ships4sst

shipborne radiometers for sea surface temperature

FRM4SST project: Annual Satellite SST Validation Report

RAL Space

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Abstract : This document contains the annual assessment of the FRM4SST satellite SST validation results, performed by the FRM4SST project team during the year 2024 - 2025.

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1. EXECUTIVE SUMMARY

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 collection, processing, analysis, publication and reporting of *in situ* FRM field measurements made using Infrared Sea surface temperature Autonomous Radiometers (ISAR) and the Scanning Infrared Sea Surface Temperature Radiometer (SISTeR) Instruments, that are near-contemporaneous with satellite data from the Sentinel-3A and Sentinel-3B SLSTR instruments.

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).

In order to ensure that the SLSTR geophysical data products are reliable, they must be validated by comparing them with measurements from the long-term *in situ* deployment of the ISARs, and also from the SISTeR instrument; these measurements confirm the consistency of the SST data products.

This report presents the annual assessment of the FRM4SST satellite SST validation results, performed by the FRM4SST project team during the year 2024 - 2025.

2. INTRODUCTION

This report is deliverable D-5 on the FRM4SST contract and describes the assessment of the FRM4SST satellite SST validation results, performed by the FRM4SST project team between April 2024 and April 2025.

This report first gives a short introduction to the shipborne *in situ* measurements that are used to validate satellite SST data such as the Sea and Land Surface Temperature Radiometer (SLSTR) onboard satellites Sentinel 3A and 3B. The validation results are presented in section 3 and show data processed between April 2024 and April 2025, before the conclusion in section 4.

2.1 Data produced and archived

The FRM4SST team deploy three sets of radiometers on ships of opportunities; these are ISAR from UoS, ISAR from DMI and SISTeR from RAL. These SST_{skin} datasets are contributed to by data from external data providers CSIRO (with ISAR) and RSMAS (with M-AERI). Figure 1 shows the collective SST L2R files by data provider plotted on the world map where pink is CSIRO, light red is DMI, green is RAL, blue is RSMAS and deep red is UoS. Each dataset on the ships4sst archive is a Fiducial Reference Measurement (FRM)[1]. This is achieved through robust traceability to the SI temperature scale (ITS-90) as shipborne radiometer calibrations derived from their internal blackbodies are regularly verified against an SI-traceable laboratory calibration target.

The ships4sst data archive is hosted at Ifremer and accessible via the ships4sst website. The Felyx tool at Ifremer processes and generates validation reports and satellite match-ups. This processing is performed by EUMETSAT. All the project partners, including external partners CSIRO ISAR and RSMAS M-AERI, store their ISFRN L2R data files at the archive once they become available, which is normally after the post-deployment calibration. The ISFRN L2R files are accompanied by calibration information, such as calibration factors from the pre- and post-deployment calibrations.

Figure 2 shows the combined archive SST_{skin} data from the ISARs, M-AERI and SISTeR, as shown on a world map. These data files are used in the validation of satellite SST.

Documentation of the traceability of all calibration equipment is also stored at the data archive, as well as on the ships4sst website.

[1] *Goryl P, Fox N, Donlon C, Castracane P. Fiducial Reference Measurements (FRMs): What Are They?* Remote Sensing*. 2023; 15(20):5017. https://doi.org/10.3390/rs15205017*

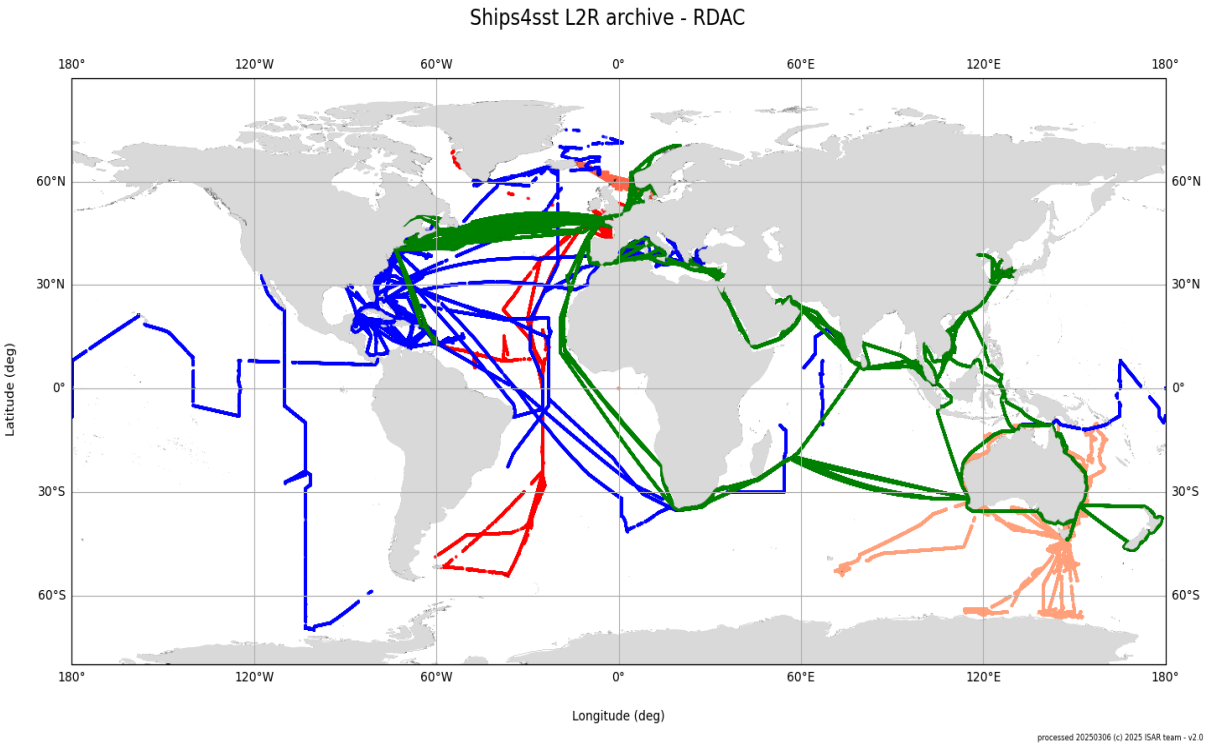

Figure 1: The ships4sst data archive L2R files plotted as by data provider, March 2025. Routes shown in red tones are collecting data with ISARs, routes shown in green are collection data with SISTeR and routes showing in blue are collection data with M-AERI instruments.

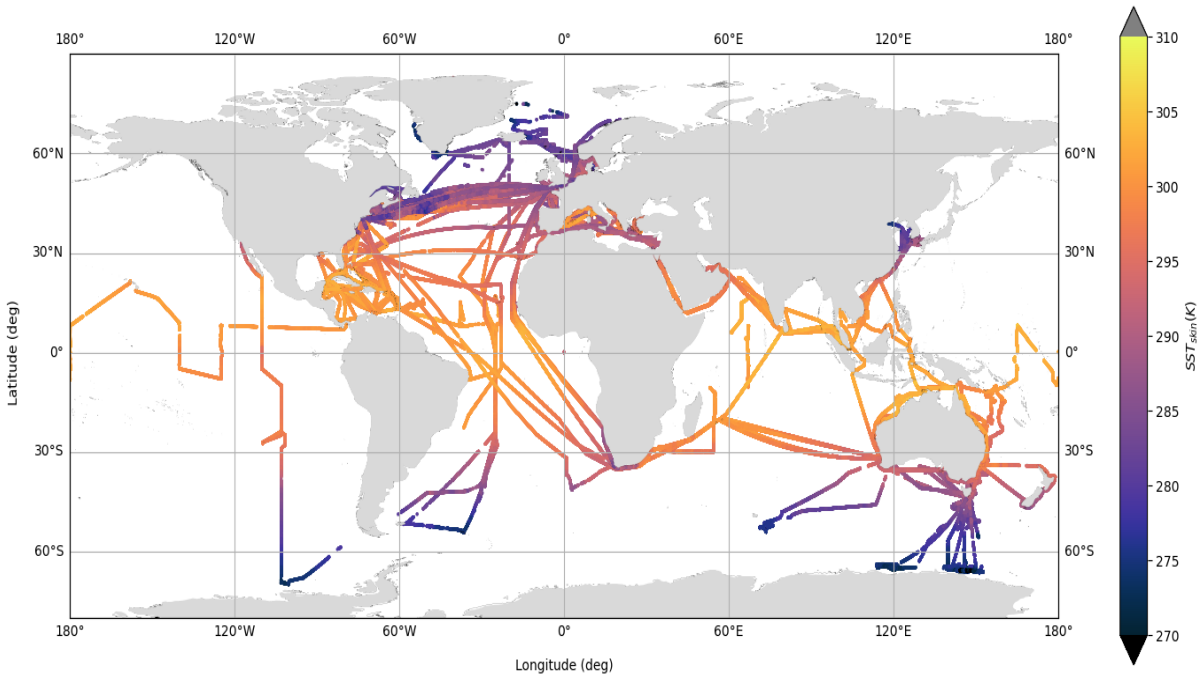

Figure 2: The ships4sst data archive L2R files plotted as SST on a world map, March 2025

2.2 Satellite measurements: SLSTR

All available Sentinel-3 SLSTR SST products are routinely collected and archived at EUMETSAT. This archive is used together with the ESA Felyx instance at EUMETSAT to produce so called “miniProd” satellite data extracts. These miniProd’s are than used by Felyx to generate the match-up database files between ships4sst data and SLSTR data. The SLSTR data are extracted around each match-up pair and stored in match-up data base (MDB) files at EUMETSAT. Each match-up pair is accompanied by 400x400 SLSTR pixels around the centre location and 6.5 hours of ships4sst data before and after the match-up time. This is done in order to be able to reprocess the MDB files at UoS in order to generate match-ups as described by Wimmer et.al. (2012).

2.3 Match-up process

The MDB data from EUMETSAT is reprocessed at UoS to generate the validation match-up pairs as described in Wimmer et al. (2012). The processing first checks if the centre match-up pair as derived by the Felyx processor is cloud free. If it is cloud free it is used as a match-up pair. If the centre match-up pair is cloudy we use the nearest cloud free match-up pair in space and time within the match-up window searched for. If no cloud free match-up pair is found, no validation data is generated.

This process is repeated for each ships4sst data point, allowing multiple match-up pairs per satellite overpass. However no ships4sst value or satellite pixel is used more than once.

The match-up processor uses five match-up windows as shown in **Table 1:** Match-up grades used for SLSTR validation. The colours are used in the plots in the results section to show the different match-up grades. The match-up windows are used to differentiate between temporal and spatial effects on the validation results and to maximise the use of the validation data.

Table 1: Match-up grades used for SLSTR validation. The colours are used in the plots in the results section to show the different match-up grades.

Grade	Temporal	Spatial	Colour
1	+/- 30 min	+/- 1 km	Blue
2a	+/- 30 min	+/- 20km	Red
2b	+/- 2 hours	+/- 1km	Green
3	+/- 2 hours	+/- 20 km	Magenta
4	+/- 6 hours	+/- 25 km	Yellow

3. VALIDATION RESULTS FOR THE PERIOD 2023 - 2024

In this section, the results from the validation of SLSTR SST data against ships4sst data for 2023 and 2024 are discussed. The main results are shown for SLSTR WST data and GHRSST quality level 5 (CV5).

First, the summary result plots for all three years are shown, followed by six sections showing the results for each year and for each sensor (SLTSTR on Sentinel 3A and 3B) separately.

3.1 Results for 2023 and 2024

The data shown in **Figure** 3, **Figure** 4 and **Figure 5** show the median (dot) and robust standard deviation (error bars) for all match-up grades colour coded as described in **Table 1** in the top panel. The bottom panel shows the number of match-up pairs for the different match-up grades, again coloured as described in

Table 1. The two SLSTR sensors are labelled as S3A and S3B for the SLSTR on Sentinel 3A and Sentinel 3B respectively.

Figure 3 shows the results for day and night data combined, **Figure 4** shows daytime only data and Figure 5 shows nighttime only data.

All validation results show a very small mean difference, and a robust standard deviation (RSD) that increases with the match-up grade, which is expected.

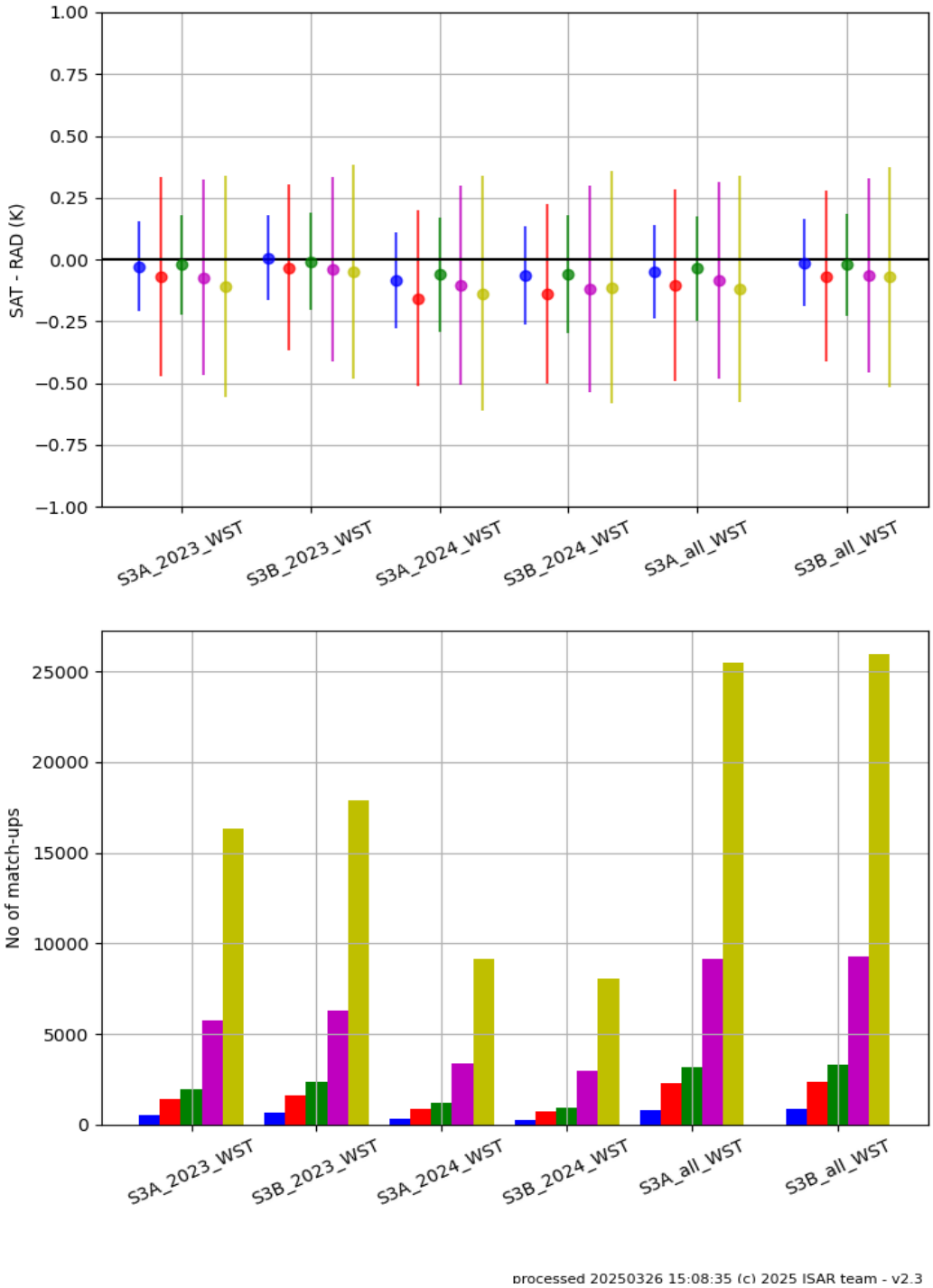

Figure 3: SLSTR - ships4sst validation results for 2023 and 2024 WST data, daytime and nighttime data, split by year and satellite sensor

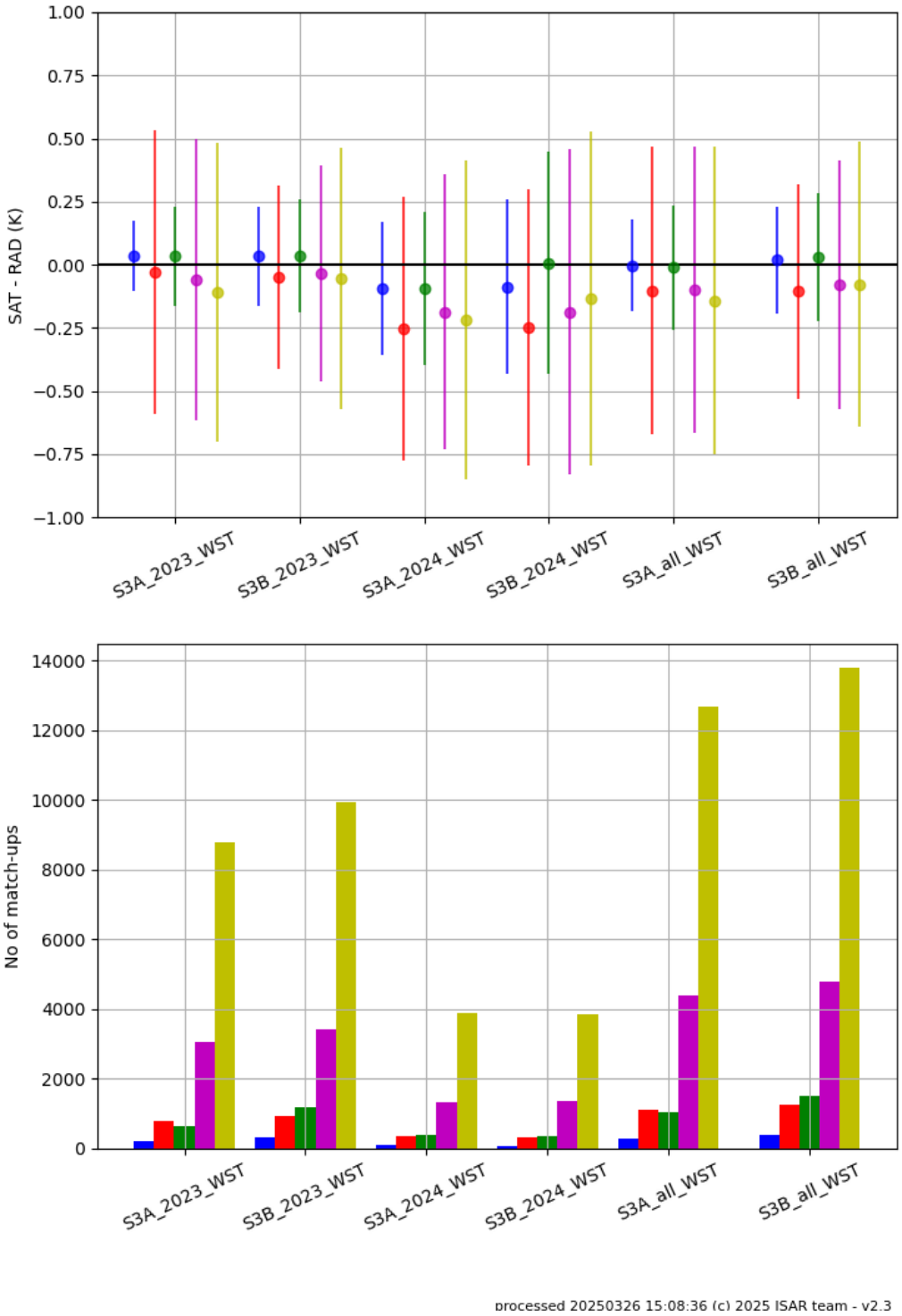

Figure 4: SLSTR - ships4sst validation results for 2023 and 2024 WST data, daytime only data, split by year and satellite sensor

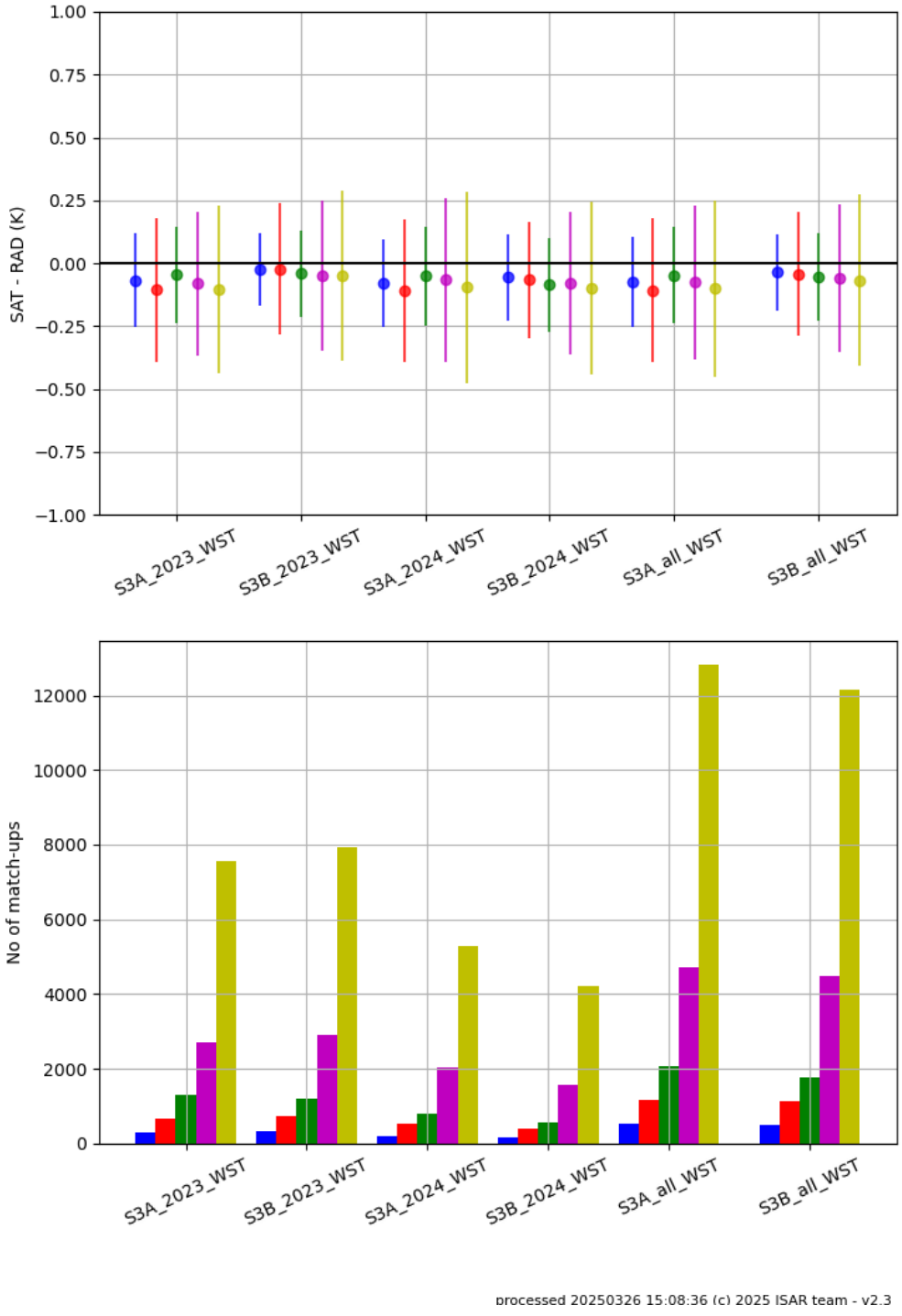

Figure 5: SLSTR - ships4sst validation results for 2023 and 2024 WST data, nighttime only data split by year and satellite sensor

3.2 Results for 2023 for SLSTR on Sentinel 3A

This is the first of the sensor specific results sections, all plots show the GHRSST quality level 5 and grade 2b match-up data. First, the location plot is shown, then the histogram for all data, followed by histograms for daytime and nighttime only data. Next are the scatter plots for day and nighttime data and finally the statistics for all match-up grades are shown.

The histograms show the data in red, a Gaussian fit in blue and the statistics in the top right corner. The scatter plots show data above the 1:1 line (black) in red, below in blue and a linear fit to the data in green, with the fit parameters in the top left corner.

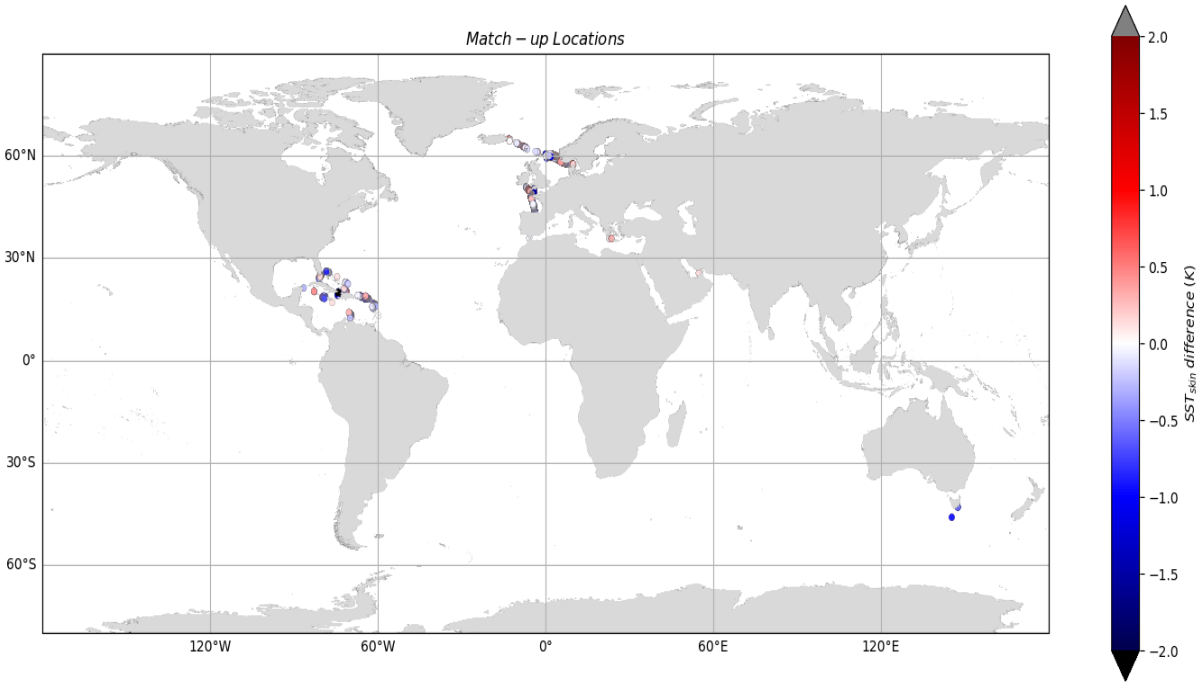

Figure 6: Location plot for the SLSTR 3A - ships4sst match-ups in 2023

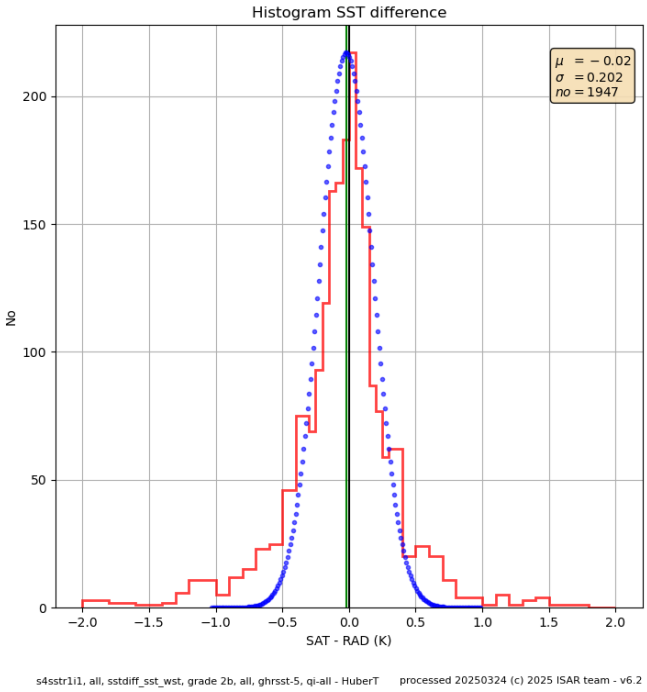

Figure 7: Histogram for SLSTR 3A - ships4sst match-ups for grade 2b match-up window in 2023.

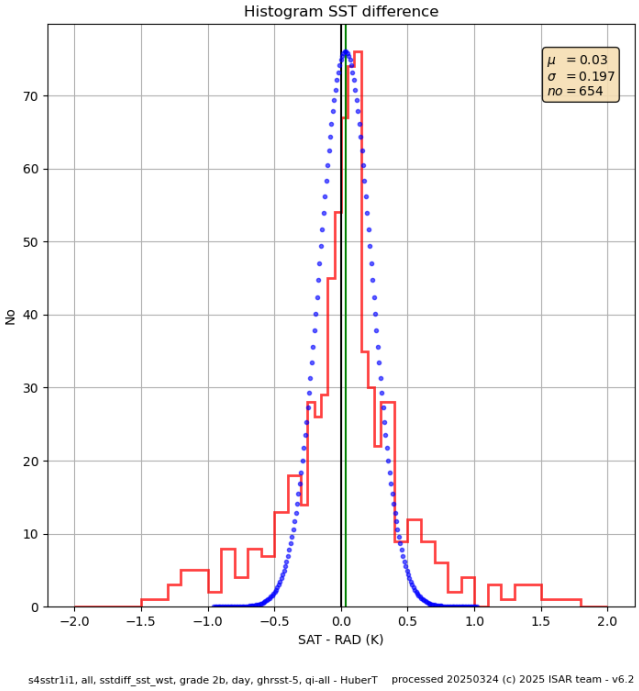

Figure 8: Histogram for SLSTR 3A - ships4sst daytime match-ups for grade 2b match-up window in 2023.

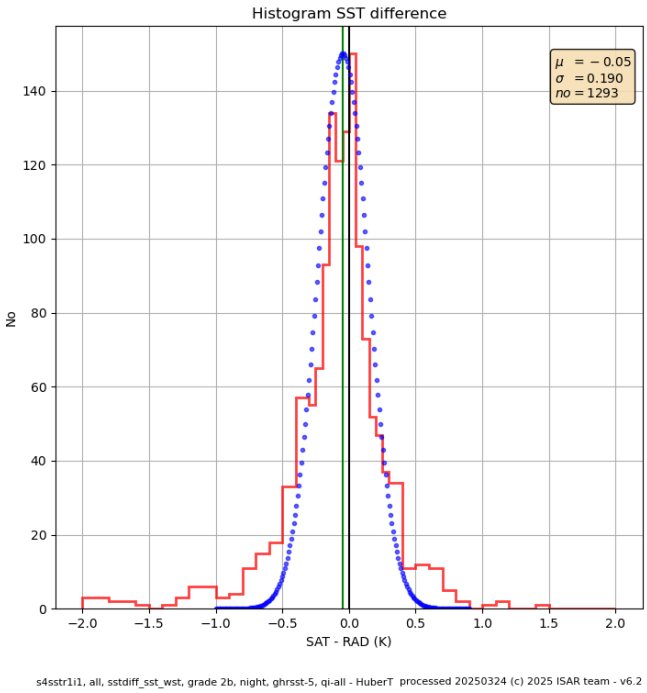

Figure 9: Histogram for SLSTR 3A - ships4sst nighttime match-ups for grade 2b match-up window in 2023.

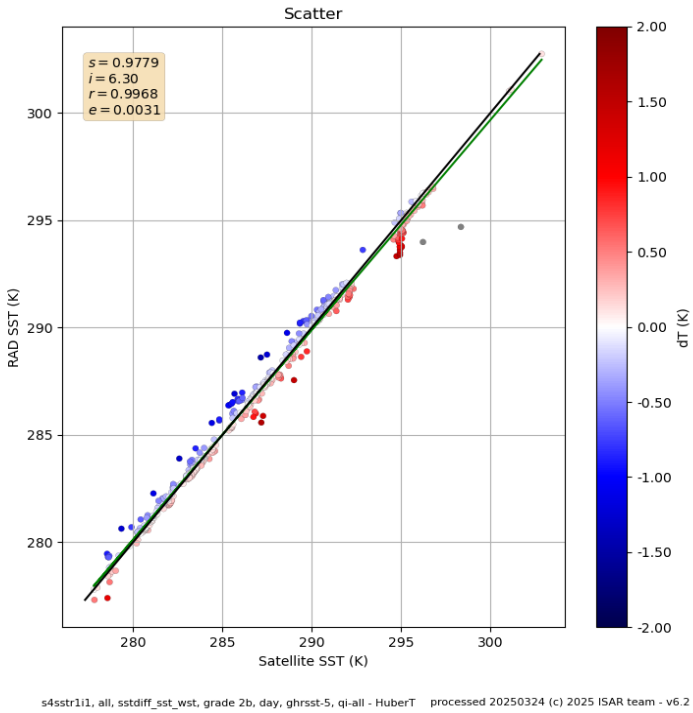

Figure 10: Scatter plot for SLSTR 3A - ships4sst match-ups for daytime grade 2b match-up window in 2023.

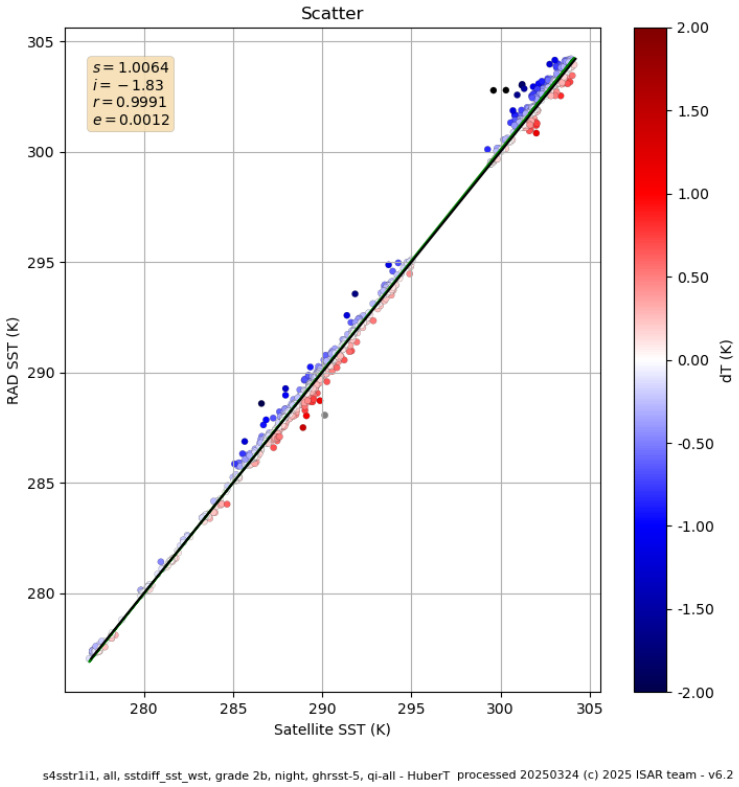

Figure 11: Scatter plot for SLSTR 3A on Sentinel 3A - ships4sst match-ups for nighttime grade 2b match-up window in 2023.

Table 2: Match-up statistics for SLSTR 3A - ships4sst in 2023

WST						
ALL						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	-0.03	0.18	499	71	276.92	304.00
2a	-0.07	0.40	1420	150	273.48	304.17
2b	**-0.02**	**0.20**	**1947**	**114**	**276.92**	**304.11**
3	-0.07	0.39	5751	172	273.42	305.17
4	-0.11	0.45	16340	231	273.42	305.63

WST						
Day						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	0.04	0.14	193	23	278.58	296.79
2a	-0.03	0.56	770	76	274.92	303.63
2b	**0.03**	**0.20**	**654**	**48**	**277.79**	**302.86**
3	-0.06	0.56	3048	93	274.92	305.17
4	-0.11	0.59	8781	157	273.96	305.17

WST						
Night						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	-0.07	0.19	306	48	276.92	304.00
2a	-0.11	0.29	650	75	273.48	304.17
2b	-0.05	0.19	1293	72	276.92	304.11
3	-0.08	0.29	2703	94	273.42	304.97
4	-0.10	0.33	7559	168	273.42	305.63

3.3 Results for 2023 for SLSTR on Sentinel 3B

As with section 3.2, all plots for the SLSTR 3B results show the GHRSST quality level 5 and grade 2b match-up data. First, the location plot is shown, then the histogram for all data, followed by histograms for daytime and nighttime only data. Next are the scatter plots for daytime and nighttime data and finally the statistics for all match-up grades are shown.

The histograms show the data in red, a Gaussian fit in blue and the statistics in the top right corner. The scatter plots show data above the 1:1 line (black) in red, below in blue and a linear fit to the data in green, with the fit parameters in the top left corner.

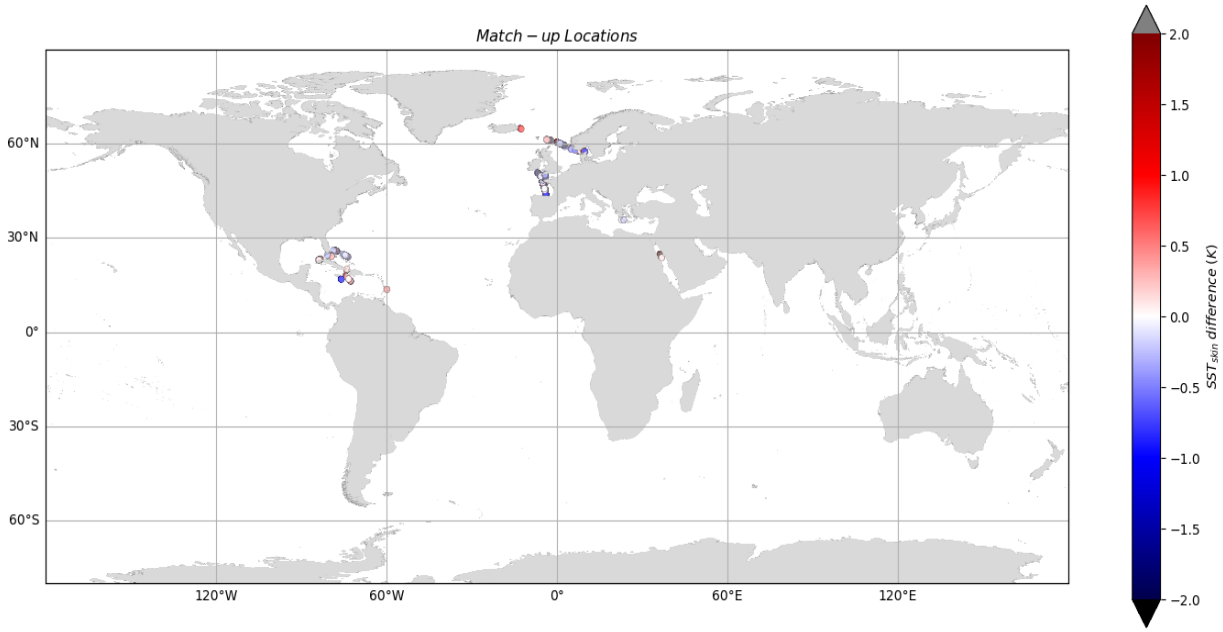

Figure 12: Location plot for the SLSTR 3B - ships4sst match-ups on 2023

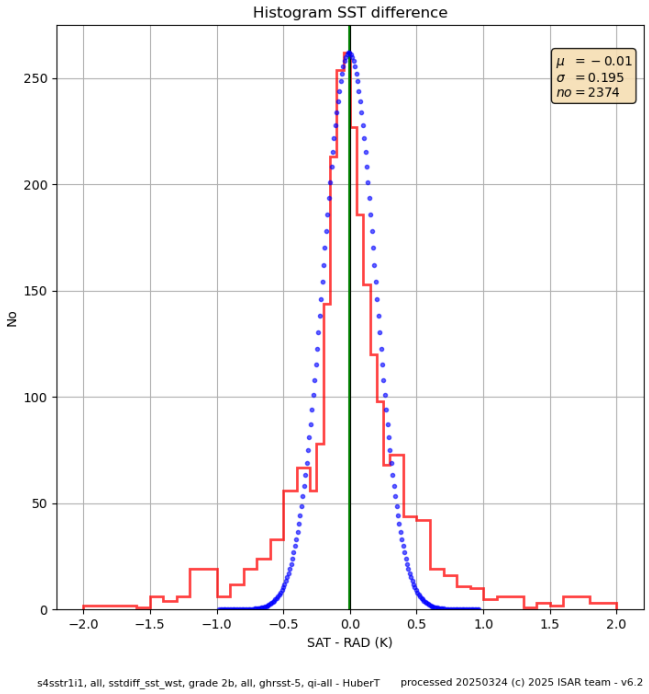

Figure 13: Histogram for SLSTR 3B - ships4sst match-ups for grade 2b match-up window in 2023.

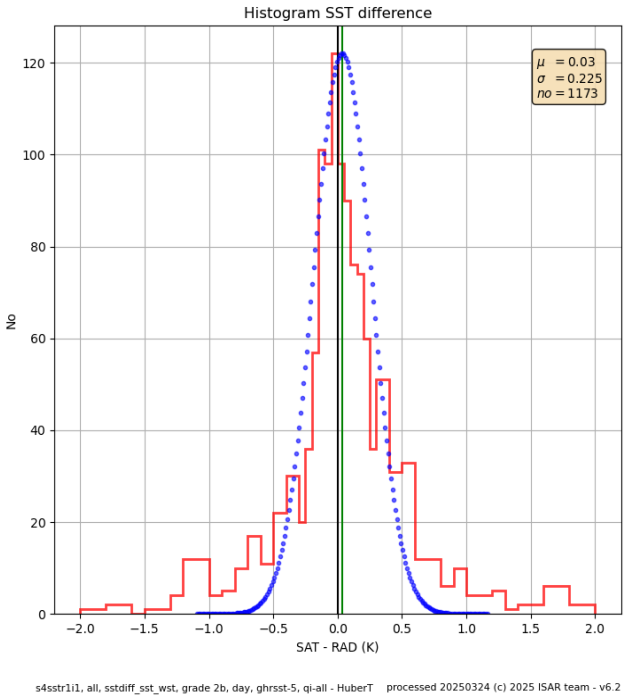

Figure 14: Histogram for SLSTR 3B - ships4sst day time match-ups for grade 2b match-up window in 2023**.**

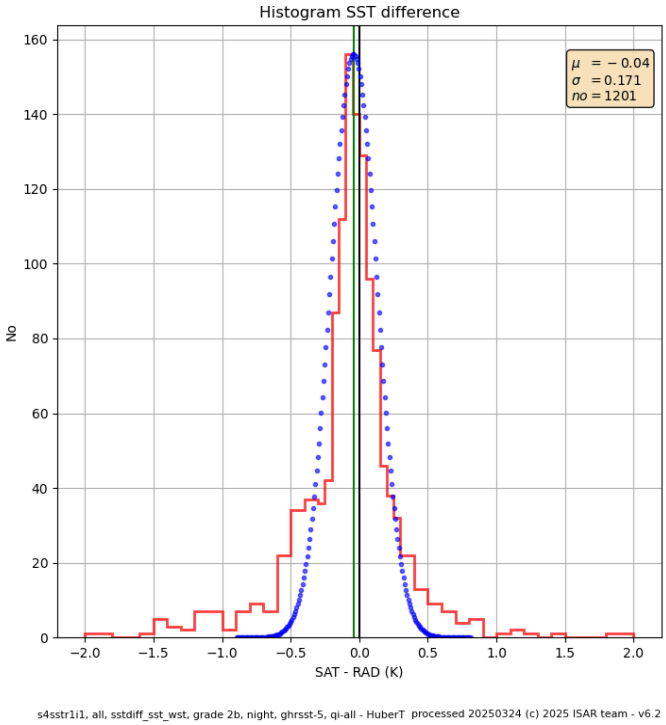

Figure 15: Histogram for SLSTR 3B - ships4sst nighttime match-ups for grade 2b match-up window in 2023

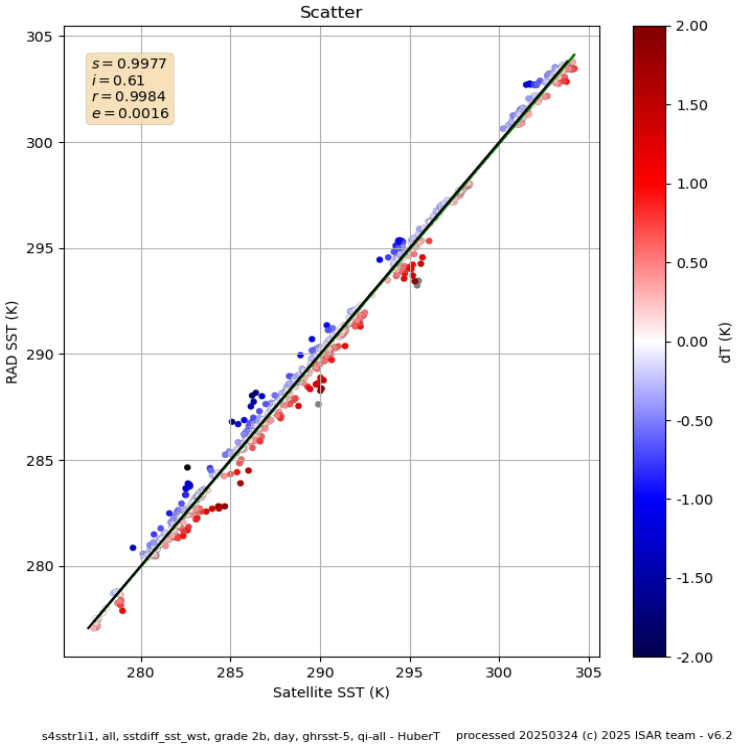

Figure 16: Scatter plot for SLSTR 3B - ships4sst match-ups for daytime grade 2b match-up window in 2023

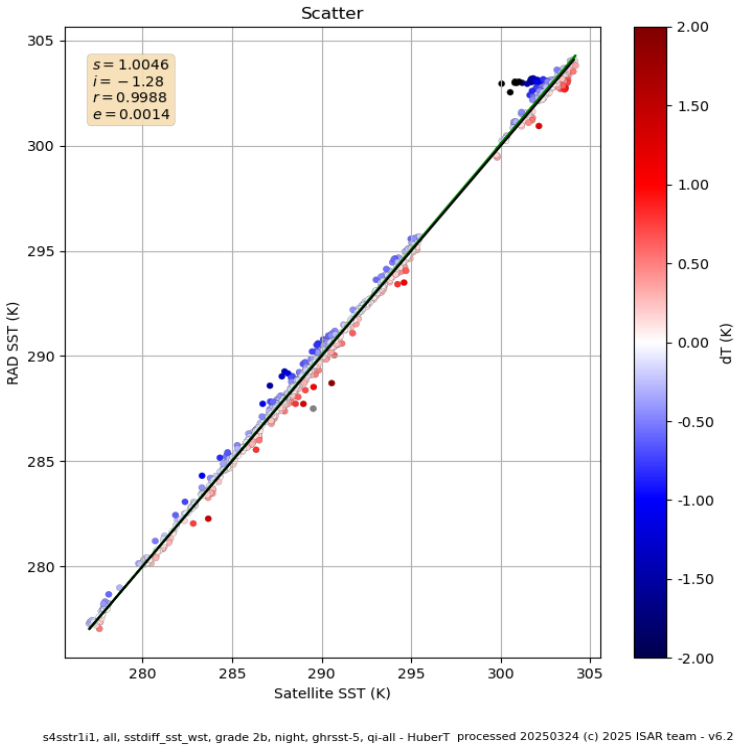

Figure 17: Scatter plot for SLSTR 3B - ships4sst match-ups for nighttime grade 2b match-up window in 2023

Table 3: Match-up statistics for SLSTR 3B - ships4sst in 2023

WST						
All						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	0.01	0.17	634	93	277.14	304.15
2a	-0.03	0.33	1640	154	275.20	304.27
2b	-0.01	0.19	2374	133	277.02	304.21
3	-0.04	0.37	6302	194	274.14	305.16
4	-0.05	0.43	17887	224	273.29	305.16

WST						
Day						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	0.03	0.20	322	45	277.48	304.07
2a	-0.05	0.36	919	85	275.27	304.27
2b	0.03	0.23	1173	66	277.37	304.21
3	-0.03	0.43	3412	108	275.27	305.16
4	-0.05	0.52	9947	159	274.52	305.16

WST						
Night						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	-0.02	0.14	312	49	277.14	304.15
2a	-0.02	0.26	721	70	275.20	304.15
2b	-0.04	0.17	1201	69	277.02	304.18
3	-0.05	0.30	2890	95	274.14	304.18
4	-0.05	0.34	7940	151	273.29	304.50

3.4 Results for 2024 for SLSTR on Sentinel 3A

As with the previous sections, all plots for the SLSTR 3A results show the GHRSST quality level 5 and grade 2b match-up data. First, the location plot is shown, then the histogram for all data, followed by histograms for daytime and nighttime only data. Next are the scatter plots for daytime and nighttime data and finally the statistics for all match-up grades are shown.

The histograms show the data in red, a Gaussian fit in blue and the statistics in the top right corner. The scatter plots show data above the 1:1 line (black) in red, below in blue and a linear fit to the data in green, with the fit parameters in the top left corner.

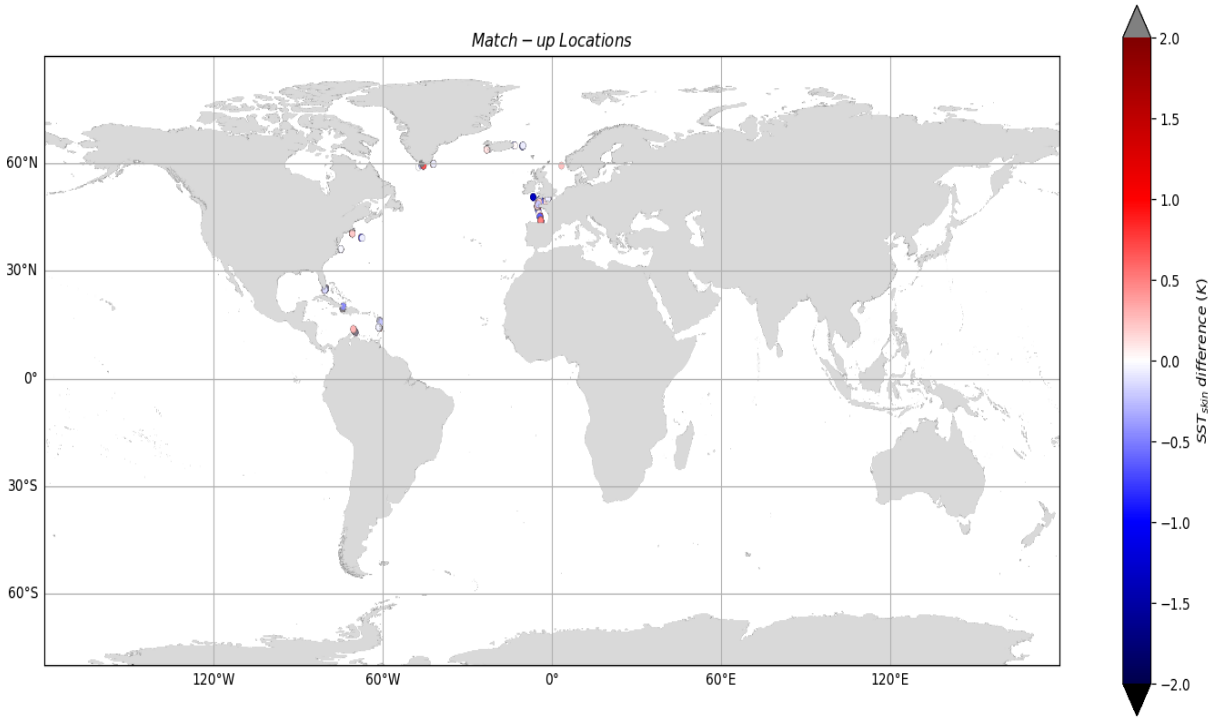

Figure 18: Location plot for the SLSTR 3A - ships4sst match-ups in 2024

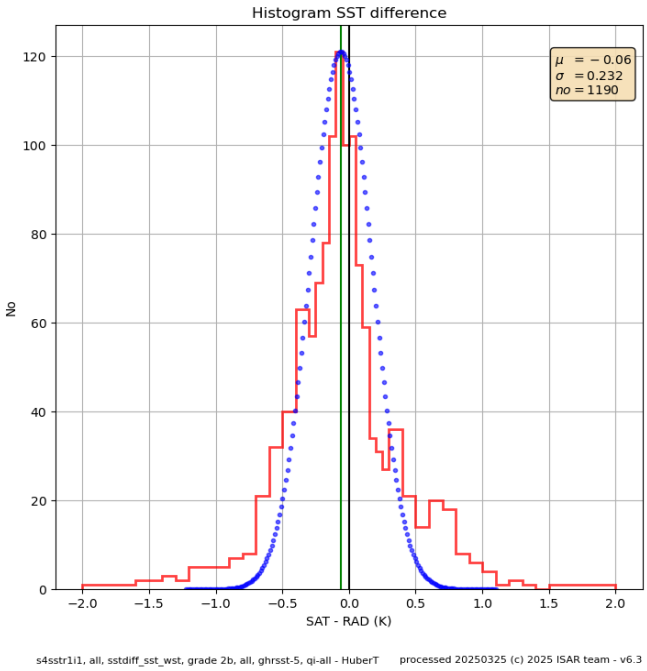

Figure 19: Histogram for SLSTR 3A - ships4sst match-ups for grade 2b match-up window in 2024.

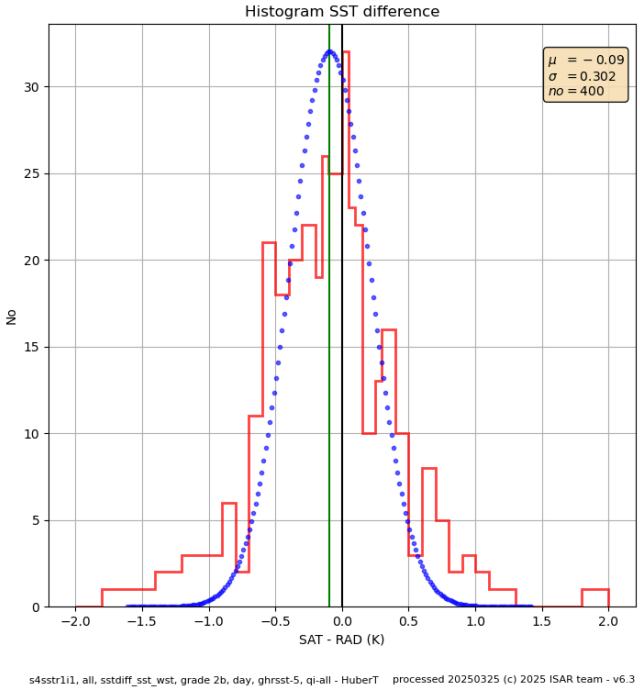

Figure 20: Histogram for SLSTR 3A - ships4sst daytime match-ups for grade 2b match-up window in 2024.

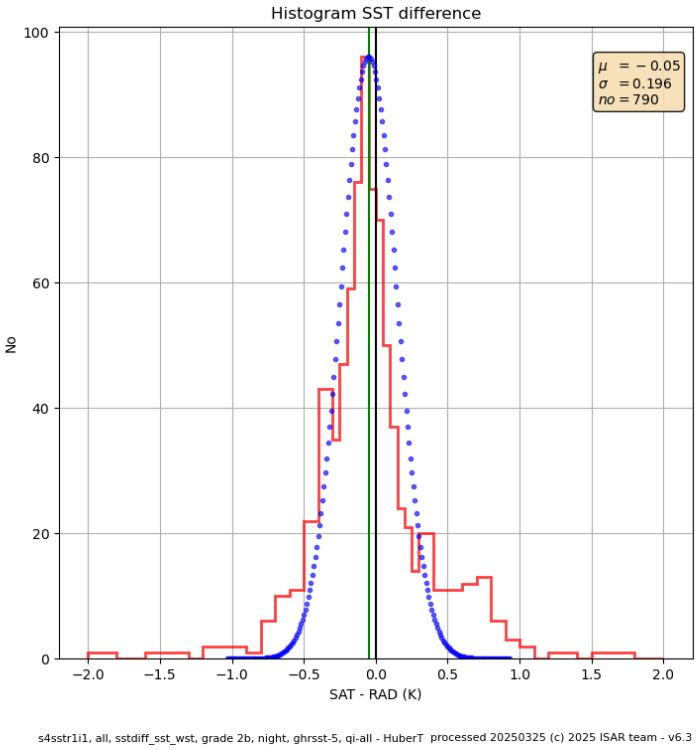

Figure 21: Histogram for SLSTR 3A - ships4sst nighttime match-ups for grade 2b match-up window in 2024.

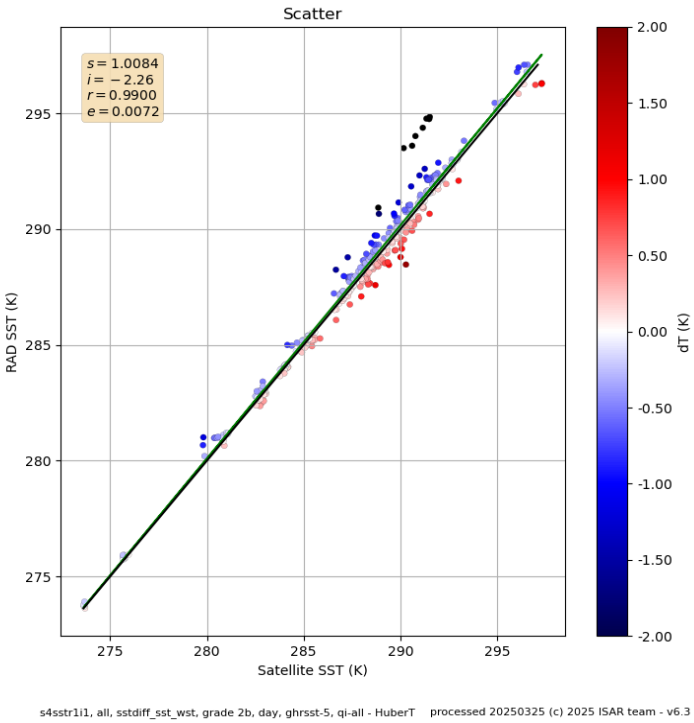

Figure 22: Scatter plot for SLSTR 3A - ships4sst match-ups for day time grade 2b match-up window in 2024.

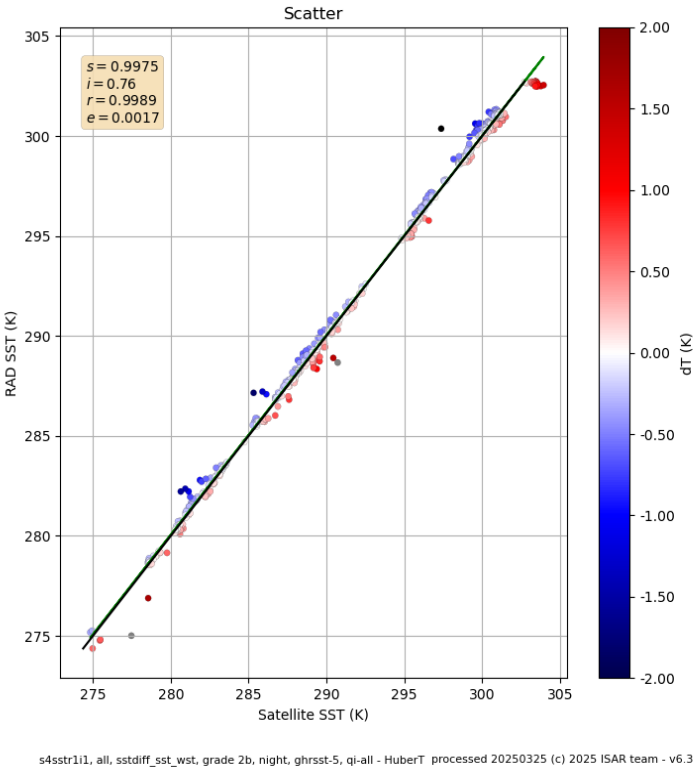

Figure 23: Scatter plot for SLSTR 3A - ships4sst match-ups for nighttime grade 2b match-up window in 2024.

Table 4: Match-up statistics for SLSTR 3A - ships4sst in 2024

WST						
All						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	-0.08	0.19	312	58	273.65	303.49
2a	-0.16	0.35	866	105	273.58	303.85
2b	-0.06	0.23	1190	85	273.65	303.94
3	-0.10	0.40	3358	135	273.24	304.30
4	-0.14	0.48	9159	167	273.24	304.30

WST						
Day						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	-0.09	0.26	104	25	273.65	296.05
2a	-0.25	0.52	354	49	273.58	303.85
2b	-0.09	0.30	400	36	273.65	297.31
3	-0.19	0.55	1338	62	273.24	304.30
4	-0.22	0.63	3890	114	273.24	304.30

WST						
Night						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	-0.08	0.17	208	33	274.97	303.49
2a	-0.11	0.28	512	57	274.97	303.49
2b	-0.05	0.20	790	50	274.82	303.94
3	-0.07	0.33	2020	78	274.56	303.94
4	-0.10	0.38	5269	119	273.65	304.29

3.5 Results for 2024 for SLSTR on Sentinel 3B

As with the previous sections, all plots for the 2024 SLSTR 3B results show the GHRSST quality level 5 and grade 2b match-up data. First, the location plot is shown, then the histogram for all data, followed by histograms for daytime and nighttime only data. Next are the scatter plots for daytime and nighttime data and finally the statistics for all match-up grades are shown.

The histograms show the data in red, a Gaussian fit in blue and the statistics in the top right corner. The scatter plots show data above the 1:1 line (black) in red, below in blue and a linear fit to the data in green, with the fit parameters in the top left corner.

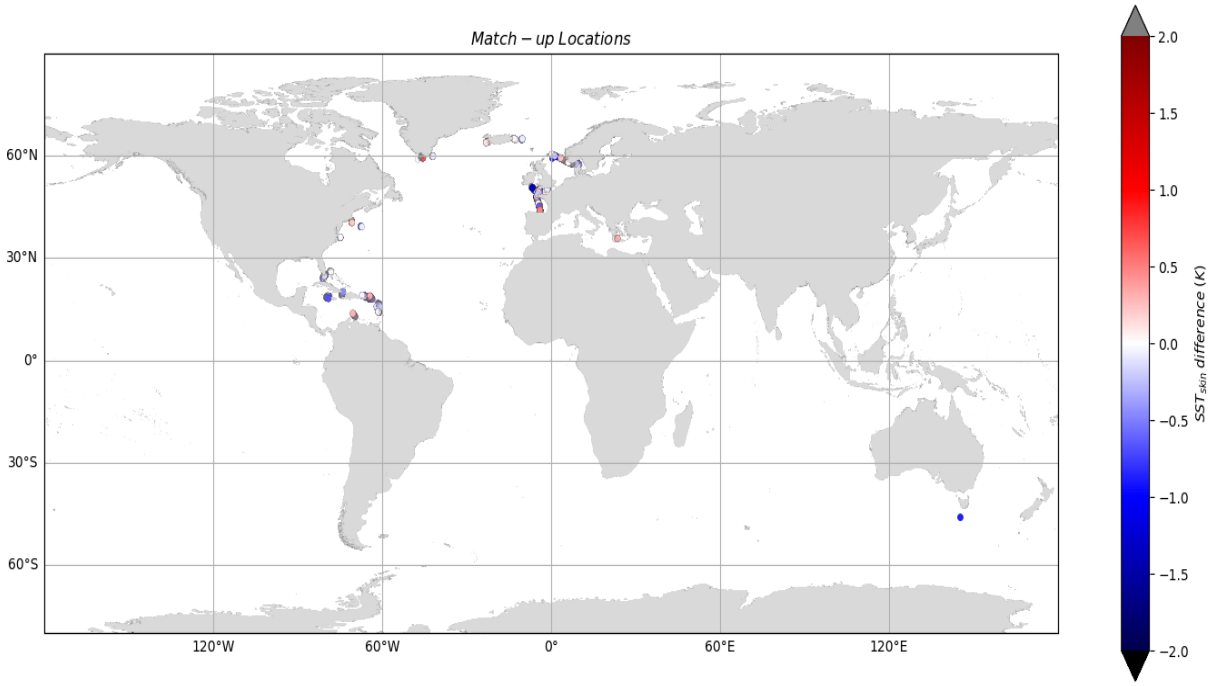

Figure 24: Location plot for the SLSTR 3B - ships4sst match-ups on 2024

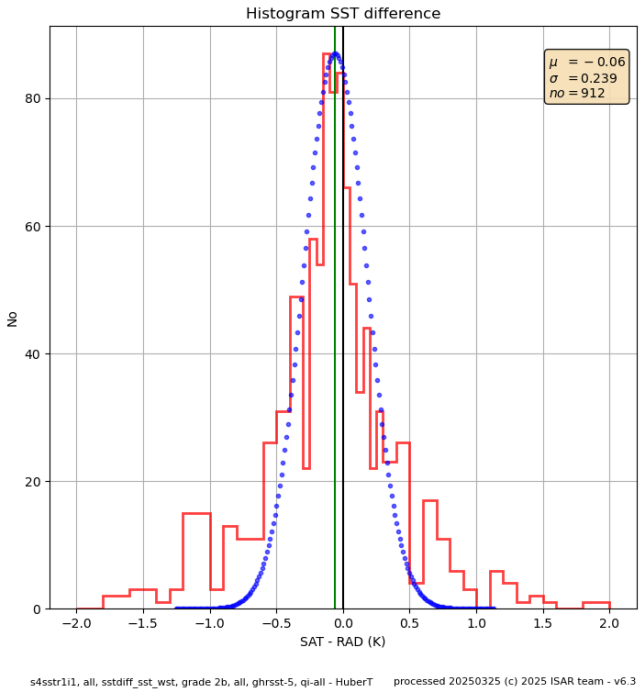

Figure 25: Histogram for SLSTR 3B - ships4sst match-ups for grade 2b match-up window in 2024.

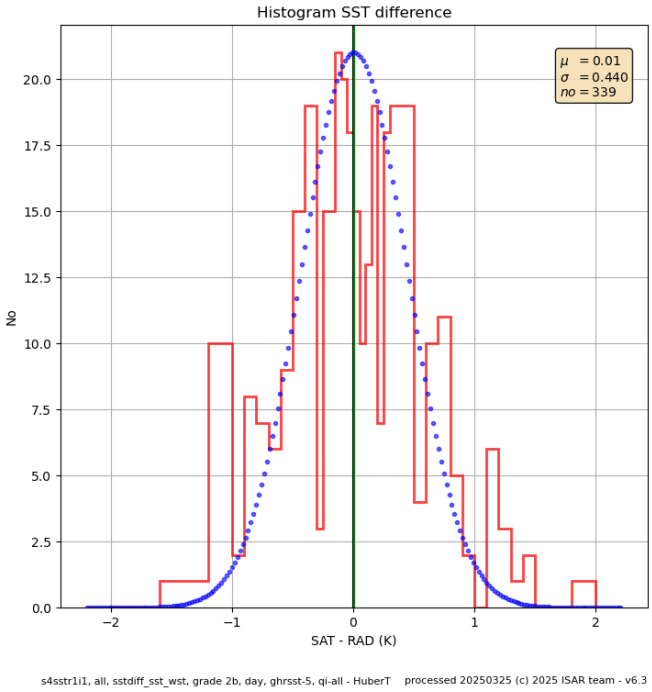

Figure 26: Histogram for SLSTR 3B - ships4sst daytime match-ups for grade 2b match-up window in 2024.

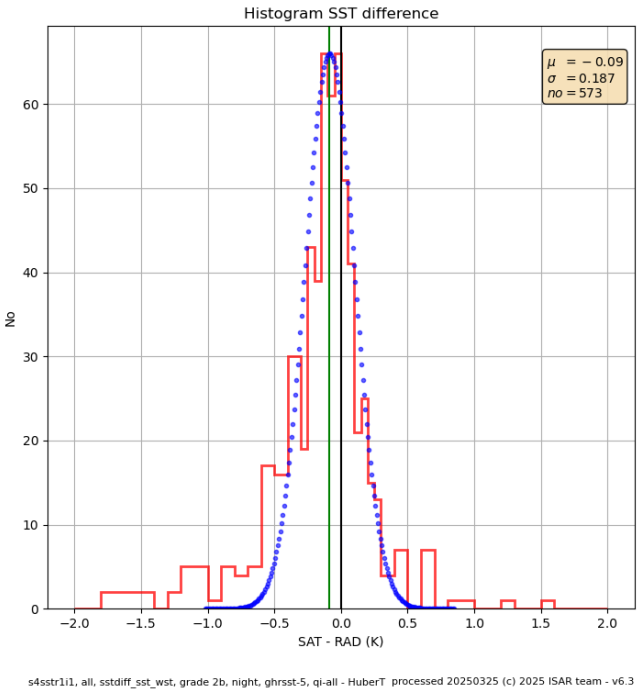

Figure 27: Histogram for SLSTR 3B - ships4sst nighttime match-ups for grade 2b match-up window in 2024.

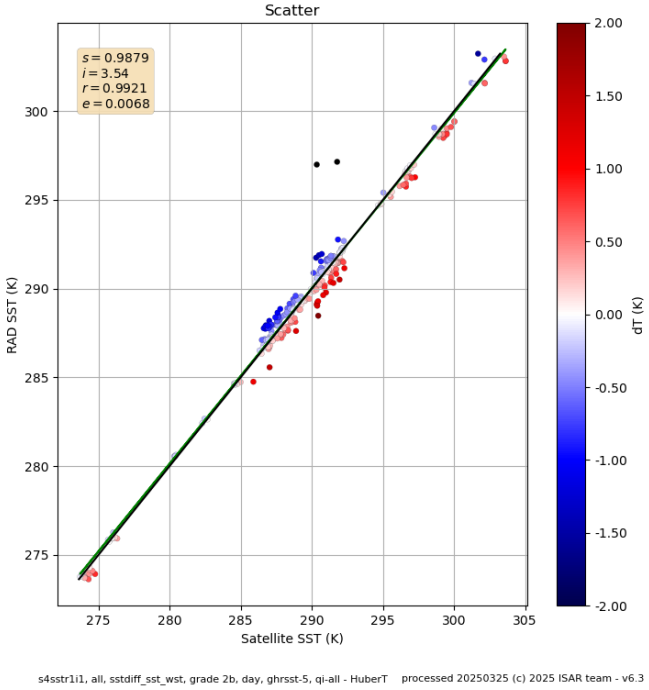

Figure 28: Scatter plot for SLSTR 3B - ships4sst match-ups for daytime grade 2b match-up window in 2024.

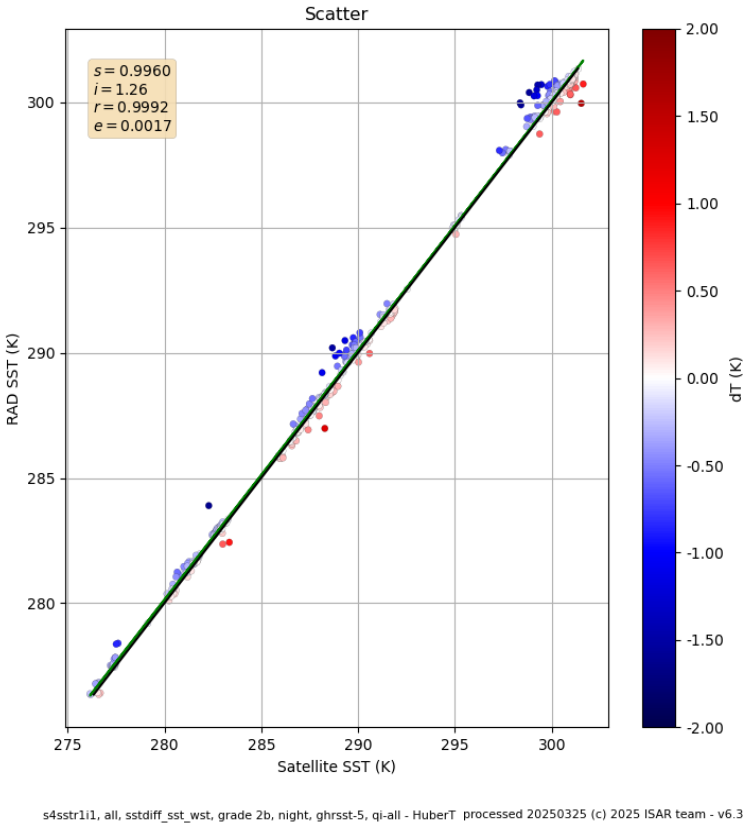

Figure 29: Scatter plot for SLSTR 3B - ships4sst match-ups for nighttime grade 2b match-up window in 2024.

Table 5: Match-up statistics for SLSTR 3B - ships4sst in 2024

WST						
All						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	-0.06	0.20	244	45	275.67	303.51
2a	-0.14	0.36	737	91	273.73	305.13
2b	**-0.06**	0.24	912	77	273.71	303.63
3	-0.12	0.42	2954	123	273.50	305.43
4	-0.11	0.47	8086	175	273.29	305.43

WST						
Day						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	-0.09	0.35	75	17	275.67	303.51
2a	-0.25	0.55	329	47	273.73	305.13
2b	**0.01**	0.44	339	37	273.71	303.63
3	-0.19	0.64	1376	68	273.50	305.43
4	-0.13	0.66	3862	110	273.29	305.43

WST						
Night						
Grade	**MDiff**	**RSD**	**No**	**Overpass**	**Min Temp**	**Max Temp**
1	-0.06	0.17	169	29	276.41	301.24
2a	-0.06	0.23	408	47	276.41	302.99
2b	**-0.09**	0.19	573	41	276.13	301.62
3	-0.08	0.28	1578	62	274.91	302.99
4	-0.10	0.34	4224	112	273.33	303.06

4. CONCLUSION

The validation of SLSTR WST 2023 and 2024 data showed that the SLSTR on Sentinel 3A and 3B perform excellently and better than their specification. The results are in line with validation data from previous years for SLSTR and show that the SLSTR sensors on Sentinel 3A and B are a match for the previous generation of dual view sensor, such as AATSR.

The validation statistics for SLSTR on Sentinel 3A in 2023 show a very small mean difference of 0.03 K for daytime and -0.05 K for nighttime data with a robust standard deviation (RSD) of 0.2 K for daytime data and 0.19 K for nighttime data. For 2024 the statistics are a mean difference of -0.09K for daytime data and -0.05K for nighttime data with a RSD of 0.30K for daytime data and 0.20K for nighttime data.

For SLSTR on Sentinel 3B in 2023, the statistics show again a small mean difference of 0.03 K for daytime data and -0.04K for nighttime data with a robust standard deviation of 0.23 K for daytime data and 0.17 K for nighttime data. For 2024, the statistics are a mean difference of 0.01K for daytime data and -0.09K for nighttime data with a RSD of 0.44K for daytime data and 0.19K for nighttime data.

Overall, the SLSTR on Sentinel 3A and 3B perform very similar, with slightly better statistics in 2023 than in 2024 mainly for day time data with the SLSTR on Sentinel 3B being slightly worse than the SLSTR on Sentinel 3A. This is partly due to a lower number of match-ups in 2024 than 2025, which is also more pronounced for Sentinel 3B than 3A and partly due to the SLSTR on Sentinel 3B being slightly worse in the day time than the SLSTR on Sentinel 3A particularity the D2 data which performed slightly less well than the other products. Nonetheless, the results are excellent and show the need for ships4sst data to evaluate these small performance changes to make sure the SLSTR data is of the highest quality.

5. ACRONYMS AND ABBREVIATIONS

AATSR	Advanced Along-Track Scanning Radiometer
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DMI	Danish Meteorological Institute
EO	Earth Observation
ESA	European Space Agency
EU	European Union
FRM	Fiducial Reference Measurements
FRM4SST	Fiducial Reference Measurements for Sea Surface Temperature
GHRSST	The Group for High Resolution Sea Surface Temperature
IR	Infra-Red
ISAR	Infrared SST Autonomous Radiometer
ISFRN	International SST FRM Radiometer Network
M-AERI	Marine-Atmospheric Emitted Radiance Interferometer
RAL	Rutherford Appleton Laboratory
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
TIR	Thermal Infra-Red
UoS	University of Southampton

6. REFERENCES

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The recommended ISFRN L2R Data Specification and User Manual, T. Nightingale, https://ships4sst.org/sites/default/files/documents/Recommended%20ISFRN%20L2R%20Data%20Specification%20and%20User%20Manual%20v1.2%20rev0.pdf

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