Metrology for Earth Observation and Climate

EURAMET

Publishable JRP Summary Report for ENV53 MetEOC2 Metrology for earth observation and climate

Background

"*Warming of the climate system is unequivocal. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased. It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century*". Intergovernmental Panel on Climate Change (IPCC) - Sept 2013. Although the IPCC has strengthened its conclusion, governments are reluctant to act, and the public remain confused. This is fuelled by the large uncertainty in climate model forecasts. Accurate and trusted measurements of sensitive climate indicators are needed to improve our knowledge of the Earth system. This project will work with the climate science community to address the urgent challenge of improving remote sensing measurements of Essential Climate Variables (ECVs), such as incoming radiation from the sun or sea surface temperature (SST). These measurements will improve the climate models and understanding of the resultant impact on society, enabling policy-makers to take urgent decisions on appropriate mitigation and adaptation strategies.

To achieve maximum impact and uptake from the project, much of its work is closely aligned to other international projects. For example the EU FP7 project QA4ECV and H2020 projects FIDUCEO and GAIA-CLIM, together with networks such as Network for Detection of Mesosphere Change (NDMC), RadCalNet of CEOS and GEO, and various ESA funded initiatives such as the ACTION project (which is establishing a test-site in Namibia and similar for validation of Ocean colour measurements). This project develops underpinning transfer standards and methods to facilitate access to (and demonstration of), traceability to SI, particularly in an 'end to end' manner. The complementary projects provide the drivers and specifications, and serve as test cases to implement the outputs. In some cases e.g. FIDUCEO and ACTION (both started post project selection) explicit reference to the complementarity of the project was included in the successful proposals.

Need for the project

ECVs are monitored to detect the small fluctuations which may reveal changes in the Earth system. In most cases, detection of changes of a few tenths of a per cent per decade are required, relying on measurements with uncertainty levels currently only realisable in the National Metrology Institutes (NMIs). The harshness of the launch and operational environment in-space, as well as the environmental conditions on aircrafts and at extreme remote earthbound observation sites can cause significant and unpredictable change in the performance of the instrumentation for remote-sensing of ECVs. Re-assessment of the accuracy of satellite instrumentation post-launch as well as regular recalibration of airborne- and ground based instrumentation is therefore essential before the validity of basic satellite data (such as reflectance and radiance) can be guaranteed. Calibration against, and traceability to, the international system of units (SI) guarantees long-term confidence, accuracy and reliability in the data and ensures consistency between instruments. These basic data products are additionally processed through complex non-linear retrieval algorithms to obtain the geo-physical and bio-physical parameters (e.g. the ECVs) that are important for understanding the state of the planet. End–to-end assessment of uncertainty and traceability is now recognised as an additional challenge that needs to be urgently addressed.

Scientific and technical objectives

This project will make progress towards establishing the tools, methods, and infrastructure to enable trustable confidence levels to be assigned to data used for climate change monitoring through the following scientific and technical objectives;

EMRP European Metrology Research Programme ▸ Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

- To develop generic measurement infrastructure for calibration validation and quality assurance by establishing the means to achieve harmonization and SI traceability of radiance and reflectance from space
- To improve measurement tools and techniques for SI traceability of sensitive atmospheric ECVs e.g. emitted radiance of the mesosphere
- To establish best practice for in situ measurements for validation of selected key biophysical ECVs e.g. Leaf Area Index (LAI), Fraction of absorbed photosynthetically active radiation (fAPAR) and ocean colour by demonstrating end-to-end SI traceable uncertainty.
- To measure and provide SI traceability for ECVs, impacting Radiation Balance, (RB) e.g. solar irradiance, and surface temperature by characterising and validating satellite measurements of incoming and outgoing radiative energy to and from Earth.
- To establish a prototype framework for a European virtual centre of excellence (European Metrology Centre for Earth Observation and Climate, EMCEOC).

The project will also increase awareness of 'metrology and uncertainty in climate' amongst climate experts, Earth Observation scientists and the general public.

Expected results and potential impact

Harmonisation and SI traceability for the Earth's Radiance and Reflectance from space

This project will:-

- Work with the Earth Observation community to develop an automated network of instrumented (ground reflectance) test sites (e.g. RadCalNet for Land) to calibrate satellites when in orbit to improve the understanding of satellite biases.
- Develop a reflectance standard for use onboard as satellite and on ground that is more stable to the sun's radiation than existing lambertian reflectance standards.
- Prototype a key part of the Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS) satellite calibration chain to allow SI traceable measurements of radiance from space.
- Combine and analyse data and uncertainties from multiple satellite instruments and hence provide mathematical techniques to perform uncertainty analysis for the specific needs of Earth Observation.

In the first 30 months of this project the consortium has:

- Supported the establishment of RadCalNet (www.radcalnet.org) as a network of instrumented test sites to provide satellite-to-ground comparisons for satellite product validation. RadCalNet was opened to Beta Release (first public access) in October 2016 and has been used by about 10 different users (mostly commercial satellite operators). These users provided positive and helpful feedback at a workshop in March 2017 and RadCalNet is currently completing testing ready for a public launch towards the end of 2017. The project has supported the establishment of RadCalNet by:
    - Performing a field campaign with CNES (French Space Agency) to find the optimum location for an ESA/CNES site in Namibia. (Autonomous measurement instruments will be installed during 2017 to make this site a RadCalNet site)
    - Writing good practice guidance on the establishment of a new field site and creating a framework of guidance documents for new sites.
    - Developing instruments to be used at these sites (e.g. LED radiometers) and ways to perform site-to-site comparisons and provide SI traceability to the network (MuSTR instrument which provides a transportable SI-traceable instrument to measure spectral radiance at the sites, and through characterising tarpaulin diffusers to be used as comparison reflectance artefacts)
    - Developing mathematical techniques to perform satellite-to-satellite and TRUTHS-to-satellite (see below) comparisons over the sites
    - Performing rigorous uncertainty analysis on the RadCalNet site radiance product and on propagating uncertainties from ground measurements to the satellite using an atmospheric correction model (radiative transfer codes), in collaboration with NASA scientists

- Supported the TRUTHS satellite concept: TRUTHS is a satellite which, if funded and launched, would carry its own SI-traceable calibration system into orbit, mimicking the calibration chain at National Metrology Institutes. This would enable the calibration of other satellites from orbit and would also provide, through TRUTHS's own measurements, a "climate benchmark" – the most accurate measurements of the state of the planet that could be compared in the future to understand climate change and which would inform climate models. The project has prototyped the calibration system of TRUTHS to increase the technology readiness level of the concept and is currently writing this up as a scientific paper. The project has also performed theoretical analysis on the uncertainties associated with using TRUTHS to calibrate other satellites, improving the scientific case for TRUTHS.
- Performed tests on potential replacement diffusers for both on-satellite calibration systems and for field campaigns and used an ESMRG (from Aalto, Finland) to extend this work to study the ageing mechanisms for such diffusers.
- Initiated further work with REG partner (University of Zurich) to improve the calibration of the airborne hyperspectral imager APEX.
- Five conference paper proceedings have been published, seven standards have been input into, eight presentations have been given at international conferences and a training course has been developed which is showing significant use amongst other professionals.

SI Traceability for Atmospheric ECVs

In order to demonstrate the value of SI traceability the project will carry out three case studies and will:

- Further develop black body targets for in-flight calibration of limb sounders which are used for the traceable monitoring of temperature and chemical composition in the atmosphere
- Provide SI traceability of emitted radiance of the mesosphere through the Network for Detection of Mesospheric Change (NDMC)
- Establish SI traceable routes for Aerosol Optical Depth (AOD) and water-vapour by measuring absorption/scattering losses through the atmosphere.

In the first 30 months of this project the consortium has:

- Submitted a report on uncertainty propagation through the GLORIA (Gimballed Limb Observer for Radiance Imaging of the Atmosphere) retrieval algorithms to provide a threshold value for the uniformity of the two in-flight reference black bodies. Improved their temperature sensors and the control electronics, verified that the blackbodies now well confirm to the required uniformity (33 mK were achieved) and successfully used them during the extensive research campaign POLSTRACC in winter 2016. A follow up reference blackbody intended for future long duration balloon missions in the stratosphere utilising a phase change material as heat reservoir and for temperature stabilisation was successfully build, fully characterised and verified to fulfill the same requirements on uniformity over the intended time of operation of at least 8 hours without any external energy consumption.
- Reviewed the application of CNT (carbon nanotubes) as novel high emitting backplanes for LARS-1 and LARS-2 (aircraft standards used to provide the in-flight calibration of GLORIA). This has been assessed at PTB from a CNT-safety perspective. Two reports have been written about the release rates of single CNTs, bundles of them or fragments from CNT coated surfaces. These release rates have been determined during extensive tests of lab handling of coated samples and during modelled blackbody operation conditions (airstream, vibration). Under the investigated conditions no released CNTs could be found which clearly indicates a concentration well below the WHO threshold value. So under these conditions no health risk could be assessed. A first set of test substrates were successfully coated and their performance will be tested.
- Analysed the climate sensitivity of the mesosphere and its impact on uncertainty requirements for the emitted radiance measurements and thus the transfer standards needed for traceability. This is more demanding than originally thought requiring a 30 mk uncertainty on the traceability. The coupling of a travelling reference spectrometer (TRSP) and travelling reference source (TRSO) was selected and modified accordingly. A complementing transfer radiometer for in-lab scale transfer was finalised and used successfully to transfer the scale to the TRSP and TRSO with the required uncertainty. Currently the first NDMC ground station is under calibration with the TRSO and TRSP. The first NDMC ground station at DLR in Oberpfaffenhofen was successfully calibrated by the TRSO and TRSP in January 2017 enabling traceable measurements in absolute radiance of GRIPS instruments for the first time. In

addition to the now traceably determinable rotational temperatures the determination of the density of the OH radicals is now possible. Currently the aging investigation of the TRSO and TRSP is performed and the calibration of the second ground station is planned for May 2017.

End to End traceability for bio physical ECVS

In order to establish end to end traceability for bio physical ECVS, the project will take case studies from the carbon cycle and natural sinks of Carbon dioxide on Land and Ocean. To do this it will:-

- Characterise and evaluate uncertainty of field-based validation instrumentation for measurement of LAI (Leaf Area Index), and faPAR (Fraction of absorbed photosynthetically active radiation)
- Traceably parameterise a forest test site for a digital representation in a radiative transfer model
- Establish traceability of spectrometers for ocean colour (OC) calibration and validation

In the first 30 months of this project the consortium has:

- Selected commonly used ECV definitions and implemented the illumination and structural variations that correspond to these definitions (e.g., leaves are black, no wood structures within canopy, direct illumination only, etc.) within highly realistic virtual 3D plant environments
- Characterised field instrumentation, including PAR and LAI sensors in both lab and field conditions, as well as conducted a comparison of terrestrial laser scanners.
- Conducted summer and winter field campaigns at Wytham Woods, Oxford using these LAI and PAR sensors as well as with ground and drone based lidar (in conjunction with one of our REG partners).
- Used the TLS data to create a tree stem map of the 6ha field site. Each of the 3500 trees have been identified in the Smithsonian inventory and have associated species, height and diameter information.
- PAR network has been installed and running since October 2015 and includes 32 sample points over ~1.5 ha of Wytham Woods.
- Published 2 papers in journals, submitted 3 other papers that are currently under review and disseminated results at 2 conferences and 2 workshops.
- Contributed to good practice guides for a biodiversity source book http://www.gofcgold.wur.nl/documents/BiodiversitySourcebook/ and for a sourcebook of methods and procedures for monitoring measuring and reporting http://www.gofcgold.wur.nl/redd/.
- Had the Terrestrial Laser Scanning work showcased on BBC news: (http://www.bbc.co.uk/news/science-environment-38335348)
- Interviewed about TLS and PAR network for an Oxford University documentary series called “the Laboratory with Leaves”, - available from http://www.ox.ac.uk/content/wytham-woods-laboratory-leaves.
- Provided an evaluation of Ocean Colour sensors to be used in spectrometers in conjunction with one collaborator and started to evaluate principle sources of uncertainty for Bousolle (the European ref buoy for Ocean Colour)
- A laboratory based comparison of absolute irradiance and radiance calibration of hyperspectral RAMSES TRIOS took place. NPL participated in this comparison run by our collaborator Tartu Observatory, European Commission Joint Research Centre and TRIOS instruments manufacturer. The results were in agreement within stated uncertainty were reported by the pilot on S3VT meeting in 2017 and on the "Options for future European satellite OCR vicarious adjustment infrastructure for the Sentinel-3 OLCI and Sentinel-2 MSI series", organised by the FRM4SOC team at ESRIN 2017.

Traceability for EVCs impacting radiation balance (e.g.: solar irradiance, and surface temperature.)

In order to establish SI traceability for the Earths incoming energy, solar irradiance and thermally emitted radiation the project will:

- Characterise the CLARA solar radiometer - used to measure incoming Total Solar Irradiance, (TSI) due for launch in 2016.
- Design and build a reference radiometer for land and sea surface brightness temperature in order to measure thermally-emitted radiation from the Earth’s surface temperature (land and ocean)
- Progress towards an SI replacement for the WMO World Radiometric Reference (WRR).

In the first 30 months of this project the consortium has:

- Assembled and fully calibrated the CLARA flight radiometer in irradiance mode against the NIST-traceable cryogenic radiometer at LASP, Boulder, USA. It was then delivered to UTIAS, Toronto, Canada, for integration with the NORSAT-1 spacecraft ready for launch. This launch was delayed due to wider technical issues – however is set for 14th July 2017.
- The Cryogenic Solar Absolute Radiometer (CSAR) and the Mitra window transmittance facility (partly developed in the previous EMRP project (ENV04 MetEOC) and updated in this project) have successfully taken part in the 5 yearly international comparison in Davos. Earlier noise in the window transmittance measurement has been reduced by more than a factor of ten leading to overall uncertainties around 0.02% and conclusive evidence of a significant bias in the WRR of around 0.27% (although within the uncertainties claimed for the WRR).
- The CSAR is now installed and routinely used at World Radiation Centre in Davos in conjunction with the WRR. It is now engaged in a long-term monitoring program to demonstrate its stability and reliability alongside the existing instruments as is required before it can be formally considered as an 'SI replacement for the WMO WRR'.
- Requirements and assessment of the state of the art (performance and traceability) of existing SST and LST radiometers has been carried out as part of an ESA collaboratively funded international comparison project called FRM4STS. Conclusions from this exercise has now being incorporated into the design specifications for a new reference instrument, the key aspects of which will be prototyped in this project.

Prototype framework for a European Virtual Centre of Excellence

This project will establish a prototype framework for a European virtual centre of excellence (European Metrology Centre for Earth Observation and Climate, EMCEOC). This will be a 'one-stop-shop' for EO and climate metrology. The provision of traceable and reliable data with known uncertainties will improve the understanding of climate dynamics and the ability to interpret trends. This will enable investment decisions to be taken with improved confidence in their outcome; the consequence is that a verifiable link can be made between the outputs of this project and society's response to the effects of climate change. By virtue of the direct involvement of NMIs as part of this project, data from European satellite missions and associated projects as well as from European aircraft missions and ground based networks will become de-facto references upon which others will build.

The consortium partners are developing a close working relationship (including joint participation in other related projects). The partnership is being recognized as a key contributor to other related projects e.g. EU QA4ECV, FIDUCEO and programs (e.g.: ESA Action and FRM4STS) and will form the basis of a subset of key metrology organisations who can work towards the establishment of a framework for a virtual EMCEOC.

Key Impacts

- The project has assisted CEOS in the development of its RadCalNet network, now approaching operational readiness and ESA/CNES to establish a new test site in Namibia as a European contribution. RadCalNet had more than 10 satellite owners take part in a 6-month beta testing phase and presented results declaring the high value of the network and encouraged it to be fully open as soon as possible and encourage additional sites to join.
- The retrievals of atmospheric composition parameters from GLORIA have been significantly improved, including end to end uncertainty analysis which has led to a specification for improvements required for future work.
- The first station of the NDMC network has been fully traceably calibrated, removing ambiguity and allowing density of OH radicals to be determined. This provides a pre-cursor to further improvements to be carried out in the future under MetEOC 3.
- The European reference buoy, BOUSSOLE, anchored off the coast of Nice, one of two in the world used for the system vicarious calibration of ocean colour monitoring satellites, most notably the recent OLCI sensor on board Sentinel 3, has had its uncertainty fully evaluated following a 9 month secondment to the French operating team.
- The QA analysis that has taken place in the project and the promotion of SI traceability has led to the explicit inclusion of this in stakeholder ITT's. This has led to significant opportunities to improve uncertainty (and the recognition of the importance of uncertainty) in climate and Earth observation in general, with Europe taking the lead here.

JRP start date and duration:	01 September 2014, 36 months
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