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# Evaluating operational AVHRR sea surface temperature data at the coastline using surfers

Robert J.W. Brewin [a, b, *], Lee de Mora [a], Oliver Billson [c], Thomas Jackson [a], Paul Russell [c], Thomas G. Brewin [d], Jamie D. Shutler [e], Peter I. Miller [a], Benjamin H. Taylor [a], Tim J. Smyth [a], James R. Fishwick [a]

[a] Plymouth Marine Laboratory, Plymouth, Devon, United Kingdom
[b] National Centre for Earth Observation, Plymouth Marine Laboratory, Plymouth, Devon, United Kingdom
[c] School of Biological & Marine Sciences, University of Plymouth, Plymouth, Devon, United Kingdom
[d] Chatham & Clarendon Grammar School, Ramsgate, Kent, United Kingdom
[e] College of Life and Environmental Sciences, University of Exeter, Cornwall Campus, Penryn, Cornwall, United Kingdom

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A B S T R A C T

Sea surface temperature (SST) is an essential climate variable that can be measured routinely from Earth Observation (EO) with high temporal and spatial coverage. To evaluate its suitability for an application, it is critical to know the accuracy and precision (performance) of the EO SST data. This requires comparisons with co-located and concomitant *in situ* data. Owing to a relatively large network of *in situ* platforms there is a good understanding of the performance of EO SST data in the open ocean. However, at the coastline this performance is not well known, impeded by a lack of *in situ* data. Here, we used *in situ* SST measurements collected by a group of surfers over a three year period in the coastal waters of the UK and Ireland, to improve our understanding of the performance of EO SST data at the coastline. At two beaches near the city of Plymouth, UK, the *in situ* SST measurements collected by the surfers were compared with *in situ* SST collected from two autonomous buoys located ~7 km and ~33 km from the coastline, and showed good agreement, with discrepancies consistent with the spatial separation of the sites. The *in situ* SST measurements collected by the surfers around the coastline, and those collected offshore by the two autonomous buoys, were used to evaluate the performance of operational Advanced Very High Resolution Radiometer (AVHRR) EO SST data. Results indicate: (i) a significant reduction in the performance of AVHRR at retrieving SST at the coastline, with root mean square errors in the range of 1.0 to 2.0 °C depending on the temporal difference between match-ups, significantly higher than those at the two offshore stations (0.4 to 0.6 °C); (ii) a systematic negative bias in the AVHRR retrievals of approximately 1 °C at the coastline, not observed at the two offshore stations; and (iii) an increase in the root mean square error at the coastline when the temporal difference between match-ups exceeded three hours. Harnessing new solutions to improve *in situ* sampling coverage at the coastline, such as tagging surfers with sensors, can improve our understanding of the performance of EO SST data in coastal regions, helping inform users interested in EO SST products for coastal applications. Yet, validating EO SST products using *in situ* SST data at the coastline is challenged by difficulties reconciling the two measurements, which are provided at different spatial scales in a dynamic and complex environment.



## 1. Introduction

Sea surface temperature (SST) is considered by the Global Climate Observing System as an essential climate variable (GCOS, 2011; Bojinski et al., 2014). It is a vital property of the aquatic system, controlling its physical (Moore et al., 1999; Nonaka and Xie, 2003), biological (Eppley, 1972; Pepin, 1991; Keller et al., 1999; Lazareth et al., 2003; Doney, 2006; Tittensor et al., 2010; Couce et al., 2012) and chemical (Lee et al., 2006; Kitidis et al., 2017) environment. SST impacts the transfer of compounds between the ocean and atmosphere (Land et al., 2013; Takahashi et al., 2002), the distributions and foraging of many marine vertebrates (Frederiksen

* Corresponding author. Plymouth Marine Laboratory, Plymouth, Devon, United Kingdom.
*E-mail address:* robr@pml.ac.uk (R.J.W. Brewin).

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et al., 2007; Scales et al., 2014; Miller et al., 2015) and the regional and global climate (Sutton and Allen, 1997; Saji et al., 1999; Lea et al., 2000; Bader and Latif, 2003; Yu and Weller, 2007; Raitsos et al., 2011). It is also a variable that can be retrieved routinely, and operationally, with high spatial coverage and good temporal resolution using Earth Observation (EO), through measurements of radiation in the infrared (Llewellyn-Jones et al., 1984) and microwave (Wentz et al., 2000) portion of the electromagnetic spectrum from radiometers mounted on satellite platforms.

To evaluate the use of EO SST products for various operational applications, it is imperative to know the accuracy and precision of the data. This typically requires direct comparison of EO data with co-located and concomitant *in situ* data. In the open-ocean, our understanding of this accuracy and precision is generally high, due to a large network of *in situ* instruments on a variety of platforms, resulting in a considerable number of co-incident *in situ* and EO SST measurements distributed over a wide geographical area (e.g. see Table 3 of Merchant et al., 2014). However, despite demonstrative evidence on the value of SST observations for monitoring of coastal seas (e.g. Goreau and Hayes, 1994; Mustard et al., 1999; Paerl and Huisman, 2008; Tang et al., 2003), the economic and ecological importance of coastal waters (Costanza et al., 1997, 2014; Tittensor et al., 2010) and their high sensitivity to human pressures and climate change (Jickells, 1998), the accuracy and precision of EO SST data at the coastline are not well known, impeded by a lack of *in situ* data resulting in few validation studies (Smit et al., 2013). The issue is complicated further by the increased complexities inherent in the retrieval of EO SST data at the coastline, for instance, from land contamination, from the complex coastal aerosol composition impacting the signal received by the satellite sensor (Thomas et al., 2002), from the heterogeneity of SST at the coastline in space and time, and from potential differences in the relationship between the skin temperature (the top 10–20 μm) measured by the satellite and the temperature at the depth typically measured *in situ* (hereafter we define SST as the temperature at 1 m depth ($z$), or SST($z$) where $z = 1$ m, as defined by the Group for High Resolution Sea Surface Temperature, see GHRSST, 2017).

Acquiring *in situ* SST measurements in coastal regions, using conventional platforms such as research vessels, buoys and autonomous vehicles, is notoriously difficult and expensive, hampered by challenges such as: biofouling; vandalisation; wave damage; complex and shallow bathymetry; and strong tidal and coastal currents. This lack of *in situ* SST data at the coastline prohibits EO validation. New solutions are required to improve *in situ* sampling coverage of SST measurements at the coastline, and consequently our understanding of the accuracy and precision of EO SST products.

Building on the work of Brewin et al. (2015b), we present results from a three-year study in which a small group of recreational surfers, based primarily in the south west United Kingdom (UK), were tagged with temperature sensors that they used when surfing to measure SST *in situ* at the coastline. The SST data collected by the surfers, together with SST data collected from two oceanographic stations (L4 and E1, ~7 km and ~33 km from the coastline of Plymouth, UK, respectively) were compared with co-incident and co-located operational 1 km EO SST data from the Advanced Very High Resolution Radiometers (AVHRR), to improve our understanding of the accuracy and precision of EO SST products at the coastline and consequently their use for coastal applications.

## 2. Methods

### 2.1. Statistical tests

To compare the estimates of SST from two sources the following univariate statistical tests that are commonly used in comparisons between satellite and *in situ* data were used (e.g. Doney et al., 2009; Brewin et al., 2015c): the coefficient of determination ($r^2$); the absolute Root Mean Square Error ($\Psi$); the absolute bias between the estimated and measured variable ($\delta$); the absolute centre-pattern (or unbiased) Root Mean Square Error ($\Delta$); and the Slope ($S$) and Intercept ($I$) of a linear regression between the estimated and measured variables. The equations used to compute each statistic are provided in Appendix A.

### 2.2. Study site: United Kingdom and Ireland

The chosen study sites were beaches around the coastline of the United Kingdom (UK) and Ireland (Fig. 1a). Like many coastal regions, the seas surrounding the UK and Ireland are sensitive to increasing human pressure and climate change (Nicholls et al., 2007; Wang et al., 2008), with implications for changes in marine biodiversity and productivity (Frost et al., 2016; Holt et al., 2016), and the monitoring of key environmental indicators such as SST (L'Hévéder et al., 2016). Whereas a few measurements were collected on the west coast of Ireland and south-east coast of the UK (Fig. 1a), the majority of SST data collected by the surfers were from the south-west coastline of the UK (Fig. 1a and b), in particular the coastline surrounding the city of Plymouth (Fig. 1c), which also hosts two oceanographic stations (Station L4 and E1) that form part of the Western Channel Observatory (http://www.westernchannelobservatory.org.uk/) run by Plymouth Marine Laboratory and the UK Marine Biological Association.

### 2.3. In situ datasets

#### 2.3.1. SST collected by surfers at the coastline

Between the 5th January 2014 and the 8th February 2017, five recreational surfers were equipped with a UTBI-001 Tidbit v2 Temperature Data Logger and a Garmin etrex 10 GPS, following methods described in Brewin et al. (2015b, see their Fig. 1). The Garmin GPS device was used to extract information on the location (latitude and longitude) of the surf session. It contains an EGNOS-enabled GPS receiver, has HotFix® satellite prediction and can track both GPS and GLONASS satellites simultaneously. The GPS device was stored in a water-resistant Aquapac inside a waist-bag worn by the surfer (typically under the wetsuit) and set to record GPS data at 1 Hz. The first and last five minutes of the GPS track were removed (approximately the time between switching on (off) the GPS and entering (exiting) the water), and the median latitude and longitude of the remaining data were extracted to derive information on the central location of data collection during the surfing session. In cases where the GPS device failed (e.g. battery depletion) or was not used, the central location (latitude and longitude) of the surf session was extracted immediately proceeding the surf session, using GIS software (https://itouchmap.com/latlong.html).

The Tidbit v2 temperature loggers were attached, using cable-ties, to the mid-point of each surfers leash (tether connecting the surfer to their surfboard) to ensure continuous contact with seawater when surfing, and measured temperature in the top metre of the water column (see Fig. 1 of Brewin et al., 2015b). Manufacturers state that the Tidbit v2 sensors have an accuracy of 0.2 °C over a range of 0 to 50 °C, a resolution of ~0.02 °C at 25 °C, a stability of ~0.1 °C per year, a response time of 5 min in water, and a battery life of ~5 years at a >1 min logging interval. To ensure good quality data collection, we monitored the performance of each sensor approximately every 6 months over the study period, by comparing the Tidbit v2 temperature loggers with a VWR1620-200 traceable digital thermometer (NIST/ISO calibrated, with an