Sea-Surface Temperature Fields from MODIS and VIIRS – an Update

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Introduction

The Global Climate Observing System (GCOS) has specified 54 Essential Climate Variables (ECVs) that are key for sustainable climate observations. Sea-Surface temperature (SST) is an ECV and satellite remote sensing offers the only method of generating global fields. As with all measurements, the correct application of satellite-derived SSTs, is successful only if the accuracy of the retrieval is well specified. The accuracy and stability requirements of satellite-derived SST fields for climate research are very stringent and difficult not only to achieve, but also to demonstrate whether the accuracies have been achieved, or not. The combination of SST fields from MODIS on Terra, MODIS on Aqua, and VIIRS on S-NPP to contribute to the generation of a Climate Data Record (CDR), is facilitated by the use of consistent algorithms and by consistent methods to assess errors and uncertainties. In particular, traceability of SI temperature standards for the instruments used in validation of the satellite-derived SSTs allows the generation of large databases from diverse instruments thereby sampling a wide range of conditions. SI-traceability is established through a series of workshops involving standards from National Metrology Institutes, the most recent of which was held at the National Physical Laboratory in the UK in June 2016. We will present results of recently improved algorithms for cloud screening and atmospheric correction, and developments in the specification of the errors and uncertainties in the retrieved SSTs, and how they can be established with confidence.

Common Algorithms for MODIS and VIIRS

Inter-sensor consistency has been achieved by using comparable atmospheric correction algorithms, cloud-screening methods, and approaches to estimate errors and uncertainties. Clear-sky atmospheric correction algorithm is based on the Non-Linear SST formulation (Walton et. al. 1998), with coefficients derived using collocated sub-surface buoy SST, adjusted for a mean skin effect:

$$SST_{sat} = a_0 + a_1 T_{11} + a_2(T_{11} - T_{12})\, T_{sfc} + a_3(\sec(\theta) - 1)(T_{11\mu m} - T_{12\mu m}) + a_5(\theta) + a_6(\theta^2)$$

Red terms added for VIIRS to extend good retrievals to edges of swath.
Common cloud screening techniques – see Kilpatrick et al. poster.

Comparison with Surface Measurements

The accuracy of the satellite-derived SSTs can be assessed by comparison with in situ measurements. Drifting and moored buoys are numerous, and have been deploys for many decades, but have uncertain accuracies, and measure a subsurface temperature at a depth of ~20 cm. Their spatial and temporal distribution is uneven (Figure 1). Ship-borne infrared radiometers are very accurate and measure a SST_{skin}, but have been deployed only since the mid-1990s and are few in number (Figure 2). They are of high accuracy and have calibrations traceable to SI-standards, and so form the basis of SST CDRs.

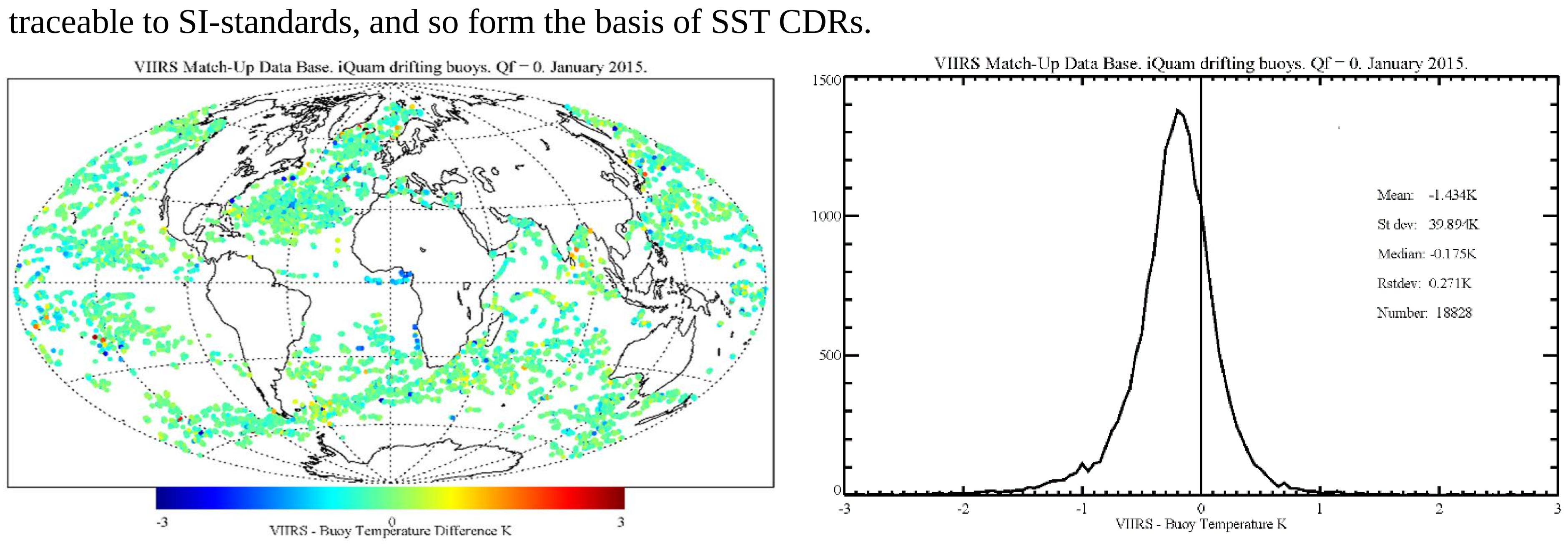

Figure 1. Example of one month of matchups between the S-NPP VIIRS and drifting and moored buoys, colored by temperature difference (left) shown as a histogram (right).

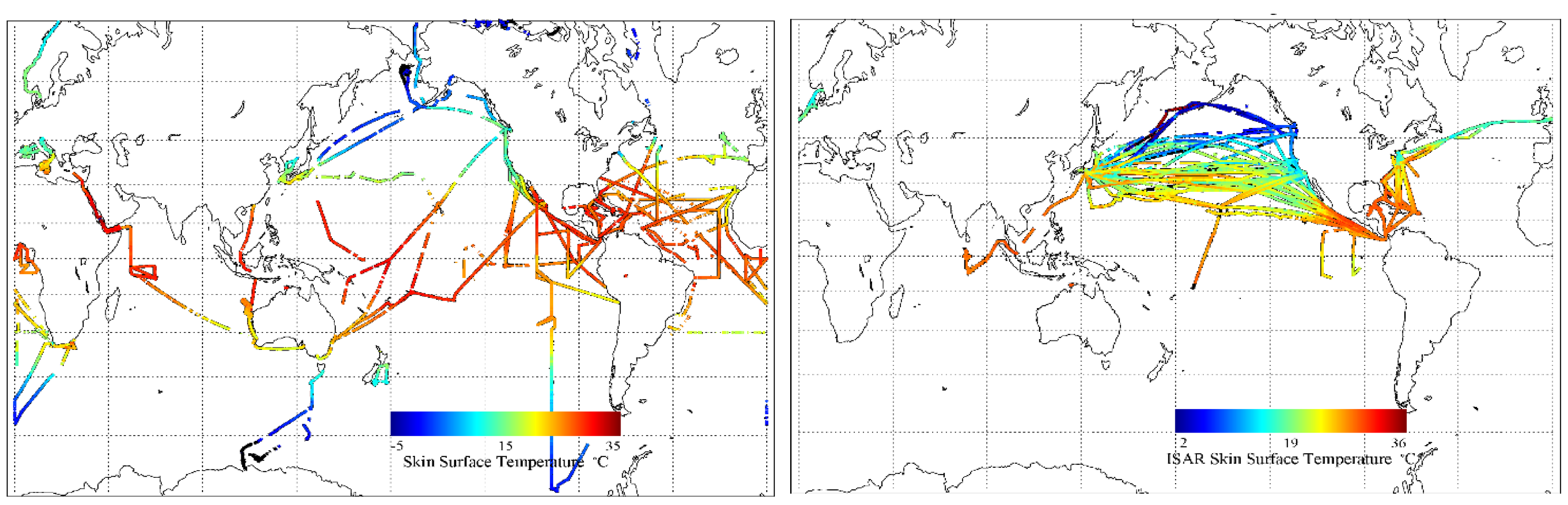

Figure 2. Tracks of RSMAS ship radiometer measurements since the launch of Terra, from the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI; Minnett et al, (2001) - left) and the Infrared SST Autonomous Radiometer (ISAR; Donlon et al, (2008), Wimmer and Robinson (2016) - right).

Establishing SI-tracability

An M-AERI participated in the Fiducial Measurements for Surface Temperatures Workshop at the UK National Physical Laboratory (NPL) in June 2016 (Figure 3) to establish SI-traceability. The accuracies of the M-AERI and the RSMAS laboratory black-body calibration target used to check the internal calibration process were within the uncertainties of the measurements (Theocharous et al., (2018a, b).

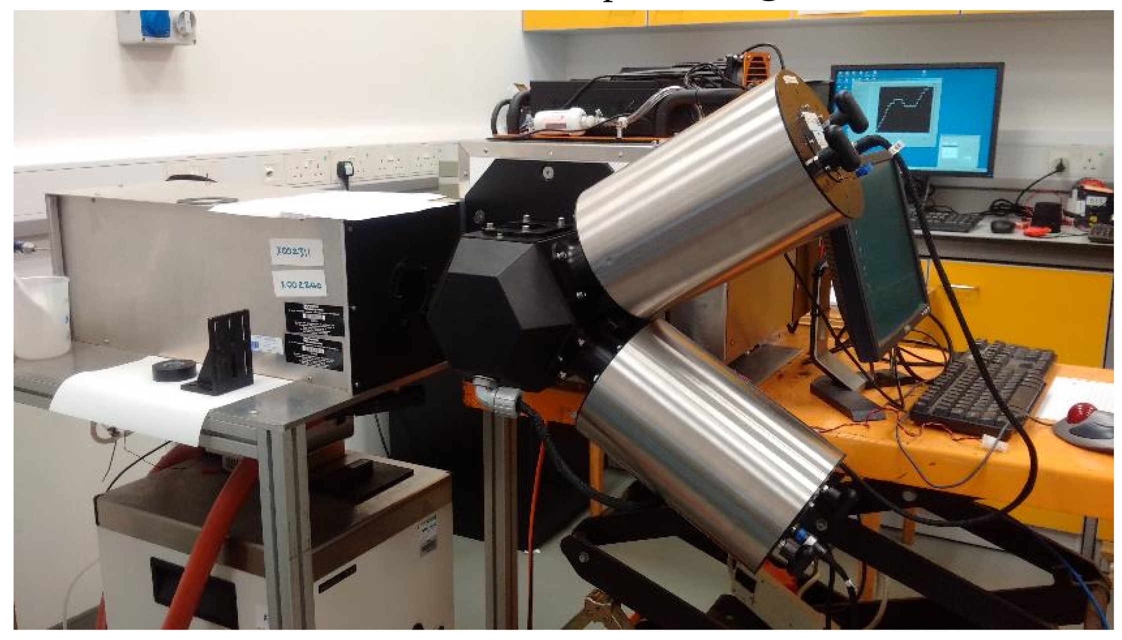

Figure 3. An M-AERI measuring the emission from the NPL standard blackbody calibrator.

Comparison time series and statistics

The time series of robust standard deviations of the monthly differences between satellite-derived SST_{skin} and in situ measurements from buoys are shown in Figure 4. Table 1 gives the statistics of differences between SST_{skin} derived from MODISs and VIIRS and buoy temperatures, and SST_{skin} measured by RSMAS M-AERIs and ISARs (Minnett et al., 2018). Night-time results are shown and those for daytime are similar.

These are simple statistics of the differences in the measurements and have not been corrected for contributions from inaccuracies in the in situ measurements, from spatial variability within the allowed separation between the measurements (10 km) and temporal variations in the time interval (± 10 minutes) so the accuracies of the satellite-derived SST_{skin} are better than shown here.

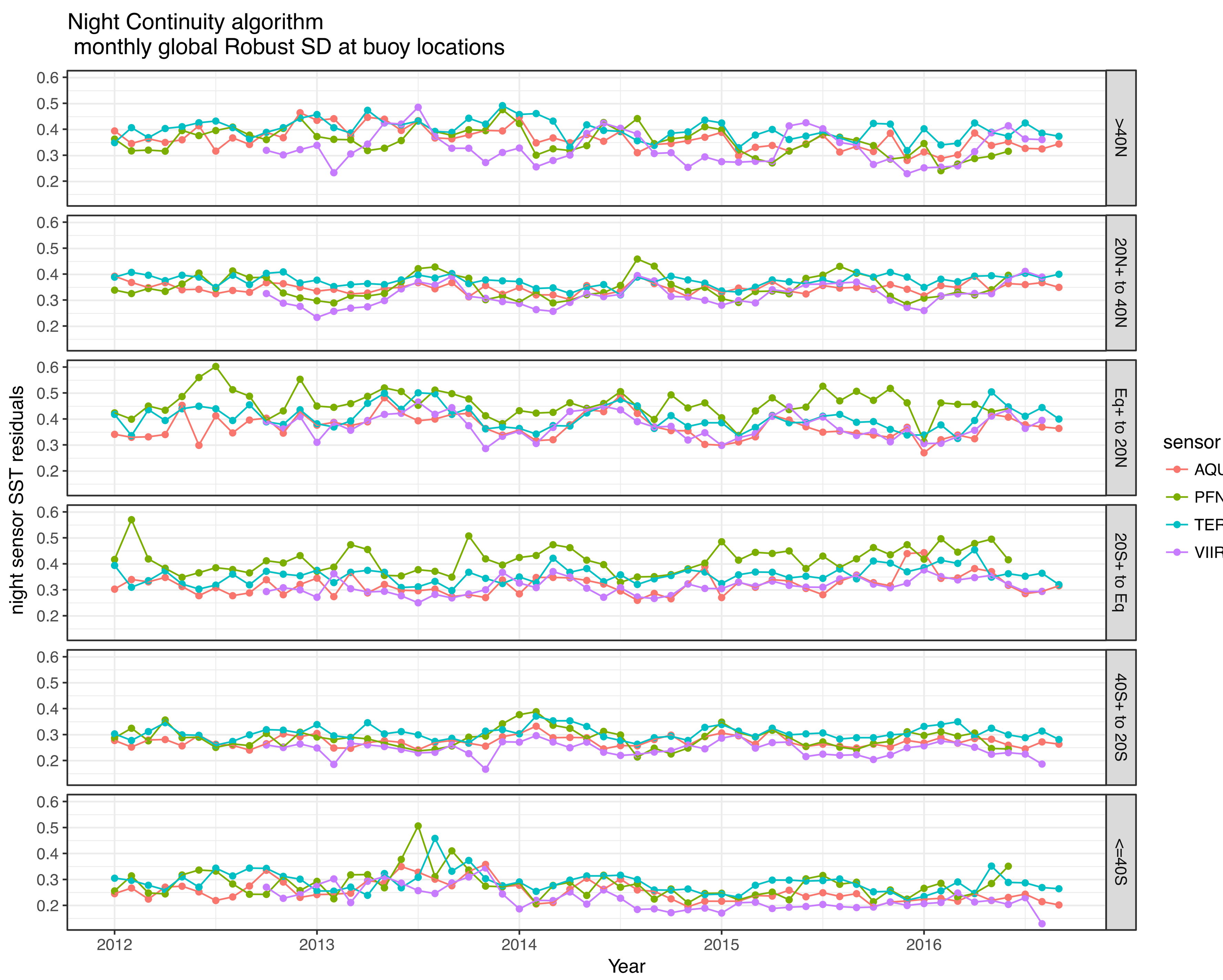

Figure 4. Time series of zonal, monthly robust standard deviations of night-time satellite-derived SST_{skin} compared to buoy temperatures in. NOAA-19 AVHRR Pathfinder comparisons are also shown.

Sensor	Quality Level	Mean	Median	Standard Deviation	Robust St. Deviation	Count
Sensor SST_{skin} – sub-surface buoy temperatures						
TERRA SST	0	-0.166	-0.150	0.442	0.319	538918
AQUA SST	0	-0.185	-0.170	0.423	0.305	508950
VIIRS SST	0	-0.126	-0.129	0.480	0.340	506740
TERRA SST	1	-0.424	-0.395	0.641	0.462	252809
AQUA SST	1	-0.424	-0.380	0.620	0.447	267214
VIIRS SST	1	-0.324	-0.314	0.736	0.524	251288
Sensor SST_{skin} – SST_{skin} from ship radiometers						
TERRA SST	0	-0.058	-0.052	0.481	0.347	3069
AQUA SST	0	0.042	0.040	0.494	0.347	2070
VIIRS SST	0	0.030	0.009	0.196	0.142	81

Table 1. Statistics of night-time MODIS and S-NPP VIIRS SST_{skin} comparisons with buoy temperatures and ship radiometer SST_{skin}.

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References:

Donlon, C., Robinson, I.S., Reynolds, M., Wimmer, W., Fisher, G., Edwards, R., & Nightingale, T.J. (2008). An Infrared Sea Surface Temperature Autonomous Radiometer (ISAR) for Deployment aboard Volunteer Observing Ships (VOS). Journal of Atmospheric and Oceanic Technology, 25, 93-113

Minnett, P. J., R. O. Knuteson, F. A. Best, B. J. Osborne, J. A. Hanafin, and O. B. Brown, 2001: The Marine-Atmospheric Emitted Radiance Interferometer (M-AERI), a high-accuracy, sea-going infrared spectroradiometer. Journal of Atmospheric and Oceanic Technology, 18, 994-1013.

Minnett, P.J., Kilpatrick, K., Podestá, G., Szczodrak, M., Izaguirre, M.A., Williams, E., Walsh, S., Evans, R.H., & Reynolds, R.M. (2018). Suomi-NPP VIIRS Sea Surface Temperature retrievals; algorithm evolution and an assessment of uncertainties. Remote Sensing of Environment, In revision.

Theocharous, E., N. P. Fox, I. Barker-Snook, R. Niclòs, V. Garcia Santos, F. M. Göttsche, L. Poutier, N. Morgan, T. Nightingale, W. Wimmer, K. Zhang, M. Yang, P. J. Minnett , M. A. Izaguirre, G. Szczodrak, M. Reiniger, C. Monte (2018a). The 2016 CEOS infrared radiometer comparison: Part 1: Laboratory comparison of blackbodies. Journal of Atmospheric and Oceanic Technology, In review.

Theocharous, E., N. P. Fox, I. Barker-Snook, R. Niclòs, V. Garcia Santos, D. Osterman, F. M. Göttsche, L. Poutier, N. Morgan, T. Nightingale, W. Wimmer, J. Høyer, K. Zhang, M. Yang, M. Arbelo, P. J. Minnett, M. Szczodrak, M.A. Izaguirre (2018b). The 2016 CEOS infrared radiometer comparison: Part 2: Laboratory comparison of radiation thermometers. Journal of Atmospheric and Oceanic Technology, In preparation.

Walton, C.C., Pichel, W.G., Sapper, J.F., & May, D.A. (1998). The development and operational application of nonlinear algorithms for the measurement of sea surface temperatures with the NOAA polar-orbiting environmental satellites. Journal of Geophysical Research, 103, 27,999-928,012.

Wimmer, W., & Robinson, I.S. (2016). The ISAR Instrument Uncertainty Model. Journal of Atmospheric and Oceanic Technology, 33, 2415-2433.