Publishable Summary for 16ENV03 MetEOC3
Further metrology for Earth Observation and Climate

Overview

The Earth's climate is changing although the scale of impact to society remains uncertain and with it government's ability to confidently take necessary mitigation/adaptation in a timely manner. A key limitation is the performance of forecast models and the quality of the data that drive them. Remote sensing from space, is the major means of obtaining the global data needed. The harshness of launch and environment of space severely limits accuracy and traceability. This project will improve pre-and post-launch calibration/validation (Cal/Val) of observations (land, ocean and atmosphere) to enable trustable information on the state-of-the-planet to be delivered to policy makers.

Need

Two thirds of the Essential Climate Variables (ECV) of the Global Climate Observing System (GCOS) rely on optical measurements. More than half must be measured from space. Improving traceability and accuracy of these data is at the top-of-the-agenda of space agencies. In many cases a factor of 10 improvement in measurement accuracy is required to optimally minimise the time to detect trends from natural variability. Climate forecast is based on models using empirical ground and space based data. Ground based is mainly local data whereas space observations deliver a global picture. The uncertainty of the empirical data determines the trustworthiness of the climate forecast. Reducing the uncertainty of this data is therefore considered mandatory. Achieving this reduction in uncertainty, places an urgency to address the following challenges:

- Maximal use of satellite observational capacity to globally detect small signals without driving cost. This requires improved (efficiency and accuracy) of pre-flight calibration and validation methods that are rigorously traceable to the SI.
- Improved confidence in multi-decadal time-series of observations and 'on demand' delivery of data requires post-launch interoperability between different sensors. Since the performance of most sensors change in-orbit this requires improved SI traceable post-launch calibration, validation and harmonisation methods including networks of 'ideally' autonomous test sites of a range of parameters.
- Policy makers and commercial users require trustable long time-base climate information i.e.-, metrologically based quality metrics assigned to bio-geophysical parameters
- Some climate parameters cannot be measured from space. Global representation requires networks of sensors tied to common international standards. Historical artefact based standards need to be replaced/enhanced through improved linkage to SI to ensure long-term reliability.

Improvement necessitates evolution of laboratory-based metrology transferred to field (and space) situations.

Although work has been successfully completed in two previous EMRP projects the challenge remains vast and global and the MetEOC series of projects continues to address the overriding traceability issue through undertaking new case studies as well as extending previous activities. Many space related projects can take a decade or more from conception to realisation, and this is similarly reflected in the timelines needed to prove and implement technological changes, where the innovation first needs to be proven in the laboratory before adaptation and migration to the field. For MetEOC laboratory techniques have now been proven and are now in adaption mode. In many cases the development of post-launch validation test sites, often in remote locations, requires, seasonally variant measurements to allow full characterisation and representation and thus long duration programs.

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Objectives

The overall aim of the project is to contribute to the establishment of the necessary metrology infrastructure, tailored to climate needs in readiness for its use in climate observing systems. This will be done through the following scientific and technical objectives:

1. To improve the accuracy, accessibility, and usability of SI traceable standards in pre-flight and post-launch calibration and validation and enable interoperability and harmonisation of 'at sensor' remote sensed 'level 1' (e.g. radiance, reflectance, irradiance) products. This will focus on transportability and the needs of small satellites (mass/size) through development of spectrally tuneable laser based sources with an uncertainty of 0.5 – 2 % for pre-flight calibration. Post-launch mathematical methods to enable bias removal and sensor to sensor interoperability including further prototyping to increase the readiness and early implementation of an SI traceable reference satellite such as TRUTHS/CLARREO will also be undertaken.
2. To further enhance the capabilities of autonomous 'SI traceable' networks of test-sites for the post-launch calibration and validation of sensors and their derived bio-geophysical products. This includes uncertainty analysis, accounting for the "non-representativeness" of sampling, scaling and propagation to the sensor at Top of Atmosphere. It will primarily focus on the uncertainty needs of Copernicus Sentinels S2 and S3 and their applications e.g. Ocean colour (Uncertainty <3 %) and vegetation ECVs e.g. LAI (Accuracy <20 %).
3. To establish a method for assigning aggregated quality metrics to a broad range of bio-geophysical ECVs, long term climate data records (CDRs) and the monitoring of mitigation strategies, through 'end to end' analysis. This will involve identifying gaps and weaknesses in retrieval algorithms, validation processes and use of historic data from extinct and not comprehensively characterised sensors such as the ATSR series.
4. To develop methods for enhancing the SI traceability of ground based networks used for climate monitoring e.g. Broad band Solar Radiation Network (BSRN) of WMO and Network for Detection of Mesopause Change (NDMC). Emphasis is given to address community based scales (e.g. World Infrared Standard Group (WISG) and World Radiometric Reference (WRR).
5. To facilitate the take up of the technology and measurement infrastructure developed in this and previous projects by the standards developing organisations, measurement supply chain (accredited laboratories, instrument manufacturers) and end users (environmental monitoring and regulation bodies such as the WMO and Group of Earth Observations (GEO)).

Progress beyond the state of the art

Significant progress towards the recognition from the EO community of the benefit of SI traceability and the means to achieve it has been made in the two previous EMRP projects (ENV04 MetEOC and ENV53 MetEOC-2). However the challenge to meet climate quality uncertainties for the majority of parameters still remains an aspiration that will take many years to achieve.

Laboratory pre-flight radiometric calibration methods have been established that largely meet user needs and this project will adapt the laboratory techniques further: increasing portability into clean room/vacuum conditions, wider and more automated spectral tunability and flexibility to allow easy adaptation to suit the emerging needs of small/micro satellites. In-flight on-board methods will continue to be developed and in some cases previous successes, such as in-flight black bodies in earlier EMRP projects will be exploited to further improve the sensor (using the blackbodies) performance itself.

New sensors will be built and traceably calibrated to improve the sensitivity and accuracy of a range of in-situ field based measurements, in particular networks for monitoring change in ECVs, as well as those providing calibration or validation of satellite observations. This will also include efforts to remove or reduce dependency on 'artefact' based standard, through development of SI traceable alternatives.

Work started in EMRP project ENV53 MetEOC-2 to validate satellite observations of vegetation based climate indicators will be extended from the initial demonstration test site in Oxfordshire to establish new sites in tropical forests of Costa Rica and Australia. This work will include further developments of techniques to create virtual forests as a means to evaluate uncertainties of satellite observations.

Methods to enable sensor to sensor harmonisation and assess the resultant uncertainties in an internationally coherent manner will be developed in collaboration with the world's space agencies through CEOS.

Results

The project will undertake a number of specific tasks to address the overall objectives some of the planned outputs are summarised below:

Objective 1

- Establish transportable tuneable laser based facilities (CW and pulsed) to facilitate pre-flight spectro-radiometric calibration of satellite sensors, at the point of need (e.g. in clean rooms) at climate quality uncertainty levels in a cost effective manner to meet the needs of cubesats – sentinels.
- Development of methods to facilitate harmonisation of post-launch sensor to sensor level 1 radiometric calibrations and how this can be improved through the use of an SI traceable reference sensor such in flight, such as TRUTHS.
- The use of ‘on-board’ black body standards and methods developed in EMRP project ENV04 MetEOC to improve the performance of limb sounding imaging spectrometers (air and satellite) used to monitor atmospheric ECVs. In particular, how to implement SI traceability on a cubesat based sensor system.
- Development of methods to establish the uncertainty of novel sensors such as Laser and spatial Heterodyne spectrometers.

Objective 2

- Transfer standards and methods to support the transition of CEOS calibration networks like RadCalNet to become fully operational and to aid new sites to efficiently establish and demonstrate SI traceability.
- Extend techniques prototyped in previous EMRP projects (ENV04 MetEOC and ENV53 MetEOC-2) to establish SI traceable validation test-sites for land products to other forest types.
- Initiate development of an SI traceable community Radiative transfer code to improve quantification and reduction in uncertainty of TOA satellite observations and the surface biosphere.
- Develop prototype hyperspectral sensors and also improved methods to evaluate uncertainties due to atmospheric propagation for ocean colour measurements particularly when used for System Vicarious Calibration of satellite sensors.

Objective 3

- Establish and utilise end to end metrological analysis for sensors on board Sentinel 3, in particular considering correlation in uncertainties and merged data products resulting in a ‘traceability document’.
- Characterise vegetated test-sties to assess and improve uncertainties in Land product ECVs leading to virtual testbeds for SI traceable satellite validation.

Objective 4

- Improve the sensitivity (an order of magnitude) and extend traceability of the Network for the Detection of Mesopause Change (initiated in EMRP project ENV53 MetEOC-2) and also to allow consistent measurements to be made from space on-board a cube-sat.
- Evaluate and remove current anomalies between different reference instruments of the World Infrared Standard Group by establishing a rigorous route to SI traceability through the development of a novel source and spectral calibration techniques. Together with further improvements in replacing the World Radiometric Reference for solar irradiance this project will remove the dependency on artefacts for WMO scales.

Impact

The impact objective *‘Facilitate the take up of the technology and measurement infrastructure developed in this and previous projects by the standards developing organisations, measurement supply chain (accredited laboratories, instrument manufacturers) and end users (environmental monitoring and regulation bodies such as the WMO and Group of Earth Observations (GEO))*’ enables the projects primary impact to be realised.

This primary impact stems from the project’s contribution to provide trustable evidence to policy makers on the scale and timescales of climate change so that they can implement timely and measured mitigation and adaptation strategies to ensure a sustainable environment and quality of life for European Citizens. Achieved from improved quality remote sensed data this will also lead to:

Impact on industrial and other user communities

Satellite manufacturers will have access to flexible, multifunctional transfer standards to improve pre-flight accuracy whilst reducing time and cost for calibrations. They will be used to demonstrate the potential of high quality data from constellations of micro-satellites.

International test-sites (radiometric and bio-physical) and networks together with associated 'good practices' will be supported with traceability and uncertainty evaluations to help validate post-launch satellite measurements: physical (level 1) and bio-geophysical (level 2) variables.

This project will develop and calibrate novel instrumentation for both satellites and ground measurements thereby providing opportunities for commercial sales from European industry, reducing dependency on imported sensors. In some cases the novelty/size of the instruments may facilitate new applications and/or significant improvement in the nature of the retrievable information.

Impact to metrological and science communities

The long time-series data sets from multiple sensors with robust quality metrics will allow scientists to reliably detect trends from backgrounds of natural variability leading to improved climate forecast models and impacts through improved knowledge of e.g. the carbon cycle.

Impact on standards

The project's activities will be carried out in close collaboration with key international coordinating bodies (e.g. CEOS, WMO) ensuring that good practices established and any community references will become de-facto standards. The project consortium will ensure that they work closely with the community to encourage the uptake and inclusion of SI traceability in any standardisation process particularly with the emergence of 'analysis ready data' and climate services.

Longer-term economic, social and environmental impacts

This project aims to establish a harmonised European metrology infrastructure to enable the EO and climate change community, to provide robust information and advice to support far-reaching socio-economic decision-making on mitigation and adaptation strategies facilitated by:

- Upgrade in performance of instruments
- Fitness for purpose data on effectiveness of carbon sinks
- Harmonised methods to identify and quantify trends in CDRs
- Improved awareness and consistency on the use and interpretation of 'uncertainty'
- A focal point providing advice on metrology aspects of climate data
- Reliable information to address concerns of sceptics

Other beneficiaries include international bodies e.g. CEOS, WMO, EUMETSAT, ESA, GEO and the EU Copernicus program together with national space agencies and associated aerospace industry from:

- International coordinated test-sites
- Raised profile of Cal/Val and traceability
- More efficient and accurate transfer standards
- A transnational focal point allowing an alignment of Cal/Val research efforts

Project start date and duration:		01 September 2017 (36 Months)
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