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The Copernicus TRUSTED Project: Overview and status of the SVP-BRST buoy.

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1. Scope of Document

This document presents the status and activities of the Copernicus funded project: Towards Fiducial Reference Measurements of Sea Surface Temperature (SST) by European Drifters (TRUSTED). The document gives a description of the TRUSTED SVP-BRST drifting buoy and provides a description of the future steps planned within the next phase of the project.

2. Introduction

There has been continuous improvement of satellite derived ocean surface temperature over the last four decades. The satellite SST community uses globally available in-situ SST data for the validation and algorithm development of the SST produced from the satellite data processing chain. SST measurements acquired by drifting buoys are therefore an essential validation dataset.

Drifting buoys conform to a standardized specification defined by the World Meteorological Organization (WMO) Data Buoy Cooperation Panel (DBCP). There are currently a significant number of buoys deployed (over 1300) and historic data go as far back as the 1980's. Drifting buoys primarily to provide ocean surface temperature and pressure measurements for weather forecasting applications. They also contribute to knowledge of ocean currents.

Although drifting buoys had been used for many years by the satellite SST community for validation and algorithm development, closer links between the drifting buoy community and the satellite Sea Surface Temperature group (Group for High-Resolution Sea-Surface Temperature, GHRSST) only started in 2009. A standard for HRSST-1 drifting buoys was proposed, defining requirements on temperature measurements and positioning accuracy as part of the GHRSST/DBCP Pilot Project (Poli et al, 2019).

Additional, more stringent requirements on measurement accuracy were outlined for the HRSST-2 standard in 2013. The full requirements are listed in a presentation given by P. Blouch at the DBCP29 meeting (Blouch, 2013) and are given in Table 1.

ID	Requirement
Rq-1	Hourly measurements
Rq-2	Report design depth in calm water to ± 5 cm
Rq-3	Report of geographical location to ± 0.5 km or better
Rq-4	SST accuracy to ± 0.05K or better, resolve 0.01K
Rq-5	Report of time of SST measurements to ± 5 minutes

Table 1: HRSST 2013 requirements

An additional request to the DBCP was made in 2021 for the HRSST-2 specification to have searchable and accessible global metadata information.

Since the quality of satellite SST has improved significantly in recent years, and with the continuation of climate quality dual-view reference infrared sensors of SST in near-real time, a critical need has emerged for very high quality and accurate in situ data, with SI-traceability and per-sensor calibration. Such Fiducial Reference Measurements (FRM) would ensure daily and long-term product quality of the satellite SST time-series.

Therefore further consideration to the requirements for instruments acquiring in situ data for the validation of satellite retrievals, and non-recoverable drifting buoys, were also given in the framework of the ESA FRM4STS project, in particular with regards to traceability to SI (http://www.frm4sts.org/wp-content/uploads/sites/3/2018/08/OFE-OP-20-V1-Iss-1-Ver-2-Final-rev-1-signed.pdf).

The TRUSTED project began in 2018 to begin developments and service towards FRM from drifting buoys as a response to the SST validation needs of the Copernicus Sentinel-3 satellites.

3. The TRUSTED Project

3.1. Overview

The launch of the Copernicus Sentinel-3 satellites in 2016 and 2018 (Bonekamp et al., 2016) with its state-of-the-art Sea and Land Surface Temperature Radiometer (SLSTR) led to a need for high quality Fiducial Reference Measurements (FRM) to validate and ensure satellite SST product quality. To fulfill these needs, a new drifting buoy was developed, building on the high accuracy of the HRSST-2 specification but additionally traced by a formal metrology procedure. The evolution of the platform and instrumentation over time needs to be traced through an improved metadata and Quality Control (QC) scheme, easily accessible by data users. These improvements were implemented in a dedicated project, the Copernicus funded TRUSTED project, to provide a service of measurements from these newly developed drifting buoy platforms.

The service provides measurements based on the on the HRSST-2 standard but with further requirements on 4 components (Lucas et al., 2021):

- Independent metrology and calibration per sensor independent of sensor manufacture.
- An uncertainty budget and traceability diagram for the buoys, including a component on the drift analysis and links to satellite SST.
- Improved Quality Control (QC) procedure, metadata collection system and archiving.
- Post deployment calibration if possible.

Table 2 gives an overview of the characteristics of TRUSTED drifting buoys

Project specification	Sensor accuracy achieved	Calibration	Positioning	Hydrostatic Pressure	Metadata level	QC
2018-2021	0.011°C	Metrology Lab	High	Yes	Medium	Partially achieved
2022-2023	To be assessed	Metrology Lab	High	Yes	High	Full scheme in progress
2024 onwards	to be assessed	NMI approved	High	Yes	High	Fully implemented

Table 2: TRUSTED characteristics

3.1.1. Independent Metrology

The TRUSTED project implemented a metrological calibration procedure (Le Menn et al, 2019) on all HRSST sensors. This procedure was additional to the calibration performed by the sensor manufacturer.

Each sensor is calibrated in a controlled environment where each component has known uncertainties regularly controlled by instruments that are linked to SI. A verification is then performed once the sensor is integrated within the buoy. This is possible because the MOSENS HRSST/HP sensor, developed by NKE, can easily be mounted and dismounted on the buoy.

This also means that it is relatively easy to retrieve a sensor and perform a post deployment calibration to investigate the sensor drift over a given period. This was performed for two buoys in the first phase of the TRUSTED project.

Le Menn et al (2019) estimated the HRSST sensor uncertainty for the buoys in the calibration laboratory was of 0.025 °C. This exceeds the HRSST-2 specification of ±0.05°C albeit in the laboratory and not at sea. Note that further calibration checks on buoys recovered gave uncertainty values of 0.011°C (Table 3)

3.1.2. Uncertainty budget

The TRUSTED project has evaluated the accuracy and uncertainty of the HRSST sensors through meticulous calibration activities (Le Menn et al, 2019) prior to their deployment. This ensures that the sensors met the specification for HRSST-2 accuracy.

The quality of the global drifter network has improved in general over the last few years as the majority of deployed buoys now meet the HRSST-2 specification (Corlett et al, 2021). The global array of HRSST-2 drifting buoys now exceed the accuracy reported by O'Carroll et al (2008) where the global standard deviation of error was 0.23°C for drifting buoys. This enables good quality SST drifting buoys to be available for satellite SST validation.

Evolutions are now ongoing to characterize the uncertainty budget for the TRUSTED drifting buoys as an important further step for FRM. The measurement accuracy and uncertainty will be considered, including all components from the instruments, ocean effects, and links to the satellite. The uncertainty budget will be reviewed by National Meteorological Institutes (NMI's) to confirm the approach for FRM drifting buoys. This will allow traceability to SI to be fulfilled for the drifting buoys, which is a crucial step for ensuring continuation of ocean surface temperature time-series of Climate Data Records.

3.1.3. Quality Control and metadata

To ensure the quality of the measurements, it is important to follow strict QC procedures and have available accessible, archived metadata. This includes the archiving of the QC performed within the measurement data streams, as well as information on the instrument platform such as the manufacturer, the deployment location, and any other relevant information. The information must be readily available in the data-streams, searchable, and accessible, and in an ideal situation included in any file that contains the data. For the TRUSTED measurements, the global metadata is easily accessible via the Ocean OPS web portal. A machine-to-machine protocol is currently being developed to enable the automatic retrieval of the relevant metadata. Evolutions of the QC methodology and access are currently in progress to ensure all the QC information is available and provided together with the data (CMM, 2022,1 &2, Ocean-Ops, 2022).

3.1.4. Post Deployment Calibration Verification

The assessment of the evolution of sensor accuracy over time, and other factors impacting their stability, is challenging due to the difficulty in recovering the buoys following deployment and service.

In the frame of the TRUSTED project, 2 buoys were recovered. The first one of which was deployed by the BSH on 20th October 2019 and was attached to its NSB3 fixed mooring in the German Bight. It was recovered on the 15th September 2020. The second buoy, deployed on 20th September 2019 in the North Atlantic was recovered by the SHOM Beautemps-Beaupré vessel east off Iceland at 66.66° N 10.66°W on the 8th August 2020. In both cases, the platforms had been at sea for over 300 days.

This enabled the SHOM metrology team to perform a post deployment calibration of the HRSST sensor and the buoys. The results showed that after almost a year, the HRSST sensor still satisfied the initial accuracy remit specified by EUMETSAT (Table 3).

Tref standard uncertainty :	0.001	°C
Bath stability standard uncertainty :	0.000	°C
Reproducibility buoy n° 017 :	0.005	°C
Repeatability buoy n° 017 :	0.001	°C
Verification expanded uncertainty:	0.011	°C

Table 3: Uncertainty table for the BSH buoy

Prior to the deployment, the BSH performed a full vibration test on the North Sea SVP-BRST buoy. Furthermore, temperature and weather data were also collected by the NSB3 instruments during the duration of the deployment (Herklotz, 2021).

3.2. Workshop on HRSST drifting buoys for satellite SST

The TRUSTED project is a continuation of the collaborative work undertaken over the last decades by the GHRSST group and the drifting buoy community, most notably the GDP and DBCP. To this end, the TRUSTED consortium provides regular updates on the project progress to the drifting buoy community at the DBCP yearly meetings and to the satellite community through presentation at GHRSST and Sentinel-3 Validation Team (S3VT) meetings.

To continue this collaboration and coordination, a workshop was organized in 2021 to review the progress and science of high-resolution SST from drifting buoys and to gather the drifting buoy and satellite SST community thoughts on future steps. The 5 sessions were attended on average by 30 people and enabled the formulation of the following recommendations:

- For the GHRSST and DBCP communities to revisit and revise the GHRSST/DBCP HRSST specification.
- For the GHRSST and DBCP communities to formulate an agreed FRM standard for drifters (e.g. could be HRSST + SI + uncertainty per measurement + metadata).
- Continuation of metadata repository activities are essential and should include automatic interrogation of the complete OceanOps metadata repository. Progress towards supplying complete metadata information per measurement is important.

Full details of the recommendations and outcomes of the workshop can be found in the workshop report: https://www.cls-telemetry.com/workshop-high-resolution-sea-surface-temperature-hrsst-drifting-buoys-for-satellite-sst/.

The continuation of FRM TRUSTED activities was recommended and should address evolutions and progress on further measurements at high-latitudes, uncertainty budgets, global and measurement metadata and Quality Control procedures, along with the development of a new sea-ice drifting buoy.

4. Towards Fiducial Reference Measurements

The TRUSTED project has provided high-quality reference in-situ measurements of SST for Copernicus Sentinel-3 satellite validation, meeting the HRSST-2 specification plus additional aspects towards FRM status including calibration and metrology per sensor. Further work towards a full FRM specification is in progress, continuing to focus on:

- Calibration per sensor in laboratory independent of sensor manufacture.
- Measurement metadata and improved QC in both real time (online) and post-processing (offline) procedures.
- Definition of uncertainty budget for the buoys including a component on drift analysis.

- Coordination with National Metrology Institutes for approval of traceability to SI and FRM standards.
- Post-deployment calibration and analysis.

Activities are in progress to coordinate with NMIs on the traceability diagrams and uncertainty budgets to provide outcomes that can benefit the whole oceanographic drifting buoy community.

The progress towards Fiducial Reference Measurements (FRM) for satellite SST validation provides in situ measurements with excellent quality & accuracy. These activities benefit other projects and parameters such as https://ccvs.eu/ where FRM methodologies can improve the quality of other satellite parameters.

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6. Appendix

6.1. The SVP-BRST Buoy

The specifications of a new DBCP compliant drifter, the SVP-BRST, are summarised below in the table.

SVP-BRST Specifications

Communication:
Transmitter: 9602 iridium modem
Antenna: Helicoidal for Iridium Patch for GPS

GPS & position:
Receiver: 72 channels, code CA
Acquisition period: from 5 minutes to 10 days (1 typical hour)
Accuracy: typical < 10 meters

Transmission:
Period: from 5 minutes to 10 days
Messages: 11 fixes in one SBD (optional)

Temperature Sensor (HRSST):
Accuracy / Resolution: +/-0.005°C / 0.001°C
Range: -2°C to +35°C
Temperature sensor position: -15 cm

Depth Sensor:
Accuracy / Resolution: 0.15% / 0.5 mm
Range: 0 to 30 dBar

Barometric Pressure Sensor:
Range: 800…1100hPA
Accuracy: +/–0.3hPA at +20°C

Analog Sea Surface Temperature (SST):
Accuracy: <+/-0.1°C

Drogue:
Drogue indicatorl: Gauge sensor
Drogue: in compliance with DBCP drag ratio >40
Drogue (option): holey socks 0.6 m length 5 meters
Line (option): drogue centered at 15 m

Battery & autonomy:
Technology: alkaline
Capacity: 72 Ah
Autonomy: according parameters setting > 1.5 year

Environmental features:
Operating temperature: -20°C to +50°C
Storage temperature: -10°C to +25°C for optimum battery shelf life
Water tightness: 10 dbars