions of each fixed sampling point and, secondly, to enable construction of a real-time dynamic head position control. Whilst differential GPS is one way of approaching this, the required level of accuracy would probably best be achieved using a terrestrial laser-based scanner with a reflective head-mounted target prism for sub-mm 3D real-time positioning. We would recommend that, at some future date, access to such equipment from the GEF pool would be of benefit not only to the current project but also the wider NERC community. **We must emphasise that the opportunity to test alternative (GPS) approaches in the development of the SkyGas system would simply have not been possible without the support of the GEF.**

Location of the archived data. The archived data are currently maintained by Andy White, Manager of Technical Support Services in the Electronics Department at the University of York (andy.white@york.ac.uk; Phone: 01904 322412). However, the data are considered to be of little value to anyone working outside the current project and are simply stored for referral by the research group at York.

Publications (including conference proceedings)

Ineson et al (2014) Presentation at the annual EGU meeting in Vienna,

Ineson et al (2015) Poster and poster presentation at the COST CLIMANI meeting in Copenhagen, June 2015.

Ineson et al (2014) Progress report at Annual NERC Macronutrients Meeting (Oxford, October 2014).

Ineson et al (in prep.) SkyGas: a novel system for monitoring terrestrial greenhouse gas fluxes reveals diurnal fluxes in nitrous oxide emissions. *Global Change Biology*, to be submitted in November 2015.