THE EARTH OBSERVATION TECHNOLOGY CLUSTER

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ABSTRACT:

The Earth Observation Technology Cluster is a knowledge exchange initiative, promoting development, understanding and communication about innovative technology used in remote sensing of the terrestrial or land surface. This initiative provides an opportunity for presentation of novel developments from, and cross-fertilisation of ideas between, the many and diverse members of the terrestrial remote sensing community. The Earth Observation Technology Cluster involves a range of knowledge exchange activities, including organisation of technical events, delivery of educational materials, publication of scientific findings and development of a coherent terrestrial EO community. The initiative as a whole covers the full range of remote sensing operation, from new platform and sensor development, through image retrieval and analysis, to data applications and environmental modelling. However, certain topical and strategic themes have been selected for detailed investigation: (1) Unpiloted Aerial Vehicles, (2) Terrestrial Laser Scanning, (3) Field-Based Fourier Transform Infra-Red Spectroscopy, (4) Hypertemporal Image Analysis, and (5) Circumpolar and Cryospheric Application. This paper presents general activities and achievements of the Earth Observation Technology Cluster, and reviews state-of-the-art developments in the five specific thematic areas.

1. INTRODUCTION

The Earth Observation Technology Cluster is a knowledge exchange initiative, promoting development, understanding and communication about innovative technology used in remote sensing of the terrestrial or land surface. The observation or measurement of some property of the land surface is central to a wide range of scientific investigations conducted in many different disciplines, and in practice there is much consistency in the instruments used for observation and the techniques used to map and model the environmental phenomena of interest. Using remote sensing technology as a unifying theme, this initiative provides an opportunity for presentation of novel developments from, and cross-fertilisation of ideas between, the many and diverse members of the terrestrial remote sensing community.

To ensure broad relevance and widespread interest in the initiative, the Earth Observation Technology Cluster covers the full range of remote sensing operation, from new platform and sensor development, through image retrieval and analysis, to data applications and environmental modelling. Following a public consultation, certain topical and strategic themes have been identified for detailed investigation: (1) Unpiloted Aerial Vehicles (UAVs), (2) Terrestrial Laser Scanning, (3) Field-Based Fourier Transform Infra-Red (FTIR) Spectroscopy, (4) Hypertemporal Image Analysis, and (5) Circumpolar and Cryospheric Application.

The aim of this paper is to outline the main activities of the Earth Observation Technology Cluster and encourage participation from interested parties (see www.eotechcluster.org.uk), and to review state-of-the-art developments and priorities in the five specific thematic areas, identified during workshops, consultations and other knowledge exchange activities taking place through the Earth Observation Technology Cluster.

2. OVERVIEW OF THE EARTH OBSERVATION TECHNOLOGY CLUSTER

The Earth Observation Technology Cluster was created in response to a perceived need for better exploitation of technological development between diverse academic disciplines and industrial sectors. That is, developments within the field of remote sensing have considerable potential for re-use elsewhere, and technological advances in other fields hold value for the remote sensing community. This initiative is funded by the UK’s Natural Environment Research Council’s Technologies Theme, and involves a partnership between three main UK umbrella bodies responsible for remote sensing development, practice and exploitation – the Remote Sensing

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and Photogrammetry Society (academia), the National Centre for Earth Observation (government) and the British Association of Remote Sensing Companies (industry). Importantly, to ensure global relevance and impact, the Earth Observation Technology Cluster is supported by leading international organisations, most notably the International Society for Photogrammetry and Remote Sensing (ISPRS). ISPRS Technical Commission VII is a registered project partner, with representation on the steering committee.

A range of media and activities are being exploited to disseminate information and foster collaboration in remote sensing technology development. A central website and mailing list are used to capture and communicate the latest information from across the terrestrial remote sensing community, and the Earth Observation Technology Cluster also has a thriving social media presence. Public interest articles and media releases are used to spread information about remote sensing beyond the traditional community in publications such as GEOconnexion International and Planet Earth, explaining its relevance and opportunities for exploitation in everyday life.

Technical events such as seminars, workshops, demonstrations and summer schools are held to illustrate and promote the potential of remote sensing technology. Special interest groups (SIGs) have been established in strategic areas such as UAVs, Technical/Operational Procedures and Laser Scanning, and a new SIG has been proposed in FTIR spectroscopy. These SIGs will ensure the Earth Observation Technology Cluster has a lasting legacy.

Finally, to ensure significant academic impact, the latest research findings in remote sensing technology are being compiled in a journal special issue: 'Innovative Sensor Systems for Advanced Land Surface Studies'. To guarantee broad accessibility for the EO community, open-access publishing is being exploited for this purpose and the special issue will be published in the *Remote Sensing* journal.

3. UNPILOTED AERIAL VEHICLES

Recent assessments of the market for UAVs have placed the value of the systems provision business alone in excess of US$2b. While a large proportion of this will relate to the military, it is likely that the market for civil and commercial applications of remote sensing system from UAVs is considerable. In fact, civilian UAVs are a new and very exciting platform for remote sensing and photogrammetry. These take the form of large-platform, High-Altitude Long Endurance (HALE) and small-platform low-altitude, normally lightweight, missions. HALE UAV systems support atmospheric science where the benefit lies in their superior capability over piloted aircraft for very long endurance upper troposphere and lower stratosphere missions. Very few piloted research aircraft apart from NASA's Lockheed ER2 can deploy to altitudes above 40,000 feet, and so UAVs such as the Northrop Grummen RQ-4 Global Hawk have a unique capability to support experiments that require long range (11,000 miles) and endurance (32 hours) and can support heavy payloads of atmospheric science and remote sensing instrumentation (Herwitz *et al.* 2004). There are, however, significant factors including technology, cost and regulatory restrictions that limit the availability and scope of HALE-type UAVs to operate in non-segregated airspace, particularly for Earth Observation applications. On the other hand, UAVs that operate at low-altitude tend to be small in size and include a range of platforms including fixed-wing, rotors, blimps/balloons and modified microlights. UAVs that operate at low-altitude are relatively easy and inexpensive to deploy and such flexibility lends itself to many land and water surface measurement and monitoring applications where very high resolution imagery, repeat coverage or deployment over a hazardous target are required.

In many countries the regulatory environment that controls UAV access to non-segregated airspace is sensitive to weight and operating altitude. Typically, platforms over 150 kg need to comply with European Aviation Safety Agency regulations which impose strict air worthiness and operating checks. Platforms under 150 kg can normally be operated under national civil aviation authority rules; however there is a general requirement for UAVs to have 'sense and avoid' capability to operate in non-segregated airspace. In most of Europe it is possible to operate a lightweight (less than 7 kg) platform to follow a precise flight-path under computer control, providing the pilot maintains visual contact with the UAV (within 500 m) to comply with sense and avoid requirements, keeps below 122 m (400 feet) and operates with permission. The risk is assessed from a number of factors including the good safety history of the operating model aircraft and the relatively low kinetic impact energy of a 7kg object free falling from 400 ft (Haddon and Whittaker 2004). The relative absence or exemption from stringent air safety regulation makes small UAVs attractive platforms when compared with piloted aircraft. For many remote sensing applications the advantages include the low cost of purchase, operation and maintenance, as well as the lack of noise or other pollution. However, a significant limitation is that low altitude UAVs can only carry small payloads; most published studies use off-the-shelf digital cameras (Eisenbeiss and Zhand 2006). At low altitude, it is possible to achieve very high spatial resolution with consumer-grade compact and SLR cameras, sufficient to allow photogrammetry and precision mapping. While there have been efforts to explore multi- and high spectral resolution imaging, including deployment of thermal infrared, RADAR, and even small laser scanners, these have been very limited in scope (Berni *et al.* 2009).

It is very likely that the next five years will see better access to HALE systems for science use and a rapid increase in small UAV remote sensing. NERC, for example are working jointly with NASA on a programme to observe and model the tropical tropopause layer using the NASA Global Hawk UAV and the NRC/Met Office BAe 146 manned aircraft. On the other hand, studies have demonstrated that low-altitude systems are ideal for monitoring crops, forests, coastal algal blooms, riparian and rangeland vegetation, and even for generating very precise digital elevation models by photogrammetry and laser scanning (Laliberte *et al.* 2012). Recent work has demonstrated unique capability that combines high spatial and spectral resolution for detecting water stress in individual plants using techniques of reflectance spectroscopy (Zarco-Tejada *et al.* 2012). On the other hand, there are considerable challenges to be overcome before UAVs are used routinely for remote sensing survey. These include: development of reliable systems with low vibration engines and airframe stabilisation suitable for imaging; achieving highly reliable systems with appropriate sense and avoid technology; appropriate training for UAV pilots to operate within an appropriately regulated environment; lightweight scientific instruments suitable for UAV deployment; methods to survey large areas; and suitable image/data processing software for geometrically correcting and accurately positioning UAV-derived imagery.

4. TERRESTRIAL LASER SCANNING

Terrestrial laser scanning (TLS) technology has become a well established method of non-invasive survey in a wide range of disciplines, including engineering, architecture, mining, urban planning and the remote sensing science (Lichti *et al.* 2008). TLS is designed for the rapid acquisition of highly detailed three-dimensional (3D) point clouds and to obtain accurate measurements of the range of a given object relative to the position of the sensor (Clawges *et al.* 2007). Moreover, these systems are capable of providing a permanent record of both man-made and natural features (Danson *et al.* 2007).

Despite the capabilities mentioned above, and the general trend of the technology to become lightweight and faster, the full potential of TLS is some way from being fully realized (Jenkins 2006). Specifically there are still a number of issues relating to modelling, registration and processing of TLS data that need to be addressed. Specifically, there is a lack of communication between scientists and computer programmers, which in many cases leads to the generation of inefficient codes for data processing and analysis. In addition, software packages provided by the manufacturers of TLS systems often do not meet essential user requirements associated with data analysis and visualisation. Furthermore, there is often limited documentation describing the data acquisition process, and in particular echo detection algorithms, which may have an impact on the interpretation of results obtained from TLS projects (Pfeifer and Briese 2007). There is also a need to overcome problems associated with the storage and management of large datasets captured by TLS systems, since tasks such as 3D-modelling and visualisation often require the combination of multiple point clouds of data creating TB of information. Efficient data extraction algorithms driven by end-user requirements should be a focus for research and development in the application of TLS.

Further investigation of full-waveform TLS may contribute to solve issues such as characterisation of ‘soft targets’ like forest canopy elements, atmospheric distortions and removing near-field clutter in long-range terrain surveys. Although full-waveform datasets offer the possibility of analysing multiple returns, a measure of the quality of returns is equally important to characterise the 3D point clouds captured (Wehr and Lohr 1999). With regards to the datasets generated by full-waveform systems, difficulties arise again from data volume, interoperability and post-processing, and further software developments are required to deal effectively and efficiently with information derived from full-waveform TLS data.

5. FIELD-BASED FOURIER TRANSFORM INFRARED SPECTROSCOPY

While reflectance-based remote sensing methods have been utilised in a wide variety of applications, there are a number of severe limitations in the range and quality of the physical parameters that can be retrieved. Thermal wavelength observation offers an exceptional opportunity to enhance the utility of remote sensing to a wide range of applications in a variety of ways. The true potential of thermal wavelength remote sensing data is apparent when the remote sensing data is acquired at very high spectral resolution. This approach, termed Fourier Transform InfraRed (FTIR) spectroscopy, has been shown to have the capability of providing quantitative information on the composition of a rock, sediment, soil, vegetation or atmosphere that reflectance spectroscopy cannot. Field-based FTIR techniques have the potential to significantly advance the application of remote sensing in a wide range of applications.

Although conventional reflectance-based remote sensing approaches can map some rock compositional variations, they are unable to resolve the key mineralogy and lithologies required for geological mapping. The emission spectra from a rock are extremely sensitive to variations in the fabric and bulk chemistry of the rock and the composition of the constituent mineral species, particularly feldspars, garnets, pyroxenes, olivines, and SiO_2 minerals (Salisbury *et al.* 1987). FTIR techniques can resolve igneous rock types, clastic and carbonate sedimentary rocks, and sediment grain size and composition (Applegarth and Stefanov 2006). FTIR techniques therefore offer the potential to overcome the current limitations of reflectance-based remote sensing data and provide a step-change in the range and quality of mineralogical, lithological and morphological datasets. FTIR spectroscopy is also affected far less by illumination conditions than reflectance-based sensors allowing them to be deployed in much more difficult and marginal conditions. Field-based FTIR approaches have the potential to acquire quantitative measurements of a wide range of gas species. This approach has been utilised to resolve the atmosphere and gaseous emissions for a number of environment-related projects, including volcanology (Oppenheimer and Kyle 2008), air quality monitoring and contaminated land monitoring (Beil *et al.* 1998). Gas measurements can be acquired using three approaches: Open-Path (using an IR source), Closed-Path (using a closed gas cell), and sun occultation (pointing directly at the sun). FTIR techniques can also identify soil composition (Linker *et al.* 2005), soil contamination (e.g. by cyanide, Rennert *et al.* 2007) and vegetation species and health (Ribeiro da Luz 2006).

Although the potential applications for field-based FTIR spectroscopy are many and varied, the utilisation of field-based FTIR spectroscopy by EO specialists in all sectors of the EO community has been limited by a number of factors including: the availability of field-portable FTIR instruments has been very limited; field FTIR equipment has been very cumbersome, fragile and difficult to use in the field; and the methodology for processing and analysing field FTIR data is complicated. These limitations are being overcome by the development of a range of field deployable FTIR instruments. Handheld FTIRs such as the EXOSCAN (Agilent Technologies) provide a light and robust means of acquiring large amounts of field spectral emissivity data. FTIRs with a wide range of functionality, such as the MIDAC (Midac Corporation), can provide emissivity, gas emission and general emission spectral data. Field-based Imaging FTIRs, such as the TELOPS (Telops), offer the potential of the development of a wide range of novel observation methodologies and analytical techniques. The increasing availability of these new field FTIR instruments will make this powerful analytical technique much more accessible to environmental scientists in all sectors of the EO community and provide an opportunity to develop new remote sensing environmental monitoring methodologies.

6. HYPERTEMPORAL IMAGE ANALYSIS

"Time is the fourth dimension; it is unlike the first three dimensions in that it is asymmetrical, and difficult to envision, much less comprehend" (Saab and Haythornthwaite 1990). With this complexity comes the opportunity to greatly enhance the information gained from remotely sensed data. One of the many virtues of observing our land surface remotely from space is the opportunity for repeat coverage under stringent data capture conditions: a capability now 40 years old. There is a plethora of examples of the value added by capturing the dynamics of the land surface; however in many of these cases it is evident that the technological trade-off between sensor and platform resolutions has led to compromise. Given that changes in land surface properties are the result of a variety of processes occurring at a continuum of temporal and spatial scales (Linderman *et al.* 2005), any possibility of overcoming this restriction would be beneficial. Any approach to reduce or measure the uncertainties associated with EO data is valuable (Justice *et al.* 2000). For example, more accurate measurement and prediction of vegetation phenology will increase the accuracy of the prediction of ecosystem productivity and gas exchange with the atmosphere, and thereby the predictions of future climate, and assist land-owners and policy makers in the selection of provenances or varieties best adapted to future climatic conditions (Cleland *et al.* 2007). Indeed, the value in hypertemporal remote sensing would be immense. Here, hypertemporal remote sensing refers to that of a fine enough temporal resolution to capture the phenomenon of interest, at the spatial and spectral resolutions required.

There is a real opportunity for hypertemporal remote sensing capability, particularly at the fine spatial resolutions and broad geographical coverage often required, by exploiting a major shift in the way remote sensing systems are deployed. A technological paradigm shift in EO data collection can meet the stringent requirement in spatial and temporal resolutions required for measuring land surface dynamics. Newly available data from EO constellations, the forthcoming ESA Sentinel-2 platforms, or in a more general sense 'virtual constellations' taking advantage of observations from any appropriate EO sensor that views a particular area, have the potential to provide daily observations of the land surface using sensors with a nominal spatial resolution up to 10m. Constellations use multiple satellite platforms flying in orbital formation and carrying similar imaging sensors to allow frequent imaging (days between observations) of the land surface. Similarly, a close collaboration with "commercial" systems could afford a system of a constellation of satellite sensors to operate to capture hypertemporal data. One such system could be the DMC constellation which currently consists of seven UK-built satellites, each carrying a wide swath (650km), high resolution (22-32m) multispectral sensor. The constellation is a unique partnership of governments and companies who each own one or more satellites. DMC International Imaging (DMCii) coordinates the collaborative use of all satellites, making it possible to meet user requirements for applications requiring large area coverage and/or frequent revisit – applications that could not be addressed with any individual satellite. DMCii now performs a centralised calibration program for all satellites each year to ensure all sensors can be used together for demanding scientific and commercial applications. DMCii is committed to data continuity, with more satellites planned for subsequent years. Underpinning these research challenges is a series of technical challenges that must be overcome in order to make the data useful for rigorous scientific work. These include optimizing the data acquisition, radiometric calibration, correction of atmospheric and surface reflectance anisotropy, cloud masking and orthorectification. This is an addition to developing methodologies to exploit the hypertemporal content as well as visualisation techniques for displaying the content.

7. CIRCUMPOLAR AND CRYOSPHERIC APPLICATION

As highlighted by large volumes of research conducted during the recent International Polar Year, the Earth's polar and cryospheric regions are undergoing rapid changes (Polar Research Board 2012). Rugged terrain, remoteness, and harsh weather make these regions ideally suited to study by remote sensing techniques. Airborne and satellite-based methods for measuring and monitoring the poles and the cryosphere allow observation at higher time resolution, lower cost, and at a more synoptic scale than would be possible via any other avenue (Rees 2006). As highlighted in previous sections, recent years have seen rapid development in many remote sensing fields, and applications to the poles and the cryosphere are no exception.

As a case study, glaciology provides a prime example of the wide development and application of airborne and satellite measurements of many varieties (Pellikka and Rees 2010). Techniques have been employed at a very wide range of scales ranging from extensive airborne geophysical observations (Bell *et al.* 2011) to very localized application of high-resolution airborne LiDAR for classifying glacier surfaces, and measuring glacier volume changes (Barrand *et al.* 2010). Gravimetry (Jacob *et al.* 2012), satellite laser altimetry, radar altimetry and multispectral image classification have all been used to study large changes to the terrestrial cryosphere. Beyond volume change and areal extent, velocity and glacier dynamics (Mansell *et al.* 2012), as well as melt and albedo variations (Box *et al.* 2012), are all crucial parameters which are monitored and studied with remote sensing techniques. Combinations of multiple techniques have yielded many new insights, as well as useful products for the glaciological community. The availability and application of remote sensing to glaciology has proved a huge boon to the field – facilitating otherwise impossible observations and allowing for study on short timescales not previously known to be important (Joughin *et al.* 2008).

Of course, the cryosphere is not limited to glaciers. The European Space Agency's (ESA) new CryoSat-2 has enabled unprecedented visualization of the extent, thickness, and dynamics of sea ice, as well as the Arctic Ocean itself. Permafrost dynamics and lake changes in many regions of the high Arctic have been analysed using satellite imagery. Arctic treeline and vegetation changes are ideally monitored with synoptic-scale remote sensing technologies (Rees 2012), and environmental impacts of industrial activity can be assessed in remote and fragile ecosystems (Kumpula *et al.* 2011). Snow water equivalent, a crucial hydrological parameter, is very difficult to measure using remote sensing techniques (Davenport *et al.* 2012). As a charismatic example of polar remote sensing, very high-resolution satellite imagery has even allowed for the first synoptic survey of an animal population from space by observing the traces of Emperor penguin colonies on Antarctic ice (Fretwell and Trathan 2009).

Thanks in part to the increasingly large amount of freely-available remote sensing and cryospheric data sets (Polar Research Board 2012), remote sensing studies of the poles and the cryosphere have increased and grown ever more insightful. In addition to strong archives and current operational products from NASA, ESA and other operators, the cryospheric research community will greatly benefit from further upcoming satellite missions and remote sensing technology development including the Sentinel constellation, future Landsat missions, Tandem-X (Schulze *et al.* 2010), the CoReH_2O proposal, and ICESat-2 (Abdalati *et al.* 2010). A few of the many crucial cryospheric parameters to be studied are surface albedo, surface temperature, snow cover area, snowmelt area, lake ice area, permafrost surface deformation, sea ice extent and characterization, glacier area, glacier surface elevation, glacier velocity and iceberg calving fluxes. Smaller missions and airborne deployments will continue to push the boundaries of remote sensing techniques in polar environments.

Circumpolar and cryospheric remote sensing will strongly benefit from this expansion of available data, continued innovation, new combinations of established methods to address pressing research questions, and the unprecedented level of spatial and temporal resolution of remotely sensed data to gain more insight and crucial understanding of these cold, remote, and rugged, but globally-important regions.

8. CONCLUSIONS

The Earth Observation Technology Cluster forms part of the NERC technologies theme which aims to stimulate technology development to meet the challenges associated with next generation platforms, remote sensing instruments, in situ sensors and modelling technology. The activities and initiatives summarized by the themes demonstrate that technologies are helping to reinvigorate Earth Observation by addressing both existing and new scientific challenges. The impacts of these activities stem from close engagement between technologists and application scientists and the success of the Earth Observation Technology Cluster depends on continuing this fruitful engagement. For further information, contact eotechcluster@nottingham.ac.uk or visit www.eotechcluster.org.uk.

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