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Author(s) :

Ruth Wilson
Project Manager

Space ConneXions Limited

Approved by :

Werenfrid Wimmer
Technical Manager

University of Southampton

Accepted by :

Digitally signed by Craig James Donlon
Date: 2020.11.05 15:23:07 Z

Craig Donlon
ESA Technical Officer

ESTEC

Distribution : FRM4SST Project Team

ESA

EUROPEAN SPACE AGENCY
CONTRACT REPORT

The work described in this report was done under ESA contract. Responsibility for the contents resides in the author or organisation that prepared it.

AMENDMENT RECORD

This document shall be amended by releasing a new edition of the document in its entirety. The Amendment Record Sheet below records the history and issue status of this document.

AMENDMENT RECORD SHEET

ISSUE	DATE	REASON FOR CHANGE
A	12/10/2020	Draft for first internal review
B	13/10/2020	Draft for review by project team
1	19/10/2020	Issued to ESA following internal updates

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1. INTRODUCTION

Satellite remote sensing of the Earth has become an essential tool in increasing our understanding of the climate, weather patterns and the impact of climate change. It has assisted, and continues to assist, scientists in their analysis of climate change and world leaders in the formation of policies to adapt to or mitigate the effects of climate change. For this reason, remote sensing data must be as accurate as possible as well as long-term; i.e. creating a reliable data series by linking different satellite sensors to common reference standards. To this end, *in situ* Thermal Infrared (TIR) radiometers are deployed on vessels across the globe to collect Sea Surface Temperature (SST) data, which is then used to validate and verify satellite measurements, ensuring optimal accuracy. The Infra-red SST Autonomous Radiometer (ISAR) and Scanning Infra-red SST Radiometer (SISTeR) instruments used on this project are two such TIR radiometers that have been deployed on various ships since 1998 and 1996, respectively.

The project team work daily with shipborne radiometer colleagues and other climate scientists worldwide. They therefore have useful personal networks within the climate and shipborne radiometer user community, and a deep appreciation of the concerns and perspectives of the radiometer network community regarding *in situ* climate data. This knowledge and experience has been combined following discussions at the International SST FRM Radiometer Network (ISFRN) Workshop on 17 - 18 September 2020 to update a service roadmap, complete with implementation strategies and priorities**.**

This report presents the service roadmap for the FRM4SST contract. The main aim of this roadmap is to:

- provide a critical analysis of the feedback from participants and institutions working in the service, including feedback from discussions during the ISFRN workshop;
- articulate lessons learned by the service providers;
- identify potential strategies for integrating the service outcomes into existing initiatives and operational institutions;
- identify priority areas to be addressed in potential future activities to support satellite TIR instrument validation activities.

2. PROJECT OVERVIEW

This project, which is funded by the European Space Agency (ESA), started on 1 April 2018 as the ships4SST contract, which then evolved into the FRM4SST project on 1 May 2019. The current contract is due to run until 31 December 2020 with plans for an extension to 31 December 2022. The aim of this contract is to validate satellite, such as the Sentinel-3A and Sentinel-3B Sea and Land Surface Temperature Radiometer (SLSTR) SST data products using Fiducial Reference Measurements (FRM). This aim is being fulfilled through the collection, processing, analysis, publication and reporting of *in situ* FRM field measurements made using the ISAR and the SISTeR instruments, that are near-contemporaneous with satellite data from the Sentinel-3A and Sentinel-3B SLSTR instruments.

Providing reliable and timely FRM to support the validation of SLSTR SST involves the use of three unique European activities and data sets:

- Continuation of the English Channel and Bay of Biscay ISAR radiometer deployments, ISAR 002 and 003,
- Continuation of SISTeR A deployments on the *Queen Mary 2* liner between Southampton and New York, and round the world,
- Deployment on Smyril-line Denmark–Faroe Island-Iceland, ISAR 008, in synergy with the Ferrybox project and instrumentation,

The work to be carried out by the project team is also:

- To support a collaborative network that enables other users of ship radiometers worldwide to contribute to the *in situ* SST Reference Database and which disseminates the data to the wider community. This includes maintenance of FRM protocols.

The FRM4SST project also provides and maintains the ISFRN, which is hosted on the website, www.ships4sst.org. The website makes information and data available on all aspects of the radiometer deployments to users and the project team, as appropriate. This includes; a Campaign Implementation Plan (CIP), a Campaign Actions and Risk Log (CARL), the most recent radiometer data and calibrated skin SST with associated uncertainties, validation plots, reports and links to scientific papers, an ISFRN data description and user manual, and details of the ISFRN Workshop.

3. ROADMAP DEVELOPMENT

3.1 COVID-19

2020 has seen a significant impact on the collection of shipborne radiometer SST_{skin} data and international conferences and meetings in which discussions including service updates would physically take place. The emergence of COVID-19 world-wide at the end of 2019 saw many shipping companies halt their cruises in the first quarter of 2020 and many have remained in ports or anchored out at the sea for many months. The result of this is a reduced amount of data collected on normal sea-voyaging routes and no face-to-face discussions with fellow radiometer operators since the beginning of 2020.

3.2 ISFRN Workshop

On the 17 – 18 September 2020 the project hosted the first virtual international ISFRN workshop, with scientific and operational users and producers of *in situ* radiometer SST data from 16 different countries attending. The aim of the workshop was to share the findings of the partners in the ISFRN service. Although the workshop had to be changed to a virtual meeting due to the COVID-19 pandemic, a positive result was that more international participants and presenters from all over the globe were able to attend, giving rise to broad international discussions about the status and influence of the service, radiometer instruments, data uses and validation activities. This builds on and adds another dimension to the 2019 roadmap which, with limited participation from America and Australia, was mostly constructed using feedback from European-based participants.

In this document, key information from the ISFRN workshop is drawn on and developed to assess the technology and networks we currently have and to outline a way forward with future satellite data validation services to ensure that deployed *in situ* radiometers fulfil the role of validating and verifying satellite data, including the ESA's SLSTR SST data, to the best of their ability.

4. SERVICE ROADMAP

Table 4-1 shows the service roadmap. Requirements and suggestions have been listed with strategies for implementation and/or comments. Each suggestion has been rated 1 to 5 for impact and difficulty and, if possible, a target date for implementation is given.

Area	Requirement / suggestion	Strategies for implementation / Comments	Impact (5 high, 1 low)	Difficulty (5 high, 1 low)	Target Date
Data and data archive	Add more data and metadata to the ships4sst database	Encourage more radiometer operators to join the network e.g. saildrone data. New routes and reprocessing of existing data to L2R	5	being done routinely	ongoing
	Simplify the ships4sst archive	Consolidation of instrument processor data version numbers. This is difficult to do as each operator has their own processor version history.	3	4	2021
Adequacy and continuity of the observing system	Perform another CEOS Radiometer Inter-comparison exercise	Performing more inter-comparison exercises will help confirm the validity, equivalence and traceability of the measurements. An exercise is being planned for 2022 (funding dependent).	5	3	spring 2022
	Improve the radiometer uncertainly model	Verification of uncertainty model (out at field). Performing more bi-lateral exercises between radiometers out on voyages will help confirm and improve the validity of uncertainty budgets and enable a re-visit into the effect of surface emissivity on SST_{skin} measurements.	5	4 (requires funding and time)	2022
	Quantified fully broken down uncertainties and sources of error in respect to SI	The quantification of uncertainness relies on component manufacturer documentation and laboratory experiments (e.g. component testing, emissivity experiments). Depending on required detail this can be very time consuming and expensive.	4	5	ongoing
Instrumentation	Push for more radiometers on ships of opportunities.	Radiometers can be more readily made traceable to SI than buoys and an increase in numbers means better stats. 4 ISARs are due for delivery in 2020/2021 (to Australia, Norway and Denmark)	5	2	ongoing
	A next generation radiometer	A next generation radiometer that could go on fixed platforms as well as ships.	5	4 (depends on funding)	2022

Area	Requirement / suggestion	Strategies for implementation / Comments	Impact (5 high, 1 low)	Difficulty (5 high, 1 low)	Target Date
Outreach and documentation	A database of information, including QA, on all radiometers to support validation	Documentation of processing versions, instrument maintenance etc. is online and just needs to be revisited to check for latest updates. A link from the ships4sst to QA4EO information will be put online.	4-5	2-3	ongoing
	Improve information on observational methods	Write and publish more papers and reports.	5	3	ongoing
	Promotion of community protocols and best practises	Data submitted to the L2R archive must follow the ships4sst protocols and documentation is provided to help the data providers.	4	2-4	ongoing
	Improve information for radiometer instrument handlers	A specification of what is expected if a radiometer is taken into different environments, particularly in sub-zero climates, was requested at the recent workshop. This could come in the form of a one page document with some requirements for a future generation radiometer based on the expected issues of instruments in different climates. A suggestion was made to revisit instrument user manuals; there were a few noted occasions where an instrument was not able to work during part or all of a voyage.	4	2	2022
Measurements	Measurements at a range of sea depths	The impact on science is large. Several months' worth of data of diurnal variability on various platforms would be useful, e.g. there is a platform being used for scientific experiments in the Mediterranean Sea.	3	5 - doable but difficult to do with ship operators	2022
	Include Microwave (MW) data with infrared (IR)	A FRM TIR/MW inter-comparison is planned for 2021. It requires refurbishment of a pre-existing MW radiometer.	4	3	2021

Area	Requirement / suggestion	Strategies for implementation / Comments	Impact (5 high, 1 low)	Difficulty (5 high, 1 low)	Target Date
	Re-visiting measurements made in extreme weather (or sub-zero) environments.	The last FRM TIR/MW field campaign for IST experiments was done in 2017. Community members feel that another campaign within the next few years would be useful.	4	5 (requires funding)	2023
	Develop new routes	The most important areas for new routes would be: 1. Reference ship tracks in cloud free regions; this could be on a ship or fixed platform. This would fulfil the need for long-term consistency. 2. More radiometers going out into problem areas (Arctic and islands) and the whole of the southern area. 3. Aerosol regions, e.g. (P&E) 24° west. Aerosols vary a lot so it is good to go to a few times.	4-5	3 (could use existing infrastructure)	2021

Table 4-1 – Service Roadmap

5. SUMMARY

Discussions throughout the service and during the ISFRN workshop identified a number of areas with a high impact on the service. Generally, these come with a high difficulty rating, often due to the need for additional funding or time but there are a number of suggestions with high impact and low-medium difficulty which could take high priority within the next 2 years of work. These are:

- Add more data and metadata to the ships4sst database.
    - It is clear from presentations made during the recent ISFRN workshop that there are a number of saildrones now producing SST skin data around the globe and the possibility of adding saildrone data to the ships4sst archive was discussed. This can be further explored using the contacts made during the workshop.
    - 5 ISARs are due to be delivered within the next 2 years. More data will most likely be obtained once the ISARs are delivered and operating in their respective countries.
- Perform another CEOS Radiometer Inter-comparison exercise.
    - Plans are underway to perform an inter-comparison exercise in 2022.
- Push for more radiometers on ships of opportunity
    - As mentioned previously, a number of ISARs are planned for delivery in 2020/2021. One will provide DMI with a second radiometer on their existing deployment, which will enable continuous deployment of an ISAR on the *MS Norröna*. Other radiometers may be deployed on new ships of opportunity.
    - COVID-19 has affected the cruise industry in 2020, some ships have been hit harder than others, and so one variable that may be considered for future radiometer ships of opportunity is their resilience during a global pandemic. Experience this year has taught is that the ships that operate due to necessity (e.g. cargo ships) are more likely to resume deployments sooner after a pandemic.
- All suggestions within the outreach and documentation section were deemed high impact and low-medium difficulty. This includes checking and updating website and data archive documentation, and publishing reports and papers. These are updated routinely and this will continue in phase 2 of the FRM4SST contract. The information provided to radiometer instrument operators could be revisited in 2021; it was noted during the workshop that there were a couple of times when the operator could not get the instrument to work for part of or all of a voyage. A revisit could establish whether updates need to be made to the documents to clarify answers to the FAQs.

- Develop new routes
    - Three areas for new routes have been identified; reference ship tracks in cloud-free regions, 'problem areas' such as the Arctic, around islands and in the southern oceans, and lastly aerosol regions. The southern oceans may be addressed when CSIRO receive their new ISAR in 2021. Existing infrastructure could be used; for example, a presentation made during the ISFRN workshop spoke of a platform in the Mediterranean Sea that is effective, easy and cheap to install and use scientific equipment on. This could be explored in 2021.

Whilst it does have a high difficulty rating, further work on radiometer uncertainty was brought up a number of times during the workshop and a verification of the uncertainty model out at sea is noted to have a high impact. The effect of surface emissivity on the SST_{skin} measurements can also be investigated at the same time. The difficulty arises as, depending on the detail required, this can be a very time consuming and expensive endeavour.

Another suggestion with high impact and difficulty ratings is the request for a next-generation radiometer. It has been a number of years since a radiometer was last designed and with the advancement of technologies and satellite measurements over the years it now appears to be the right time to revisit the design. A case study for a next generation radiometer is currently being written and discussed with the ISFRN community, and there is enthusiasm for not only a TIR shipborne radiometer but also one which includes microwave measurements, to validate satellite instruments such as CIMR. The high difficulty rating is due to the funding that is required to build a next generation radiometer.

Plans to promote the ISFRN and actively engage with the community will also continue into phase 2 of the FRM4SST project.

6. CONCLUSION

This service roadmap has provided the project with very useful feedback and future strategies to take into phase 2 of the ESA-funded FRM4SST study. The recommendations, which include strategies for implementation, difficulty and impact ratings, will facilitate this project in focussing on the high priority areas that are doable within the framework of the contract, as noted in the summary section of this document.

Importantly, the service roadmap details a number of goals that are needed to ensure that *in situ* radiometers continue to fulfil their role of validating and verifying satellite SST_{skin} data and enable scientists to understand better the dynamics of the oceans and their impacts on the global climate.