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ships4sst

shipborne radiometers for sea surface temperature

FRM4SST Project

ISFRN Workshop Book of Abstracts

RAL Space

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Author : _____

Ruth Wilson /
Sorrel Nelson
Space ConneXions Limited
(Project Manager)

Approved : _____

Werenfrid Wimmer
University of Southampton
(Technical Leader)

Accepted by ESA: _____

Craig Donlon
ESA Technical Officer

Distribution : FRM4SST Project Team
ISFRN Workshop Participants
ESA

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1. SESSION 1: INTRODUCTION

The FRM4SST project is funded by the European Space Agency (ESA) and, through various activities, aims to sustain and evolve the International Sea Surface Temperature (SST) Fiducial Reference Measurement (FRM) Network (ISFRN). One way that this aim is fulfilled is through the annual ISFRN Workshop, which aims to bring together scientific and operational users and producers of *in situ* radiometer SST data to review progress, achievements and developments within the radiometer community. The meeting this year is held in-person and online, and is open to anyone actively involved and interested in SST science, satellite validation and the uses of *in situ* radiometer measurements.

The objectives for the FRM4SST project are:

- OBJ-1: Deploy and maintain shipborne thermal infrared (TIR) FRM radiometers and necessary supporting instrumentation to validate satellite SST products.
- OBJ-2: Maintain FRM protocols for satellite SST measurements and uncertainty budgets.
- OBJ-3: Process, quality control, archive and deliver approved FRM4SST data sets following documented FRM procedures and approve their use for FRM satellite validation.
- OBJ-4: Validate satellite SST products to FRM standards and publish monthly results.
- OBJ-5: Promote the FRM4SST outputs and maintain the International SST FRM Radiometer Network (ISFRN).

This report contains abstracts from the talks at the 2024 ISFRN Workshop.

2. SESSION 2: EXPERIENCES OF RADIOMETER OPERATORS

2.1 ISAR UK

Speaker: Dr Werenfrid Wimmer

Institute name: University of Southampton

Email address: w.wimmer@soton.ac.uk

Abstract:

W. Wimmer[1], I. Robinson[1], R. Holmes[1], J.Marin[1], G. Fisher[1], C. Donlon[2]

[1]University of Southampton , [2]ESA

The Infrared Sea surface temperature Autonomous Radiometer (ISAR) is a self-calibrating instrument capable of measuring in situ sea surface skin temperature (SSTskin) to an accuracy of better than 0.1 K. The ISAR instrument has been developed for satellite SST validation and other scientific programs. The ISAR can be deployed continuously on ships of opportunity without any service requirement or operator intervention for periods of up to 3 months. The ISAR instrument is a single channel radiometer with a spectral band pass of 9.6 µm – 11.5µm to be adapted for autonomous use. The entire instrument infrared optical path is calibrated by viewing two blackbody reference cavities at different temperatures in order to maintain high accuracy while tolerating moderate contamination of optical components by salt deposition. During bad weather, an innovative storm shutter, triggered by a sensitive optical rain gauge, automatically seals the instrument from the external environment. Data are presented that verify the instrument calibration and functionality in such situations. A watchdog timer and auto-reboot function support automatic data logging recovery in case of power outage typically encountered on ships.

The University of Southampton ISARs have completed nearly 100 deployment over the last 25 years used for validating the Advanced Along Track Scanning Radiometer (AATSR) on Enivsat, the Sea Land Surface Temperature Radiometer on Sentinel 3 and the AVHRR on Metop and NOAA satellites. Examples of the deployments and experience will be shown together with lessons learned and the improvements made to ISAR over the years.

2.2 Update on the deployments of the Marine-Atmospheric Emitted Radiance Interferometers (M-AERIs)

Speaker: Dr Peter J Minnett

Institute name: Rosenstiel School of Marine, Atmospheric and Earth Science, University of Miami

Email address: pminnett@earth.miami.edu

Abstract

Peter J Minnett, Miguel Angel Izaguirre, and Goshka Szczodrak

Before the COVID pandemic, we had four Marine-Atmospheric Emitted Radiance Interferometers (M-AERIs) deployed at sea; three on cruise ships of the Royal Caribbean Group and one on the NOAA Ship Ronald H Brown. The Royal Caribbean ships were idled during the pandemic with no data being taken. The Ronald H Brown, in Cape Town, South Africa, when travel restrictions were imposed, returned to the USA where she remained docked for many months. She eventually returned to scientific cruises before entering drydock in July 2023 for an extended period. She is expected to return to service later this year. Having fully refurbished two instruments and recalibrated them again SI-traceable laboratory blackbody targets, we currently have one system on Celebrity Equinox and another on the R/V Neil Armstrong of the Woods Hole Oceanographic Institution. The Celebrity Equinox has spent much of the past year in the Mediterranean Sea, and the Neil Armstrong cruised in the northwest Atlantic Ocean, including around Iceland and Greenland. The presentation will give an update on progress, outline plans, and discuss outstanding problems and issues.

2.3 Advances in Measuring Ocean Surface Skin Temperature using the InfraRed Instrument for Sea Surface Temperature (IRISS)

Speaker: Dr Andy Jessup

Institute name: Applied Physics Laboratory, University of Washington, Seattle, WA

Email address: jessup@uw.edu>

Abstract

The design and performance of a shipboard instrument for underway measurement of ocean surface skin temperature is presented. The InfraRed Instrument for Sea Surface temperature (IRISS) is a simplified design that uses separate sensors for measuring the sea and sky radiance and a one-point in situ calibration. The standard wavelength band (9.6-11.5 mm) and a so-called optimal band (7.5-7.85 mm) were evaluated by comparison to the Remote Ocean Surface Radiometer (ROSR) during an extensive field deployment. Both versions were found to have accuracy comparable to ROSR and thus meet the design goal of ±0.10 °C. The sky radiance spectrum was modeled with MODTRAN using radiosonde profiles of air temperature and water vapor. The results show that for the optimal band version the modeled sky radiance can be used in place of the measured sky radiance without significant effect on the accuracy. The combined simplification of a one-point calibration and no sky measurement will significantly increase the practicality and accessibility of ocean surface skin temperature measurements from uncrewed surface vehicles and buoys.

3. SESSION 3: THE ISFRN NETWORK

3.1 Status of the ISFRN and the ships4sst data archive

Speaker: Dr Werenfrid Wimmer

Institute name: University of Southampton

Email address: w.wimmer@soton.ac.uk

Abstract

W. Wimmer[1], T. Nightingale[2], J. Høyer[3], H. Kelliher[4], R. Wilson[4], J-F. Piolle[5], C. Donlon[6]

[1]University of Southampton , [2]RAL Space, [3]DMI, [4]Space ConneXions, [5]Ifremer, [6]ESA

The International Shipborne Fiducial reference Radiometer Network (ISFRN) represents the shipborne infrared radiometer operators and data users around the world. Its aim is to maintain and deploy Infrared Radiometers of fiducial reference measurement (FRM) quality which are necessary to validate Sentinel-3 SLSTR SST products. Furthermore, all data are processed, archived, formatted and quality controlled following documented FRM procedures and protocols.

We will give an update of the current status of the ISFRN, the data providers and the users. Furthermore, we explore some the central archive (hosted by IFREMER), which due to the common data format, allows common tools to be used for the data exploitation. Examples of the data usage will be demonstrated, however the main use of the ships4sst data is for the SLSTR validation, which is shown in separate talk.

4. SESSION 4: ENSURING HIGH-ACCURACY MEASUREMENTS

4.1 ASTeRN: A Next Generation In-Situ Radiometer

Speaker: Dr Dave Smith

Institute name: STFC, UK

Email address: dave.smith@stfc.ac.uk

Abstract

SST validation is supported by a number of autonomous self-calibrating ship-borne radiometers deployed by a number of institutes. The current UK in situ radiometer designs (ISAR, SISTeR) are now 20+ years old. Hence, a new generation of radiometers are required to enhance and maintain capability for next decade.

The Advanced Surface Temperature Radiometer Network (ASTeRN) is a project to design and manufacture radiometers with the capability for measuring sea, land and ice surface temperatures with high accuracy and precision. The radiometers will be an evolution of existing designs with the same basic measurement approach as existing instruments but drawing on lessons learned and incorporating modern components. The design includes: additional spectral channels for atmospheric characterisation, extended capability for measuring Land Surface Temperatures, address obsolescence issues, and to improve manufacturability and maintainability. We present the status of the radiometer development and plans for deployment.

4.2 The TRUSTED Project

Speaker: Dr Marc Lucas

Institute name: CLS

Email address: mlucas@groupcls.com

Abstract

The Copernicus TRUSTED project aims to provide high quality sea surface temperature data in order to help improve the calibration and validation of the sentinel 3 radiometers. It is articulated around 4 pillars, namely hardware, Procedures, Data Management and Documentation to ensure that each data point collected can be classified as a Fiducial Reference Measurement.

In this presentation, we will look at the maturity level of each of these pillars and how this breakdown translates into the project activities such as calibration, deployment and data collection. We will also look at current and forthcoming activities for Ice Surface Temperature retrieval that have recently been included within the project objectives.

5. SESSION 5: SST DATA IN PRACTICE

5.1 The new evidence of the importance of sea surface temperature measurements for constraining global carbon budgets

Speaker: Prof Jamie Shutler

Institute name: University of Exeter

Email address: J.D.Shutler@exeter.ac.uk

Abstract

The ocean is one of two observational constraints on the global carbon assessments used to guide policy on the emission reductions that are urgently needed to stabilise our climate. Within these observation-based ocean sink estimates, sea surface temperature is a strong controller of ocean carbon concentrations and its exchange with the atmosphere. The evidence for its importance, the need for continued efforts with sea-surface temperature climate data records and particularly the need for in situ skin measurements continues to grow. This talk will discuss how the impact of seemingly small differences in sea surface temperature measurements, that can lead to large differences in the resulting ocean carbon budgets, have now been observed in situ across the Atlantic. It will also discuss the increasing need for ocean carbon specific sea-surface temperature climate data records, and why these could be critical for future global carbon assessments and the policy advice that stems from them.

5.2 The Response of Ocean Skin Temperature to Rain: Observations and Implications for Parameterization of Rain-Induced Fluxes

Speaker: Carson Witte

Institute name: Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA

Email address: cwitte@ldeo.columbia.edu

Abstract:

Witte, C. R., C. J. Zappa, and J. B. Edson

Rainfall alters the physical and chemical properties of the surface ocean, and its effect on ocean skin temperature and surface heat fluxes is poorly represented in many air-sea

interaction models. We present radiometric observations of ocean skin temperature, near-surface (5 cm) temperature from a towed thermistor, and bulk atmospheric and oceanic variables, for 69 rain events observed over the course of 4 months in the Indian Ocean as part of the DYNAMO project. We test a state-of-the-art prognostic model developed by Bellenger et al. (2017, https://doi.org/10.1002/2016JC012429) to predict ocean skin temperature in the presence of rain, and demonstrate a physically motivated modification to the model that improves its performance with increasing rain rate. We characterize the vertical skin-bulk temperature gradient induced by rain and find that it levels off at high rain rates, suggestive of a transition in skin-layer physics that has been previously hypothesized in the literature. We also quantify the small bias that will be present in turbulent sensible heat fluxes parameterized from ocean temperature measurements made at typical “bulk” depths during a rain event. Finally, a wind threshold is observed above which the surface ocean remains well-mixed during a rain event; however, the skin temperature is observed to decrease at all wind speeds in the presence of rain.

5.3 Mid and Thermal Infrared Validation using the JPL Radiometer Network with a focus on the Lake Tahoe and Salton Sea Sites

Speaker: Dr Simon Hook

Institute name: Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, California 91109

Email address: simon.j.hook@jpl.nasa.gov

Abstract:

Post-launch calibration and validation over the lifetime of missions is needed to ensure that any long-term variation in an observation, e.g. an area getting hotter, can be unambiguously assigned to a change in the Earth system, rather than a change in calibration. Such activities enable measurements from different satellites to be inter-compared and used seamlessly to create long term multi-instrument/multi-platform data records, which serve as the basis for large-scale international science investigations into topics with high societal or environmental importance. In order to help address this need we have established a set of automated validation sites where the necessary measurements for validating mid and thermal infrared data from spaceborne and airborne sensors are made every few minutes on a continuous basis.

We have established automated validation sites at several locations including Lake Tahoe CA/NV, Salton Sea CA, La Crau, France, Venice Lagoon, Italy with several additional sites planned for the future. The Lake Tahoe site was established in 1999, the Salton Sea site was established in 2008 and the La Crau site was established in 2023. Each site has one or more JPL custom-built highly accurate (50mK) radiometers measuring the surface skin temperature. All the measurements are made every few minutes and downloaded hourly via the internet or a cellular modem.

Data from the sites have been used to validate numerous satellite instruments including the Advanced Very High Resolution Radiometer (AVHRR) series, the Along Track Scanning Radiometer (ATSR) series, the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), the Landsat series, the Moderate Resolution Imaging Spectroradiometer (MODIS) on both the Terra and Aqua platforms, the Visible Infrared Imaging Radiometer Suite (VIIRS) and the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS). In all cases the standard products have been validated including the standard radiance at sensor, radiance at surface, surface temperature and surface emissivity products.

The data from these sites are also planned to be used to validate future missions including the ASI/NASA Surface Biology and Geology (SBG) thermal infrared (TIR) mission, the ESA Land Surface Temperature Monitoring (LSTM) mission and the ISRO/CNES Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment (TRISHNA) mission.

We will present results from the validation of the mid and thermal infrared data using the automated validation site

6. SESSION 6: EXPERIENCES OF RADIOMETER OPERATORS

6.1 Advancing Sea Surface Temperature Validation: Insights from In-Situ Observations in the Nordic Sea and Arctic

Speaker: Dr Guisella Gacitua

Institute name: DMI

Email address: gga@dmi.dk

Abstract

The Danish Meteorological Institute (DMI) is a key contributor to the extensive network of in-situ Sea Surface Temperature (SST) observations for satellite data validation through the FRM4SST project. This project focuses on in-situ Fiducial Reference Measurements (FRM) for SST, crucial for validating Copernicus Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) SST data, particularly in the Nordic Sea and Arctic regions associated with the Atlantic Meridional Overturning Circulation.

DMI has consistently provided SST data since 2017 using Infrared Sea Surface Autonomous Radiometers (ISARs) installed onboard the Smyril Line passenger ferry, Norröna, which traverses from Denmark to the Faroe Islands and Iceland weekly. Furthermore, in spring 2021, DMI, in collaboration with the Technical University of Denmark (DTU), conducted the first shipborne inter-comparison of thermal infrared (TIR) and passive microwave (PMW) SST observations over a week-long period. This initiative aimed to compare the skin and subskin temperatures derived from simultaneous observations, offering insights to enhance the methodology of such inter-comparisons, thus advancing the accuracy and consistency of combined TIR-PMW SST data.

6.2 SISTeR

Speaker: Dr Tim Nightingale

Institute name: STFC, UK

Email address: tim.nightingale@stfc.ac.uk

Abstract

The SISTeR (Scanning Infrared SST Radiometer) is a chopped, autonomous, self-calibrating infrared filter radiometer that can measure IR brightness temperatures to high accuracy (~30mK). It is split into three compartments, the inner being the calibration enclosure which hosts two blackbodies and a rotating scan mirror. SISTeR measures the upwelling radiance from the sea surface and corrects for the reflected sky component with measurements of the downwelling sky radiance. The blackbody thermometer calibrations are traceable to ITS-90. SISTeR generates level 0 data and a dedicated processor unpacks this data.

SISTeR was first deployed in 1997 and since 2010 has been deployed on the Cunard Queen Mary 2 (QM2) liner where it is mounted on a dedicated platform above the starboard bridge wing.

The usual routes are sailings between Southampton and New York with additional Caribbean, Canadian and European trips, and historical data have included an annual world cruise.

7. SESSION 7: SST DATA IN PRACTICE

7.1 ISAR Korea : Observations of Skin-Bulk SSTs and Air-Sea Interactions in the Northwest Pacific during Pronounced Marine Heat Wave Events

Speaker: Prof Kyung-Ae Park

Institute name: Department of Earth Science Education, Seoul National University, Korea

Email address: kapark@snu.ac.kr

Abstract

Kyung-Ae Park*, Hee-Young Kim, Hye-Jin Woo, Ji-Won Kang, and Che-Young Lim
*Department of Earth Science Education, Seoul National University, Korea

The sea surface temperature (SST) around the Korean Peninsula exhibits greater variability than the global ocean due to active ocean-atmosphere-land interactions driven by its proximity to the continent. In recent years, Marine Heat Wave (MHW) events have become more frequent and intense in the northwestern Pacific. To understand these phenomena, we conducted skin-bulk SST observations in regions where MHWs typically develop, with the goal of investigating related ocean-atmosphere interactions. From October 27 to November 16, 2023, observations were carried out across the East Sea, starting from the southern coast of Korea, passing through the Tsugaru Strait into the northwestern Pacific Ocean, traversing the Kuroshio Current, and returning westward via southern Japan, the East China Sea, and the Korea Strait. Using ISAR measurements alongside bulk temperature data, we simultaneously recorded wind speed, wind direction, and atmospheric conditions, enabling a comprehensive analysis of ocean-atmosphere interactions. A comparative analysis with AMSR2 SST data provided valuable insights into the intricate relationships between wind effects and diurnal variations in skin temperature differences. A comparative analysis with AMSR2 SST data provided new insights into the complex relationships between wind effects and diurnal variations in skin temperature differences. To investigate long-term trends, we analyzed 41 years (1982–2022) of satellite-derived sea surface temperature data, focusing on marine heat wave (MHW) characteristics, including frequency, duration, total occurrence days, maximum intensity, average intensity, and cumulative intensity. Combining this long-term dataset with recent ISAR observations allowed us to explore recent sea surface temperature anomalies. This study advances our understanding of skin temperature variability in Northeast Asia and the Northwest Pacific and contributes to the improvement of SST retrieval techniques using Korea's geostationary satellite data.

8. SESSION 8: RADIOMETER PERFORMANCE AND UNCERTAINTIES

8.1 Radiometer uncertainty models

Speaker: Dr Werenfrid Wimmer

Institute name: University of Southampton

Email address: w.wimmer@soton.ac.uk

Abstract

When reporting the result of a measurement of a physical quantity, it is obligatory that some quantitative indication of the quality of the result be given so that those who use it can assess its reliability. Such an indication of quality is essential for any measurement but especially for Fiducial Reference Measurements (FRM) to comply with metrological and QA4EO standards.

To show how and uncertainty model can be derived for self-calibrating infrared radiometers the example of the Infrared Sea surface temperature Autonomous Radiometer (ISAR) uncertainty model will be shown. To develop the ISAR uncertainty model all the sources of uncertainty in the instrument are analysed and an uncertainty value is assigned to each component. Finally, the individual uncertainty components are propagated through the ISAR Sea Surface Temperature skin (SSTskin) retrieval algorithm to estimate a total uncertainty for each measurement. The resulting ISAR uncertainty model applied to a 20-year archive of SSTskin measurements from the Bay of Biscay shows that 77.6 % of the data are expected to be within ± 0.1 K and a further 17.2 % are within 0.2 K.

9. SESSION 9: VALIDATION OF SATELLITE SST AND IN SITU SST MEASUREMENTS

9.1 Sentinel-3 SLSTR SST Validation using Fiducial Reference Measurements (FRM).

Speaker: Dr Werenfrid Wimmer

Institute name: University of Southampton

Email address: w.wimmer@soton.ac.uk

Abstract

W. Wimmer[1], T. Nightingale[2], J. Høyer[3], H. Kelliher[4], R. Wilson[4], J-F. Piolle[5], C. Donlon[6]
[1]University of Southampton , [2]RAL Space, [3]DMI, [4]Space ConneXions, [5]Ifremer, [6]ESA

ESA is building on over 20 years of continuous Fiducial Reference Measurements (FRM) from UK-funded shipborne radiometers by establishing a service to provide historic and ongoing FRM measurements to the wider sea surface temperature (SST) community through an International SST FRM Radiometer Network (ships4sst). The ships4sst is open for partners around the world, currently compromising of partners from the UK (University of Southampton, Rutherford Appleton Laboratory, Space ConneXions), Denmark (Danish Meteorological Institute) and France (Ifremer) and not only collects shipborne radiometer data but also uses the data to validate satellite SST products.

Ships4sst not only provides FRM SST measurements, put also includes a long term data archive of the FRM datasets at Ifremer where the data are stored in the ships4sst netCDF L2R format. Furthermore, a validation service based on the ESA felyx match-up database (MDB) hosted at EUMETSAT is provided. The ships4sst data is freely available to anyone, as are the validation results. At ships4sst we organise and participate in regular inter-comparisons at the National Physics Laboratory (NPL) in the UK and the National Institute of Standards and Technology (NIST) in the USA, to ensure not only the SI (International System of Units) traceability of our remeasurements but also the validity of the per SST value uncertainties.

To demonstrate the value of the FRM SST, we will first show some examples of the ships4sst data around the world and second show the most recent validation results from SLSTR A and B from the ships4sst network regions. This will not only demonstrate that SLSTR A and B are preforming to specification and at least as well as their predecessor AATSR, but also show a potential route for SI-traceability for SLSTR SST measurements.

9.2 Comparison (of shipborne radiometers) with other in situ measurements

Speaker: Dr Gary Corlett

Institute name: 1EUMESAT, Eumetsat-Allee 1, 64295 Darmstadt, Germany

Email address: Gary.Corlett@eumetsat.int

Abstract

Gary Corlett, Anne O'Carroll, Igor Tomazic

Accurate long-term measurements of ocean temperatures are required to understand key physical processes at the ocean-atmosphere interface and any changes that may occur to these processes over time. The first Copernicus Sentinel-3A Sea and Land Surface Temperature Radiometer (SLSTR-A) was launched on 16th February 2016. SLSTR-A is a multi-spectral dual-view radiometer with two on-board blackbodies and cooled detectors ensuring accurate radiometric measurements. SLSTR-A was joined in orbit by its twin, SLSTR-B, on 25th April 2018. SLSTR-A SST products were released operationally from the EUMETSAT marine centre on 5th July 2017 and SLSTR-B products were released operationally on 12th March 2019.

SLSTR provides high-quality dual-view SSTs that are used as a reference sensor in several operational systems. In this presentation we summarise how SLSTR SSTskin measurements are validated using a range of in situ measurements at various depths including Fiducial Reference Measurements (FRM) from shipborne IR radiometers and recently deployed Copernicus drifting buoys. We describe the validation process as well as the concept of a validation space and show that the combination of in situ measurement and FRM provides high confidence in the quality of all datasets, as well as models of the skin-layer and diurnal variability required to adjust the temperature measurement from various depths.

9.3 Status and evolution of EUMETSAT SST/IST Multi-Mission Matchup Database (MMDB)

Speaker: Dr Igor Tomazic

Institute name: 1EUMESAT, Eumetsat-Allee 1, 64295 Darmstadt, Germany

Email address: Igor.Tomazic@eumetsat.int

Abstract

Igor Tomazic[1], Gary Corlett[1], Anne O'Carroll[1]

Sea Surface Temperature (SST) and Sea Ice Surface Temperature (IST) are key reference products provided by the Copernicus Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) series and are essential variables for global climate monitoring. Consequently, there are very stringent needs on SLSTR SST/IST data quality, with the current goal for total standard uncertainty defined as 0.1 K /1 K and stability 0.1 K/0.1 K per decade (for SST/IST respectively). A comprehensive set of calibration/validation and routine monitoring tools are implemented at EUMETSAT to confirm the performance of SLSTR SST and IST products meet their goals.

The primary activity for SST/IST validation are comparisons with in situ reference measurements, including Fiducial Reference Measurements (FRM) using a multi-mission matchup database (MMDB) implemented with the felyx tool. In this presentation, we summarize the current status of the Radiometer MMDB and outline the evolution of full MMDB framework, along with the expected schedule aligned with the SLSTR L2 SST/IST processor evolutions.

10. ACRONYMS AND ABBREVIATIONS

AATSR	Advanced Along-Track Scanning Radiometer
ASTeRN	The Advanced Surface Temperature Radiometer Network
ATSR	Along-Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BB	Blackbody
CDR	Climate Data Record
CCI	Climate Change Initiative
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DMI	Danish Meteorological Institute
DTU	Danish Technical University
ECV	Essential Climate Variable
EDS	Engineering Data System
EGSE	Electrical Ground Support Equipment
EO	Earth Observation
ESA	European Space Agency
ESL	Expert Support Laboratory
ESOC	European Space Operations Centre
EU	European Union
FPA	Focal Plane Assembly
FRM	Fiducial Reference Measurements
FRM4STS	Fiducial Reference Measurements for validation of Surface Temperature from Satellites
FTP	File Transfer Protocol
GHRSST	Group for High Resolution SST
GTMBA	Global Tropical Moored Buoy Array
HTTP	HyperText Transfer Protocol
IPCC	Intergovernmental Panel on Climate Change
IR	Infra-Red

ISAR	Infrared SST Autonomous Radiometer
ISFRN	International SST FRM Radiometer Network
ISSI	International Space Science Institute
KIT	Karlsruhe Institute of Technology
L0	Level 0
L1	Level 1
L2	Level 2
LST	Land Surface Temperature
M-AERI	Marine-Atmospheric Emitted Radiance Interferometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NOCS	National Oceanography Centre, Southampton
OP	Operational Processor
RAL	Rutherford Appleton Laboratory
RP	Reference Processor
RSD	Robust Standard Deviation
SCL	Space ConneXions Limited
SISTeR	Scanning Infrared Sea surface Temperature Radiometer
SLSTR	Sea and Land Surface Temperature Radiometer
SST	Sea Surface Temperature
ST	Surface Temperature
STFC	Science and Technology Facilities Council
TIR	Thermal Infra-Red