FINAL PUBLISHABLE REPORT

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Short name, country	PTB, Germany UCL, UK, UZH, Switzerland			

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1 Executive summary

Introduction

Earth observation data provide a wealth of information concerning climate and environmental change that is of enormous value to society. Remotely sensed data, collected from both terrestrial Earth observation instruments and satellites, underpins climate forecast models and our studies of global climate trends.

The Problem

Deriving useful information about these trends necessitates the comparison of Earth observation data, and in order to ensure that such comparisons are meaningful, it is essential to quantify the stability of the sensors collecting these data in addition to the differences between different sensors and their associated uncertainties.

This problem can be addressed through the application of metrology, the science of measurement, to the field of Earth observation. In this regard, this project has led to the creation of a globally accessible e-Learning training solution designed to disseminate knowledge and awareness of key metrology topics as applied to the field of Earth observation.

International initiatives such as QA4EO (Quality Assurance Framework for Earth Observation) are increasing the community's awareness of the importance of quality assurance, rigorous uncertainty analysis, traceability to the International System of Units (SI) and calibration. However, traditionally, the availability of training courses covering these topics in relation to Earth observation applications has been limited.

The Solution

This project builds on the face-to-face training developed in EMRP joint research project ENV04 Metrology for Earth Observation and Climate (MetEOC) to extend its uptake to a wider Earth Observation (EO) community via a new on-line training course.

The face-to-face course provided a wealth of training materials to participants from several sectors and captured the interest of the wider EO community, who were unable to take part due to the limited number of seats available (40) and/or geographic restrictions.

This support for impact project has built upon on the MetEOC project's training output to maximise its outreach, impact and potential through the development of a globally accessible e-Learning training solution.

Impact

The 'Uncertainty Analysis for Earth Observation' e-Learning course not only acts as a stand-alone online training resource, but also forms a coherent foundation of core metrology topics to allow for the addition of future online modules. The development of these future modules will be supported by a 'Documented model framework', which has been produced as part of this project.

The primary impact of this course is the availability of a tailored training solution, accessible to the global Earth observation community, designed to disseminate key metrology knowledge to support the acquisition, analysis and use of Earth observation data. The increased awareness of these metrology topics within the Earth observation community, resulting from the uptake of this e-Learning course, will ultimately enable more reliable climate forecasts and increased confidence in consequent adaptation and mitigation policies.

2 Need for the project

Climate forecast models, which remain the only method to predict the future evolution of climate change, are underpinned by remotely sensed data. Thus, improving the traceability and accuracy of this data is important for space and research agencies. A factor of 10 improvement in measurement accuracy is required in the shortest time possible to discriminate between the natural variability of the climate system and the 'anthropogenic' (human-caused) signal. Such an improvement would provide more reliable climate forecasts and increased confidence in adaptation and mitigation policies. International initiatives such as Quality Assurance Framework for Earth Observation are increasing the community's recognition of the importance of quality assurance, rigorous uncertainty analysis and metrological traceability. However, EO professionals would like a training course tailored to their needs and addressing their particular challenges, rather than having to use generic uncertainty analysis courses. The primary supporter for this project, the European Space Agency (ESA), recognises the need to increase the awareness and understanding of the importance of traceability to the International System of Units (SI) and to increase skills in assessing and calculating uncertainties in the EO traceability chain. ESA believes that the availability of high quality training for EO scientists, engineers and managers will be essential in achieving these goals.

In line with this pressing need, EMRP project ENV04 MetEOC delivered a two-day training course in February 2015 on 'Uncertainty Analysis for Earth Observation' in the United Kingdom to 40 scientists from across Europe. The training course received excellent feedback from the delegates and direct interest was expressed by a number of worldwide companies from a wide number of areas, such as weather, climate, space, and academia, thereby highlighting the relevance and high demand of this training. Nevertheless, because of the global nature of the subject and the geographic distribution of future delegates, greater impact could be achieved by investing in the creation of an online EO e-Learning Course. This would enable knowledge to be transferred more widely, upskilling more delegates and giving them the freedom to access this training 'on demand'.

3 Objectives

As discussed in the previous section, there is a clear requirement for globally accessible, structured training materials designed to deliver metrology knowledge to the Earth observation community. In line with this requirement the objectives of this project are to:

1) **Maximise outreach, impact and potential of the initial EMRP project ENV04 MetEOC investment**, transferring valuable metrology skills to the EO community leading to maximum end-user benefit from the MetEOC project and disseminating the project's outputs more widely.
2) **Develop a scalable e-Learning training course framework to enable the transfer of knowledge (from objective 1)**, that will not only stand on its own as a valuable training resource, but will also lay the foundation (the framework) for further development of new modules, such as surface temperature or surface albedo (i.e. the fraction of solar energy reflected from the Earth back into space), over time.

4 Results

A detailed description of the outputs of this project, created to meet the two primary project objectives, is given in the sections that follow.

4.1 The 'Uncertainty Analysis for Earth Observation' e-Learning course

The course materials from EMRP project ENV04 MetEOC's face-to-face course were used, and built upon, to create a certified, globally accessible 'Uncertainty Analysis for Earth Observation' e-Learning course. This course, which consists of text, images and videos, introduces learners to an 8-step procedure for uncertainty analysis for Earth observation applications over the course of three modules:

- **Module 1**, which introduces fundamental concepts relating to uncertainty analysis and introduces a procedural approach for uncertainty analysis in Earth observation
- **Module 2**, which applies the procedural approach introduced in Module 1 to a real-life practical example
- **Module 3**, which builds on the content introduced in Modules 1 and 2 to explore the application of uncertainty analysis to post-launch calibration techniques

Prior to development of the e-Learning course, the content to be covered was outlined by NPL before being reviewed and added to by staff members at the University of Zurich (UZH), University College London (UCL) and Physikalisch-Technische Bundesanstalt (PTB) in Germany. This ensured that the topics covered in the course were relevant to the target audience by capturing knowledge and expertise from experienced professionals working in the field of Earth observation. The course was then scripted by NPL, and reviewed by an Earth observation scientist from UZH in order to quality assure the course content. This collaborative approach to course design and development represents a pooling of knowledge from both industry and academia, which, in turn, has allowed the creation of a quality assured e-Learning training solution in which academic knowledge is supported by, and conveyed through, real life Earth observation examples. Overall, the collaborative input from Earth observation professionals at UZH, UCL and PTB allowed this project to draw upon a wealth of knowledge greater than the knowledge of each single institution, thereby helping to ensure that the final e-Learning course is a valuable training resource for the wider Earth observation community.

The three modules within the ‘Uncertainty Analysis for Earth Observation’ e-Learning course were designed to be progressive, meaning that the introductory content in Module 1 supports the practical examples given in Modules 2 and 3. The content covered in each of the three modules is supplemented by relevant supporting materials, allowing learners to further their knowledge of topics that are either: (a) particularly relevant to their field of study; or (b) of particular personal interest.

In order to ensure that learners have an appropriate level of knowledge to access the course, an optional ‘Test your knowledge’ assessment has been created. This short assessment was specifically designed to give learners the opportunity to assess whether they possess the knowledge required to understand the concepts presented throughout the course. Upon taking this optional assessment, users obtaining a passing grade are directed to Module 1 of the ‘Uncertainty Analysis for Earth Observation’ e-Learning course. Conversely, learners that do not achieve a passing grade are directed to supporting materials within the e-Learning course that they can use to revise or revisit topics that they found difficult before beginning the course. A graphical overview of the complete course structure, along with the learning pathway by which users navigate the course (black arrows) is shown below in Figure 1.

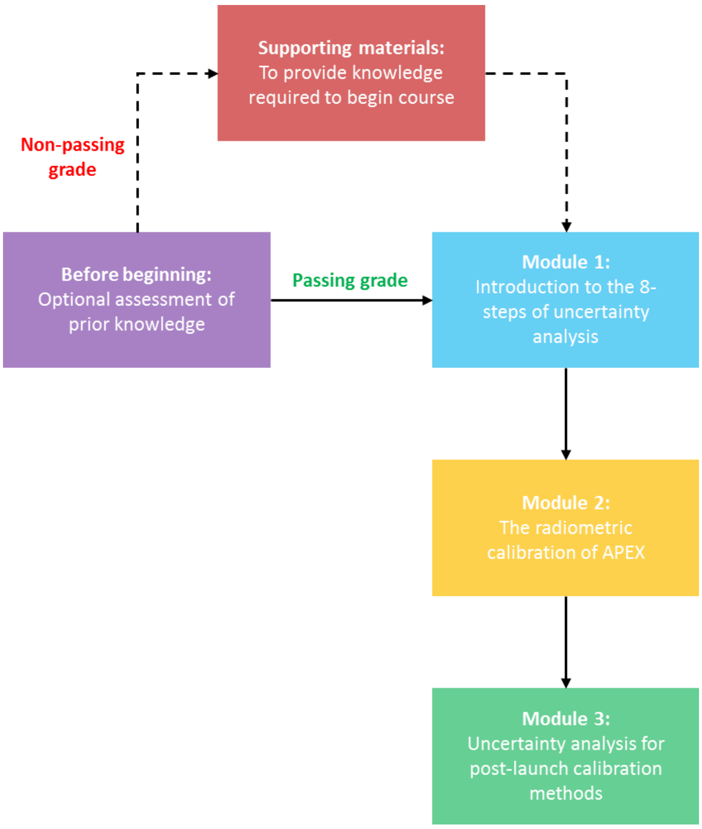

Figure 1. *The modular structure of the ‘Uncertainty Analysis for Earth Observation’ e-Learning course.*

At the end of each of the three modules, learners assess their knowledge by completing an end of module assessment. Those that achieve a passing grade over these three modular assessments receive an NPL certificate, thereby demonstrating that they have successfully completed the course.

All of the components of the ‘Uncertainty Analysis for Earth Observation’ e-Learning course are compatible across multiple devices (desktop, module and tablet), operating systems (Windows, OSX, iOS, Linux) and browsers, thereby allowing users to access the course remotely on a wide range of devices.

The full course is accessible via NPL’s Learning Management System. Promotional material, including a description of course structure and learning outcomes, can be found on the external NPL website at: http://www.npl.co.uk/e-learning.

4.2 An e-Learning course framework

The 'Uncertainty Analysis for Earth Observation' e-Learning course was carefully designed to: (a) fit within NPL Training's uncertainty training framework; and (b) create a foundation to which future Earth observation-specific modules can be added. With regard to point (a), the e-Learning course is aligned with NPL's existing e-Learning courses within the field of measurement uncertainty, meaning that learners are able to follow a defined measurement uncertainty e-Learning pathway in order to progress from a minimal level of knowledge to a high level of knowledge of the application of uncertainty analysis in the field of Earth observation. It should be noted that the 'Uncertainty Analysis for Earth Observation' e-Learning course is self-contained, and it is not a requirement that learners follow this complete uncertainty pathway. However, the preliminary courses within this pathway act as a support to learners without the prerequisite knowledge, as identified, for example, by the optional 'Test your Knowledge' assessment.

With regard to point (b), the 'Uncertainty Analysis for Earth Observation' e-Learning course has been designed to provide learners with knowledge of the core topics in uncertainty analysis applied to the field of Earth observation. Consequently, the course acts as a foundation for the exploration of more specific future topics, such as the application of uncertainty analysis to Earth observation data processing, or other products (e.g. climate, land, ocean, atmosphere, etc.). In this regard, a 'Documented Model Framework' has been produced by NPL, with input and support from subject matter experts at UZH, UCL and PTB, as part of this project, which acts as a foundation for the addition of future modules.

A diagram showing how the 'Uncertainty Analysis for Earth Observation' e-Learning course is aligned with NPL's existing uncertainty training courses, and how future Earth observation-specific modules would sit within this wider framework is shown below in Figure 2.

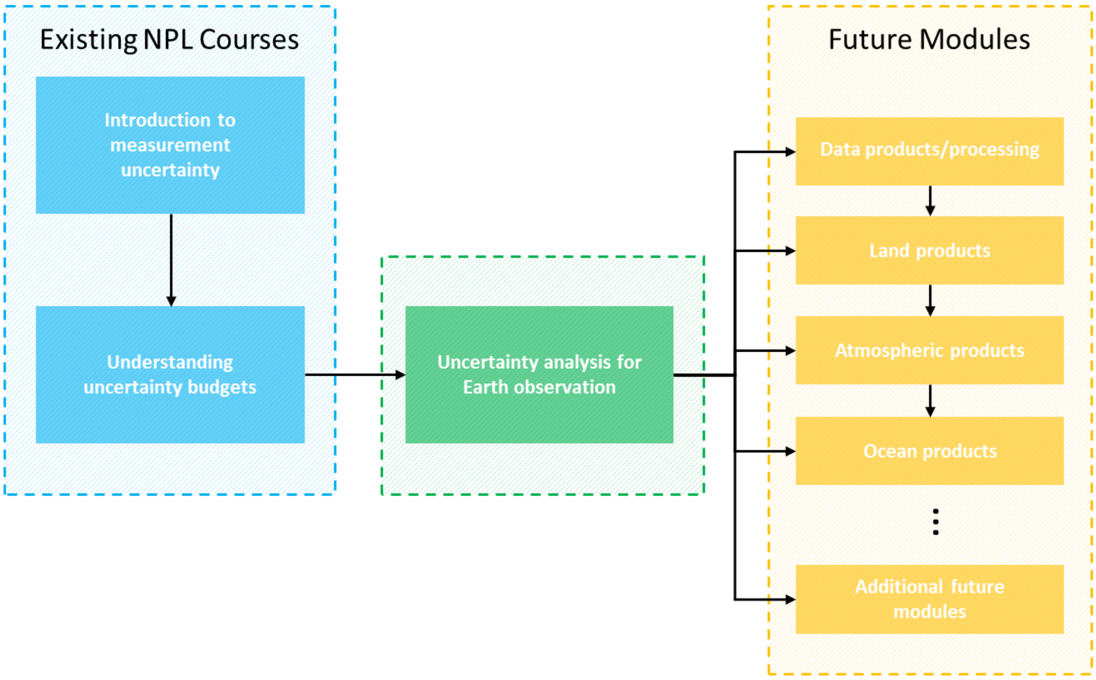

Figure 2. *Alignment of the 'Uncertainty Analysis for Earth Observation' e-Learning course with NPL's existing uncertainty training courses, including proposed future expansion modules*

5 Impact

The ‘Uncertainty Analysis for Earth Observation’ e-Learning course is now live and available for use by both the primary supporter (ESA) and the wider EO community. Although licenses for the course have only recently been released, it has impacted both the primary supporter and the wider EO community in the following ways:

- Direct impact, through the availability of a remotely accessible, EO-specific uncertainty analysis course for ESA employees
- Indirect impact, through engaging members of the wider EO community; members of this community represent potential collaborators, supply chain elements and future employees for ESA. Consequently, their training will have long-term impact via an increase in awareness and technical capability in the area of uncertainty analysis applied to EO

To date, three ESA employees have enrolled in the course, and evidence of direct impact has come from one user who has completed all aspects of the course and provided very positive feedback regarding the quality and usefulness of the course. Having passed all the assessments, this employee is now able to demonstrate that he has acquired knowledge of the application of uncertainty analysis to Earth observation applications.

Discussions are currently underway between NPL and ESA’s Learning and Development department regarding the addition of the ‘Uncertainty Analysis for Earth Observation’ course to ESA’s internal course portfolio. This inclusion of the eLearning course to ESA’s portfolio will further increase awareness of the course, making it available to a wide range of employees. This is expected to lead to further uptake thereby disseminating metrology knowledge within the primary supporter’s organisation to support future products, projects and processes.

With regard to the indirect impact, the wider EO community has benefited from the availability of a remotely accessible, flexible training solution. To date, 35 ‘learners’ from the EO community in space, academia and other research institutes have enrolled on the ‘Uncertainty Analysis for Earth Observation’ e-Learning course. These include University College London, University of Zurich, University of Surrey, University of Reading, University of Swansea, University of Edinburgh, University of Aveiro (Portugal), University of Twente (Netherlands), National Institute of Aerospace Technology (Spain), Max Planck Institute for Biogeochemistry (Germany), Ocean University of China and Profilab (Belarus).

At the time of writing, 13 users have completed all three modules of the e-Learning course, and consequently have improved understanding of:

- The application of metrology to EO applications; and
- The evaluation of measurement uncertainty and its application to EO

Such an increase in appreciation of measurement uncertainty in the EO community is essential for addressing the improvement in traceability and accuracy of EO data required for future monitoring of environmental trends. This knowledge is also important in facilitating communication between the international metrology community and the EO community, helping to overcome conceptual and technical barriers through the dissemination of metrology knowledge applied to EO applications. This combination of improved knowledge of uncertainty and communication will have significant societal and environmental impact, ultimately providing trustable climate forecasts and increased confidence in consequent adaptation and mitigation policies

A large component of the future impact of the e-Learning course will be its use to educate students and early career researchers in the EO field. In this regard, NPL has registered interest from a number of academic institutions regarding the inclusion of the ‘Uncertainty Analysis for Earth Observation’ e-Learning course into their graduate and post-graduate programmes. In particular, it is anticipated that the e-Learning course will be used to support UCL’s MSc courses in Remote Sensing and Space Science in 2018. The University of Zurich have also expressed interest in using the course to train new graduate and postgraduate students as they enter appropriate MSc or PhD programmes. Discussions are underway with two other organisations.

Outside of Europe, NPL has been contacted by the University of South Dakota, who has shown interest in using the e-Learning course as the centrepiece of the delivery of their Image Processing Seminar course. In addition, the National Institute of Metrology in China has also shown interest in extending the ‘Uncertainty

Analysis for Earth Observation' e-Learning course to meet their own requirements in the Chinese EO community.

Aside from these examples of the future dissemination of the e-Learning course, individual members of the EO community, regardless of institution or employer, will be able to access the course from anywhere in the world, and at a time of their convenience.

Furthermore, the 'Uncertainty Analysis for Earth Observation' e-Learning course developed by this project will serve as the basis for the addition of future modules covering the application of uncertainty analysis to specific areas within the field of EO, such as land products, ocean products, data processing etc. This will result in a progressive learning pathway, which learners can use to build a solid foundation of the core principles of uncertainty analysis applied to EO, before moving on to apply this knowledge to a particular area of the field that is directly relevant to their work. The addition of these new modules will also increase the scope of a course, allowing it to impact a wider audience spanning all levels of the EO community, from instrument calibrators to data scientists to users of EO products. This will not only lead to impact for members of the EO community and the primary supporter ESA, but will lead to significant societal impact by providing robust, metrologically sound climate data to inform decision making and support policy implementation.

6 Website address and contact details

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