

Toward a buoys reference network for SST measurements

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Abstract – The Earth Observation EU funded Copernicus mission Sentinel program has driven the development of new space borne sensors, a new ground segment and improvement to the data processing chains. Of particular interest to oceanographers is the acquisition of high quality sea surface temperature data. In order to ensure data quality, the Copernicus funded TRUSTED project initiated by EUMETSAT, aims to deploy an independent fiducial reference network of over 100 Data Buoy Cooperation Panel (DBCPC) compliant Surface drifters. This development has implied the metrological characterization of the High Resolution SST (HRSST) sensor of the buoys and the insuring of the metrological traceability to the SI (International System of Unit) of their measurements.

I. INTRODUCTION

Sea-Surface Temperatures (SST) play a key role in the understanding of the interactions ocean-atmosphere but also to characterize the mesoscale variability of the upper ocean and to realize numerical weather predictions.

Measurements made in the upper 10 meters of the ocean are considered as SST measurements. However, satellite infrared radiometers measure radiations emitted from the upper few tens of microns (skin temperatures) or millimeters (subskin temperatures) for microwave radiometers [1]. Therefore, surface drifting buoys observations are preferred for comparisons with satellites data, as their sensors are to a nominal depth of between 10 and 20 cm [2]. According to the Data Buoy Cooperation Panel (DBCPC) about 1500 drifting buoys cover nowadays the seas of the globe and according to Kennedy (2014), they provide about 90 % of in situ SST data.

The Earth Observation EU funded Copernicus mission Sentinel program has driven the development of new space borne sensors, a new ground segment and improvement to the data processing chains.

More of that, in order to ensure data quality, EUMETSAT has initiated the Copernicus funded TRUSTED project. It aims to deploy an independent fiducial reference network of over 100 DBCPC compliant Surface drifters, based on the development of a new type of buoy, the SVP-BRST or Surface Velocity Program with Barometer and Reference Sensor for Temperature.

The drifters are drogued at 15 meters and carry 2 temperature sensors, a standard SST and one high resolution sensor called HR-SST, coupled to a hydrostatic pressure sensor with a sampling frequency of 1Hz, a barometer, a strain gauge and an iridium modem allowing them to send back observation data in near real time. The genesis and the design of these drifters are completely described in the reference [3].

One challenge was to ensure the metrological traceability to SI of the measured temperatures, with a determined uncertainty. Another challenge was to be able to calibrate 100 buoys to ensure the uncertainty of this reference network.

This paper describes the new kind of buoy developed, the metrological work made on the two prototypes built before the production of two series of 50 units, and the first results obtained.

II. CONCEPTION OF THE BUOY SVP-BRST

The baseline SVP-B design is from Sybrandy *et al.* [4]. Designed in the 1980s to study ocean currents in the context of the Surface Velocity Program (SVP) [5] and for meteorological purposes, these buoys had to be inexpensive, easy to deploy and reliable during at least 18 months. The design specifications of SVP drifters were standardized in 1991. In 1993 it became possible to equip a SVP drifter with a barometer port to measure the sea-level air pressure. The result was called SVP-B drifter. SVP drifters were also equipped with SST sensors. This sensor should have an accuracy of 0.1 K with a stability better than 0.1 K/year [5].

The buoy we developed is called SVP with Barometer

and Reference Sensor for Temperature (SVP-BRST) (see [6]). It is a spherical drifter of 40 cm diameter made of high pressure molded polypropylene. A 12.5 m line (including an elastic section) is attached below the buoy and linked to a stainless bracket. On the figure 1, only the drifter with the place of its sensors is drawn. A holey socks drogue centered at 15 m depth is suspended to the line. It is 0.8 m in diameter and 6 m length. The drogue loss is detected by a strain gauge, instead of a submergence sensor.

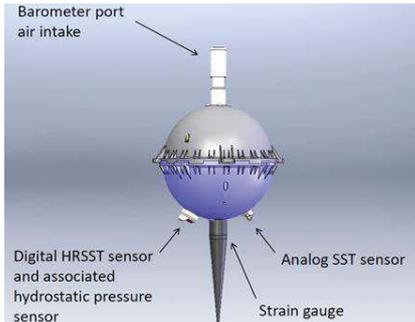


Fig. 1. Drawing of the buoy with its sensors. Doc. © nke Instrumentation

The temperature sensor called HRSST, because of its calibration and resolution of 1 mK, and an hydrostatic pressure sensor are integrated in a module called MoSens. This sensor is used to assess the measurements depths and the sea states. The temperature sensor called ‘analog SST’ (see Fig.1) answers the SVP-B specifications. The sensible part of analog SST and HRSST sensors is a thermistor. The air pressure is measured with a Vaisala PTB 110 BAROCAP (± 0.6 hPa from 0 to 40 °C) traceable to NIST calibration standards.

The MoSens device can be calibrated alone before integration in the buoy. That’s the solution found to be able to calibrate 100 buoys to the required uncertainty (< 0.05 °C).

III. THE METROLOGY WORK

The first work was to demonstrate the advantages of using a smaller and lighter temperature sensor.



Fig. 2. Photos of a MoSens module and of an analog SST sensor.

The figure 2 shows a MoSens module with the small needle of the HRSST sensor, and an analog SST sensor found on SVT-B buoys.

In accordance with the SVP-B design manual [3], these sensors are protected by a cap to prevent the solar heating

by direct radiation on the sensor, but one part of the sunlight enters also the ocean and can be reflected to the surface. Seawater is close to a blackbody in the infrared part of the spectrum and the blue-green radiations can be reflected at depths as great as 50 m [7].

As demonstrated in [6], a numerical comparison shows that the effect of heating by radiation is divided by 3.4 to the advantage of HRSST sensor. In fact, De Podesta *et al.* [8] have shown that this effect is proportional to the ratio (D/V) where D is the diameter of the sensor and V the flow speed. Therefore, the HRSST sensor measures temperatures closer to water temperatures.

Another numerical comparison shows also that the theoretical response time τ of the HRSST sensor is divided by 7.4 per comparison to SST sensor, τ being proportional to the ratio (m/A), where m is the mass of the sensor and A its surface of exchange. The results of this comparison are showed on Fig.3.

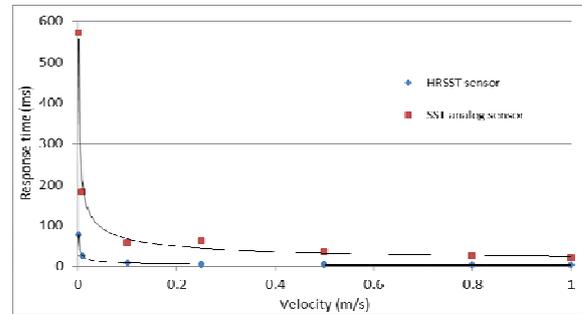


Fig.3. Response times of HRSST and analog sensors for different velocities.

However, the main contribution of the metrology in the TRUSTED project is in the calibration and the linkage or traceability to the SI of temperature measurements made by the buoys.

The MoSens devices are calibrated per comparison in a calibration bath whose thermal stability shows standard deviations between 0.1 and 0.3 mK during temperature plateaus. MoSens sensors are completely immersed and placed close to the sensitive part of a SBE 35 reference thermometer. This thermometer is verified and calibrated periodically in triple point of water (ptH₂O) and fusion point of Gallium (pfGa) cells, to ensure the linkage to the International Temperature Scale of 1990 (ITS-90), of the measured temperatures. The ptH₂O and pfGa cells are calibrated to the French National Institute of Metrology (LNE-CNAM), to 0.1 mK and 0.26 mK (at 2σ) respectively.

Eight temperature plateaus are created between 1 °C and 35 °C to allow the comparison between the devices and to calculate the coefficients of the Bennett relation to linearize each MoSens sensor, with a least-squares technique.

A calibration uncertainty budget is established for each module. The results for the two MoSens prototypes are given in Table 1. In this Table, contributions are given as

standard uncertainties. The value given for the reference temperature is the result of a combined uncertainty calculation. Bath stability, MoSens reproducibility and repeatability are obtained with a type A method. Bath stability is a standard deviation which can be obtained with series from 20 to an infinity number of values. Reproducibility and repeatability are calculated from eight series of at least twenty measurements which gives 7 degrees of freedom (ν) for the reproducibility and 152 for the repeatability. The reproducibility assessment includes the errors due to the thermal inertia of MoSens module.

The model used to calculate the combined uncertainty on the deviations D is:

$$D = t + \delta_{rep} + \delta_{repro} - t_{ref} + \delta_{bath} \quad (1)$$

In this equation, t is the average of the series of temperature values given by the sensor under calibration, t_{ref} is the average reference temperature, δ_{rep} is the short term variation of the sensor temperature, δ_{repro} is the long term variation of the sensor temperature and δ_{bath} is the difference in temperature due to the stability and the homogeneity of the bath which introduce small errors between t_{ref} and t at the time of measurements. Applying the GUM method [9] to relation (1) and assuming a correlation coefficient of 1 between δ_{rep} and δ_{bath} yields the following expression of the expanded uncertainty U_c :

$$U_c = 2 \sqrt{u_{t_{ref}}^2 + (S_{rep} + u_{bath})^2 + S_{repro}^2} \quad (2)$$

Table 1. Uncertainty budget of two MoSens calibrations.

| | n° 4656 (mK) | n° 4658 (mK) | ν |
|---|-----------------|-----------------|----------|
| Ref. temperature ($u_{t_{ref}}$) | 0.9 | 0.9 | ∞ |
| Bath stability (u_{bath}) | 0.3 | 0.3 | ∞ |
| MoSens reproducibility (S_{repro}) | 1.7 | 0.9 | 7 |
| MoSens repeatability (S_{rep}) | 0.3 | 0.3 | 152 |
| Expanded uncertainty | 4.0 | 2.8 | - |

Once calibrated, the MoSens sensors are integrated in buoys. One buoy per batch of ten is verified to ensure that the trueness and the uncertainty are conserved. Concerning the two prototypes, as it can be seen on figure 4, a platinum 100 Ω thermometer was fixed on one of them and protected from the air temperature variations with a piece of foam, in order to measure the external temperature of the buoys and to try to detect its influence on the HRSST and SST measurements.



Fig. 4. Two SVP-BRST prototypes in the calibration bath.

In order to study this point, a measurement series was made where the buoys were covered with a survival blanket, in order to shield them from radiation with the room and thus to partially insulate them from the room temperature, to enclose the radiations of the bath and to limit the air exchanges.

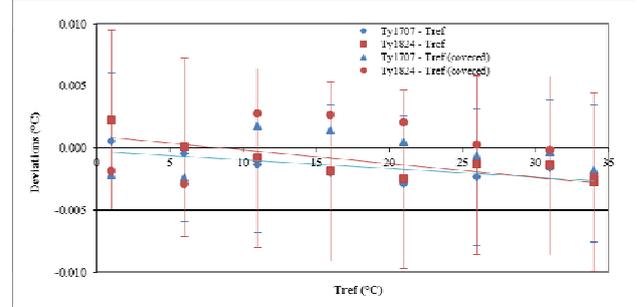


Fig. 5. Deviations obtained during the verification of HRSST sensors of two prototypes during the two series, with the expanded uncertainty of the verification.

The measurement series realized with the two prototypes have been used to assess in details the reproducibility of temperature measurements and the expanded measurement uncertainty of two buoys. It gives 6 mK for one and 7 mK for the other, with a coverage factor of 2, which is inferior to 0.05 $^{\circ}\text{C}$ as required. The results obtained show also that these deviations are more dependent on cooling or warming of the water than of the air temperature. A complete description of measurements and results is given in the reference [6] to be published at this time.

IV. TRIALS AT SEA

In order to demonstrate that the accuracy estimate still holds once the buoys are deployed at sea, the two prototypes were compared to a CTD profiler (SBE 911+) and a reference thermometer SBE 35 fixed on a Multi-Bottle Sampling Array (MBSA), during an oceanographic cruise in Mediterranean Sea.

The drifters were held in place near the ship by means of a line. When the MBSA was completely immersed, the CTD and the SBE 35 temperature measurements were recorded at about 1 m under the surface. After the surface

measurements were collected, the MBSA was lowered to 15 m depth in order to estimate the temperature profile of the first layers. This profile shows that on the four first meters, the temperature of the water was homogeneous and close to 16.4 °C, allowing fair comparison with the HRSST buoy (see Fig. 6). Between 4 and 5.5 m (depth where Argo floats surface temperature measurements are sometimes used as references) there was a strong temperature gradient of -1.25 °C m^{-1} . Beyond 15 m depth, the temperature was still very stable but shifted by about 2 °C as compared to the surface.

Measurement series have showed that without any correction, HRSST values are in the standard dispersion range of the values measured with the SBE 35 and the deviations compared to the CTD and the SBE 35 sensors are inferior to 0.01 °C: respectively -7 and -6 mK for one buoy and 0 and 1 mK for the other.

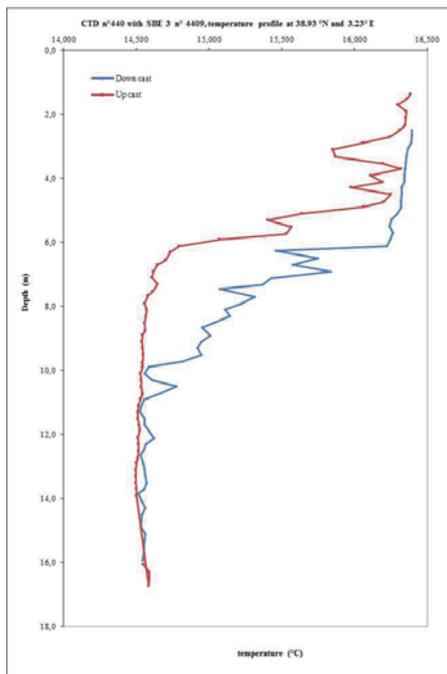


Fig. 6. Temperature profile measured by the CTD.

After this comparison, the two prototypes were released at the same time in an eddy feature. The details of this deployment are given in [3]. According to Poli *et al.* [3] they show that once freely drifting, the SST spread within 5 minutes is usually smaller than 0.1 K, especially when the sea-state is well-mixed and the buoys are within an eddy core (See trajectories on Fig. 7). That means that to understand the representativeness of the *in-situ* SST data it is necessary to take into account the sea-state. In the case of the SVP-BRST, this parameter can be retrieved thanks to the pressure sensor of the MoSens module.

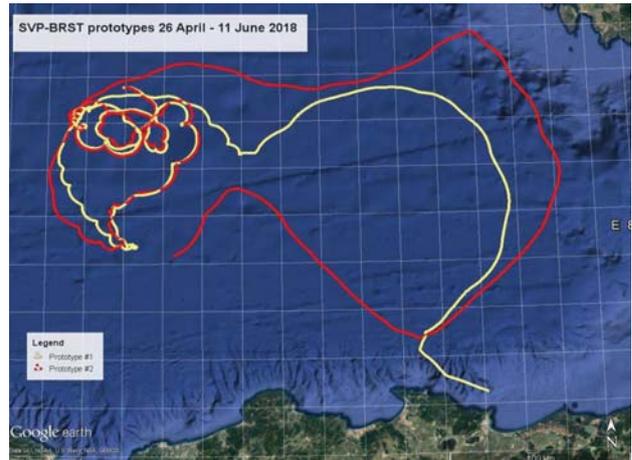


Fig. 7. Trajectories of two prototypes after their release in Mediterranean Sea.

V. CONCLUSION

The setting up of a fiducial reference network, cannot be dissociated of a complete metrology process in laboratory made of theoretical and/or experimental characterization of sensors and of their environment of measurement.

At this time, hundred MoSens have been calibrated and integrated in buoys. Ten buoys have been verified in the calibration bath. It stays now to demonstrate that the accuracy estimate remains valid for the lifetime of the buoys.

This point will be verified by mooring one buoy next to a platform in the North Sea. At least one buoy, previously deployed in the oceans during the phase 2 of the TRUSTED project, will also be recovered by Shom, based on the geographic positions of the array of buoys regularly tracked by Meteo France.

Therefore, this fiducial reference network is the fruit of collaboration between oceanographers, meteorologists, metrologists and industry.

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