Fiducial Reference Measurements for validation of Surface Temperature from Satellites (FRM4STS) – Methodologies for maintaining FRM TIR radiometer calibration under Sea Surface Temperature (SST) field conditions.

Protocol for the FRM4STS SST FICE (FICE-IP)

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1. Introduction

A number of groups around the world have been measuring SST with TIR radiometers since the 1990s (Jessups, et. al 2002, Minnett et. al, 2001, Donlon et. al 2008). The Protocols used by these groups for the measurements of SST are all similar and have been evaluated against each other at TIR inter-comparisons (Barton, et. al, 2004). However a more formalised version of these protocols was only recently published by Minnett, et. al (2012) and Donlon et. al (2014 & 2014a).

Donlon et. al (2014 & 2014a) define a set of 9 protocols intended to guide any group collecting ship borne infrared radiometer data for use in satellite SST validation activities towards a "common sense" best practice that will improve the quality and reduce the uncertainty in the satellite SST validation process. Each individual deployment of a ship-borne radiometer is highly specific and the protocols summarised below are considered as a minimum requirement for the FRM TIR SBRN.

2. Definition of measurement methodology.

The exact methodology used to measure SST_{skin} using a ship-borne radiometer shall be fully documented. This shall include:

- A full technical description of the radiometer instrument (e.g. spectral characteristics, sampling characteristics, measurement technique, a description of the instrument internal calibration approach etc.).
- The spectral characteristics of the measurement system (i.e. instrument band-pass).
- The value used for seawater emissivity.
- How the component of "sky radiance" reflected at the sea surface into the radiometer field of view is properly addressed (Donlon and Nightingale, 2000).
- A description of the radiometer mounting arrangements and the geometric configuration of the radiometer with all measurement angles accurately documented.
- A description of steps taken to ensure that measurements are free of ship effects (e.g. ship's bow wave, significant emission from the ship superstructure, emissions from ship exhaust plumes etc.).
- On-board instrument software used (e.g., version, release date, etc.).
- Data post processing software (e.g., version, release date, etc.).
- Any other aspect considered relevant to better understanding the quality of the measurements obtained.

3. Definition of laboratory calibration and verification methodology and procedures.

Infrared radiometers typically used for satellite validation work are calibrated using on-board calibration reference radiance sources (blackbodies). The purpose of performing pre-and post-deployment verification using external reference blackbodies is to assess the accuracy of the internal calibration system, and to provide a link in an unbroken chain of comparisons linking the shipborne radiometer to an SI reference. The exact methodology and procedures used to perform a laboratory calibration and verification of a radiometer shall be defined and documented (Theocharous and Fox, 2010; Theocharous et. al., 2010)

4. Pre-deployment calibration verification.

Following the defined methodology and procedures set out under Protocol 2, the calibration performance of a shipborne radiometer used for satellite product validation shall be verified prior to deployment using an external reference radiance source that is traceable to SI standards over the full range of sea surface temperatures expected for a deployment at sea. Ideally, the verification measurements should be repeated over a range of ambient temperatures to assess the influence of stray radiation on the radiometer measurements. The radiometer hardware, on-board configuration, on-board processing software, and data post processing software shall not be modified in any physical way between the calibration and the sea deployment (with the exception of dismounting and transporting the instrument to the calibration laboratory).

5. Post-deployment calibration verification.

Following the defined methodology and procedures set out under Protocols 2 and 3, the calibration performance of a shipborne radiometer used for satellite product validation shall be verified after deployment.

6. Uncertainty budgets.

Shipborne radiometer calibration and verification data shall be linked to uncertainty budgets determined in agreement with defined National Standards Laboratory protocols (JCGM, 2008) accounting for a comprehensive range of uncertainty sources (e.g. contributions from instruments, processing, deployment restrictions, and environmental conditions etc.). An uncertainty budget for the end-to-end SST_{skin} measurement shall be provided.

7. Improving traceability of calibration and verification measurements.

Efforts should be made where possible to define community consensus schemes and measurement protocols for calibration and verification. Well-documented data processing schemes and quality assurance criteria shall be established to ensure consistency and traceability to SI standards of in situ radiometer measurements used for satellite validation. Ship-borne radiometer users must participate regularly in inter-comparison 'round-robin" tests and comparison with international standards to establish SI traceability for their data. International radiometer and reference blackbody inter-calibration experiments (Kannenberg, 1998; Rice et al, 2004; Theocharous. and Fox, 2010; Theocharous et. al., 2010) are essential under this protocol and the need for regular activities of this type is obvious (Minnett et. al., 2012). They promote the dissemination of state-of-art knowledge on instrument calibration, measurement methods, data processing, training opportunities and quality assurance. In preparation for the launch of new satellite instruments and the on-going validation of currently flying satellite instruments, the CEOS community has recognized the need for a fourth FRM infrared radiometer and reference blackbody inter-calibration experiment. The proposed experiment includes the following components:

- A laboratory-based comparison of the calibration processes for FRM TIR SBRN radiometers and verification of blackbody sources used to maintain calibration of FRM TIR radiometers and provide traceability to SI.
- Initiation of field inter-comparisons using pairs of FRM TIR radiometers to build a database of knowledge over a period of several years.

The benefits of radiometer inter-comparison work includes:

- Establish and document protocols and best practice for FRM TIR radiometer and reference blackbody inter-comparisons for future use.
- Establish community best practices for FRM TIR radiometer deployments,
- Evaluate and document differences in IR radiometry primary calibrations and performances under a range of simulated environmental conditions,
- Establish and document formal SI-traceability and uncertainty budgets for participant blackbodies and radiometers,
- Evaluate and document protocols and best practice to characterise differences between FRM TIR radiometer measurements made in field (land, ocean, ice) operational conditions,
- Follow QA4EO principles and in particular Guidelines: QA4EO-QAEO-GEN-DQK-004, version 4.0 (Fox and Greening, 2010).

8. Accessibility to documentation.

Documentation describing ship-borne radiometer calibration and verification process shall be made available to the user community to promote peer review and ensure appropriate promulgation of knowledge on shipborne radiometer calibration and verification.

9. Archiving of data.

Ship-borne radiometer calibration and verification data should be archived following good data stewardship practices providing access to records by research teams on request. Laboratory calibration and verification data shall be published in a format that is freely and openly available to users of the data.

10. Periodic consolidation and update of calibration and verification procedures.

Ship-borne radiometer calibration and verification measurement procedures should be consolidated as a result of a critical review of those currently documented in peer-review literature or already included in compilations produced by former programs and "lessons learned" from deployments aboard ships and in the laboratory. Consolidated protocols should be maintained and published.

11. Summary

This section lists all the required steps needed to measure SST with FRM field TIR Radiometers. The aim was to keep this list fairly short so a good overview of all the steps can be given. A more detail discussion for each section can be found elsewhere (Donlon et al 2014 & 2014a) and (Minnett et. al. 2012a,) where the latter also discusses the design of FRM field TIR Radiometers.

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