



ships4sst

shipborne radiometers for sea surface temperature

FRM4SST project: Annual Satellite SST Validation Report



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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 2023 - 2024.

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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 2023 - 2024.

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 June 2023 and June 2024.

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 June 2023 and June 2024, 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>

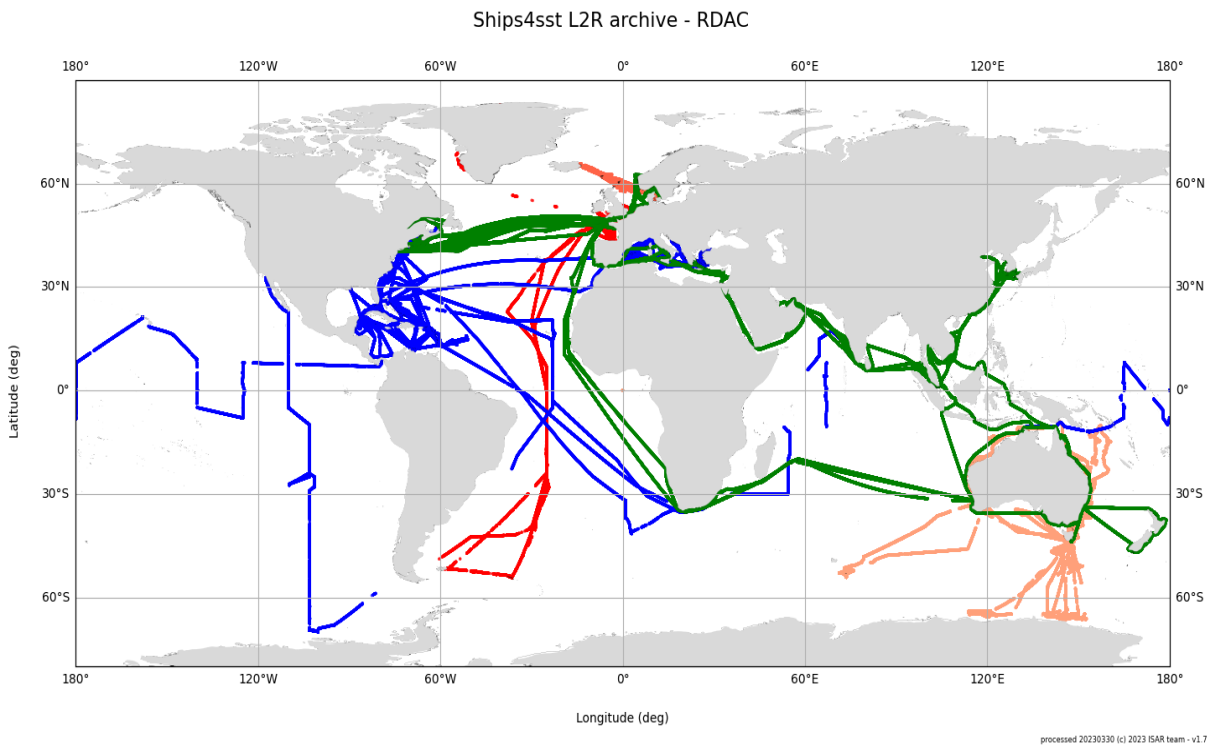


Figure 1: The ships4sst data archive L2R files plotted as by data provider, March 2024. Routes shown in red tones are collecting data with ISARs, routes shown in green are collection data with SISTeR and routes showing in blue are collection data with M-AERI instruments.

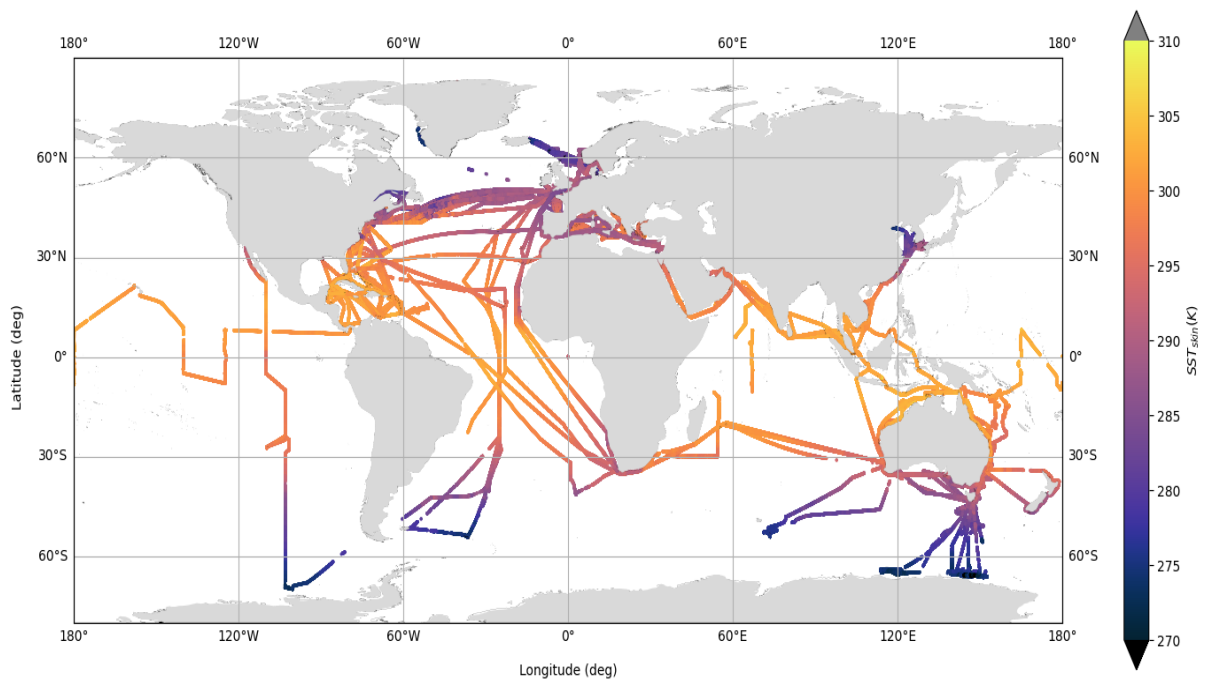


Figure 2: The ships4sst data archive L2R files plotted as SST on a world map, March 2024

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 then 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 2020 - 2022

In this section, the results from the validation of SLSTR SST data against ships4sst data between 2020 and 2022 are discussed. The main results are shown for SLSTR WST data and GHRSSST 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.

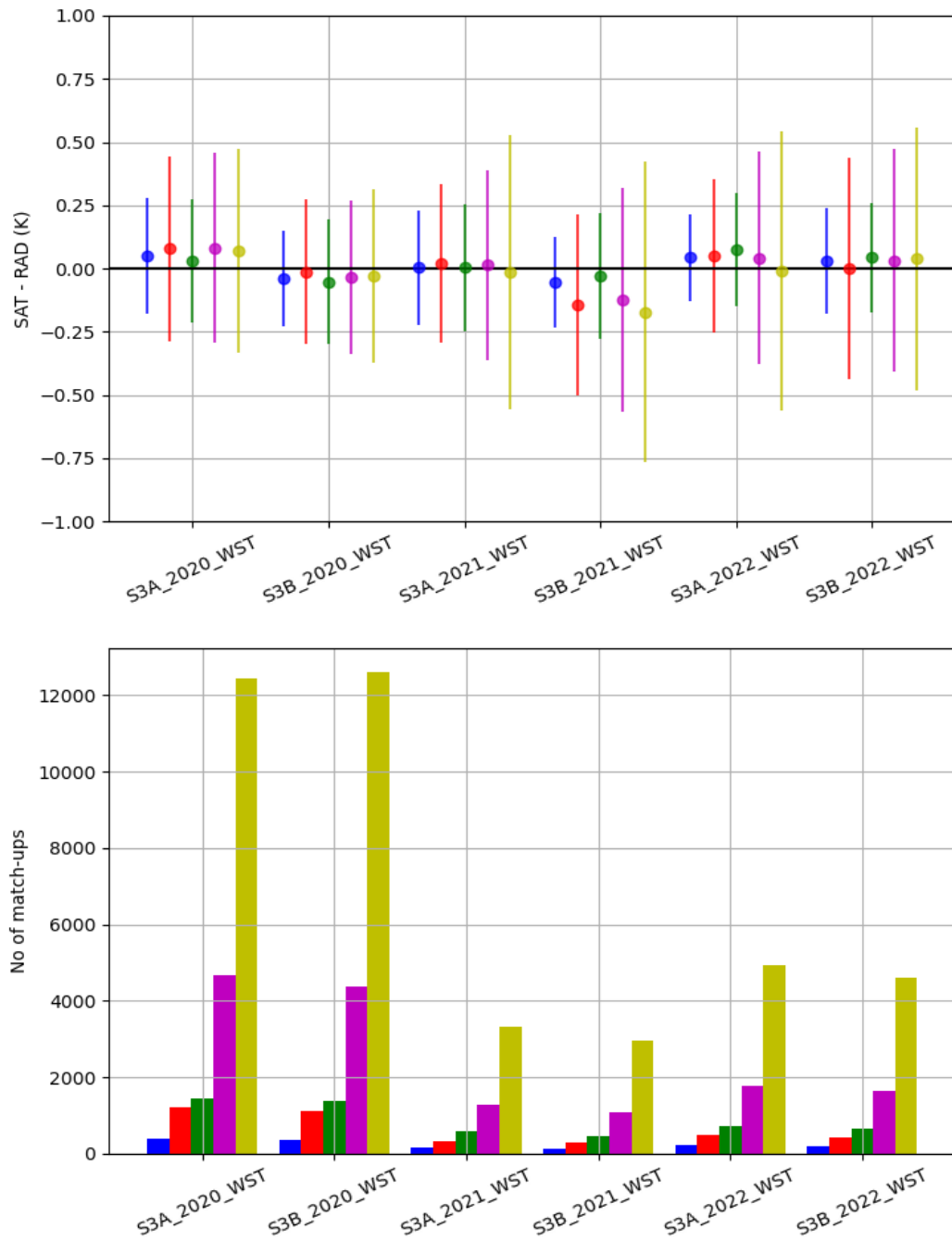
3.1 Results for 2020 to 2022

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.

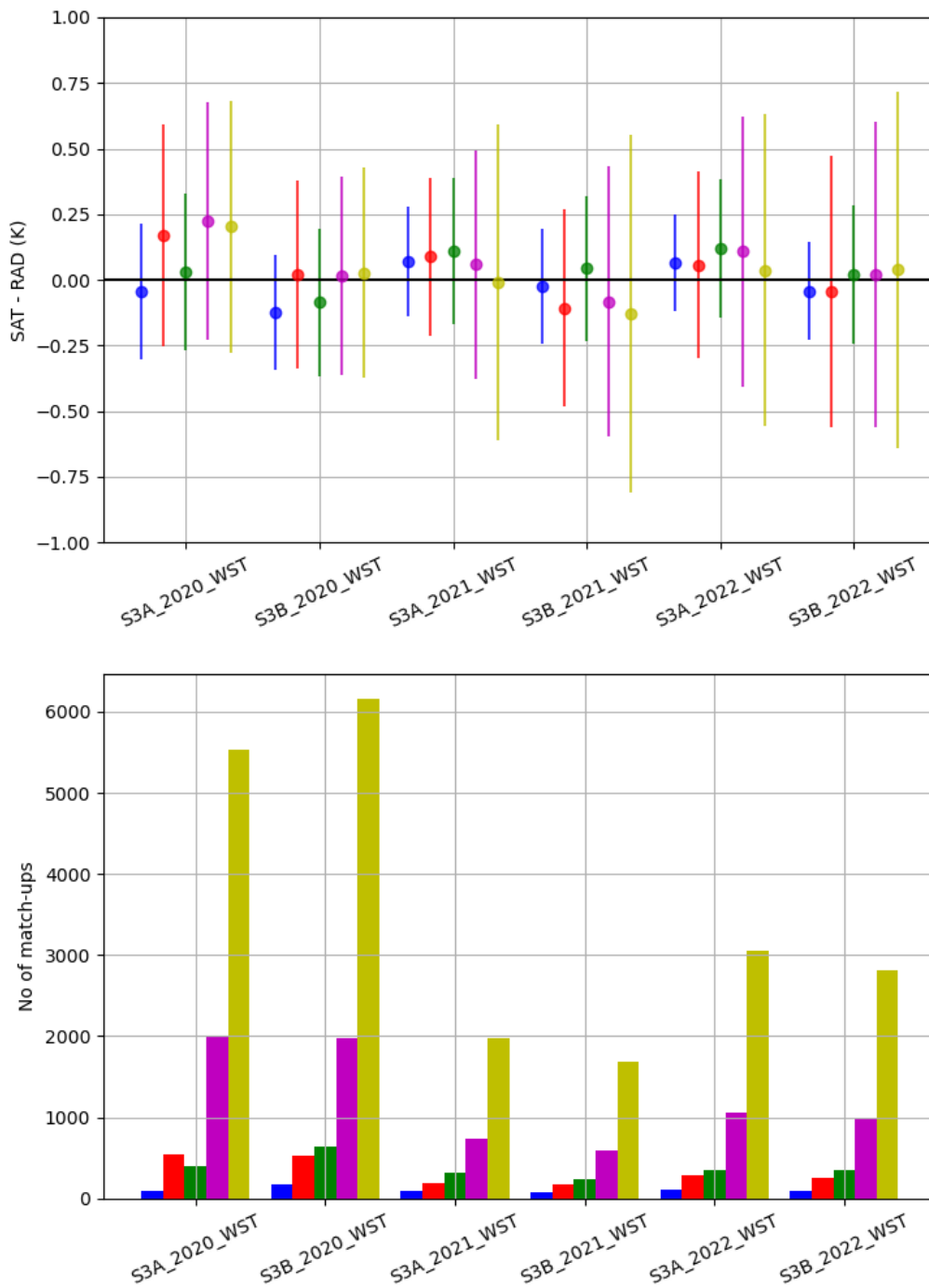
Figure 3 shows the results for day and night data combined, Figure 4 shows daytime only data and Figure 5 shows nighttime only data.

All validation results show a very small mean difference, with the exception of SLSTR on Sentinel 3B in 2021, and a robust standard deviation (RSD) that increases with the match-up grade, which is expected.



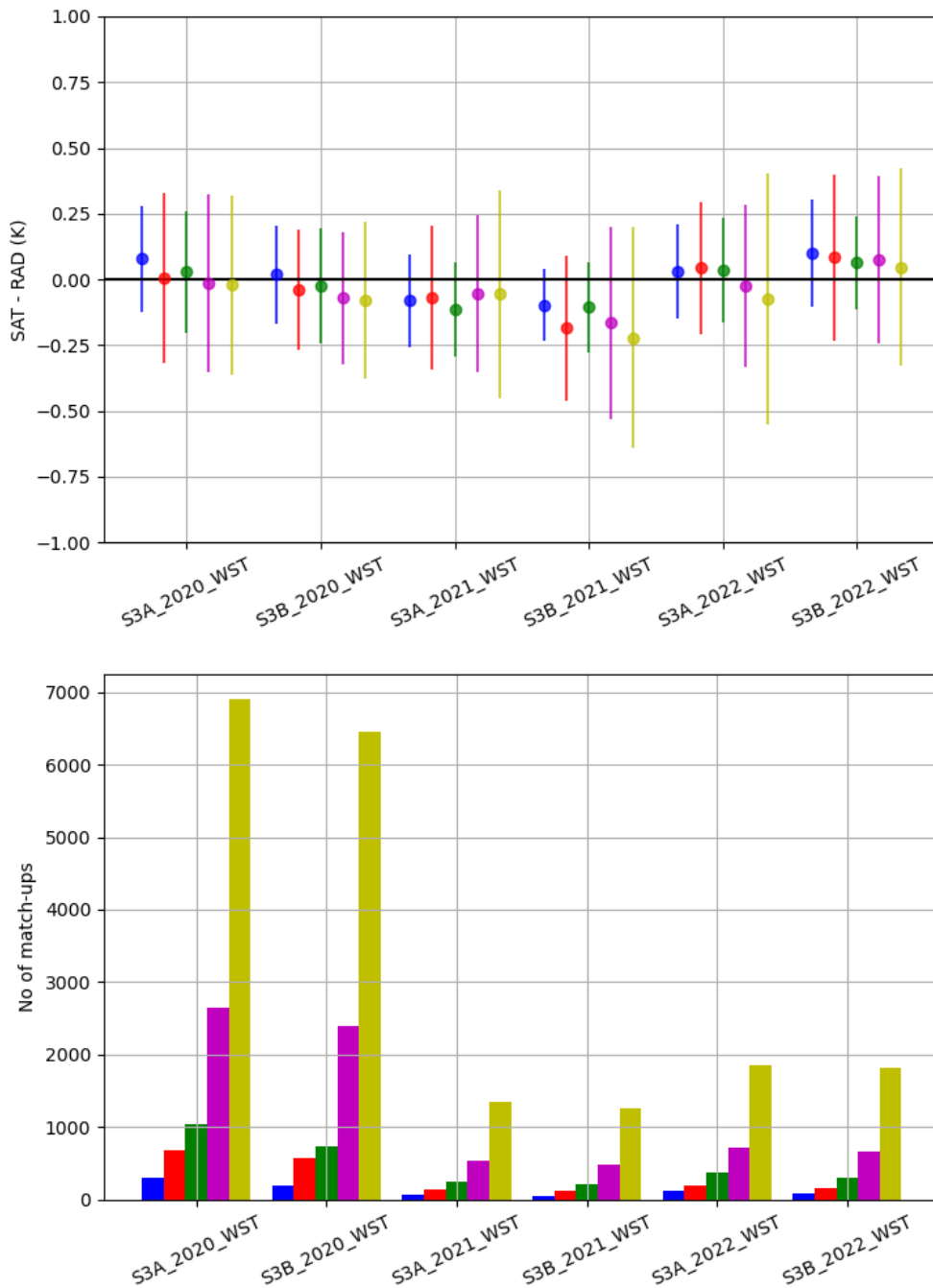
processed 20231206 00:42:07 (c) 2023 ISAR team - v2.1

Figure 3: SLSTR - ships4sst validation results for 2020 to 2022 WST data, daytime and nighttime only data, split by year and satellite sensor



processed 20231206 00:42:07 (c) 2023 ISAR team - v2.1

Figure 4: SLSTR - ships4sst validation results for 2020 to 2022 WST data, daytime only data, split by year and satellite sensor



processed 20231206 00:42:08 (c) 2023 ISAR team - v2.1

Figure 5: SLSTR - ships4sst validation results for 2020 to 2022 WST data, nighttime only data split by year and satellite sensor

3.2 Results for 2020 for SLSTR on Sentinel 3A

This is the first of the sensor specific results sections, all plots show the GHRSSST 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.

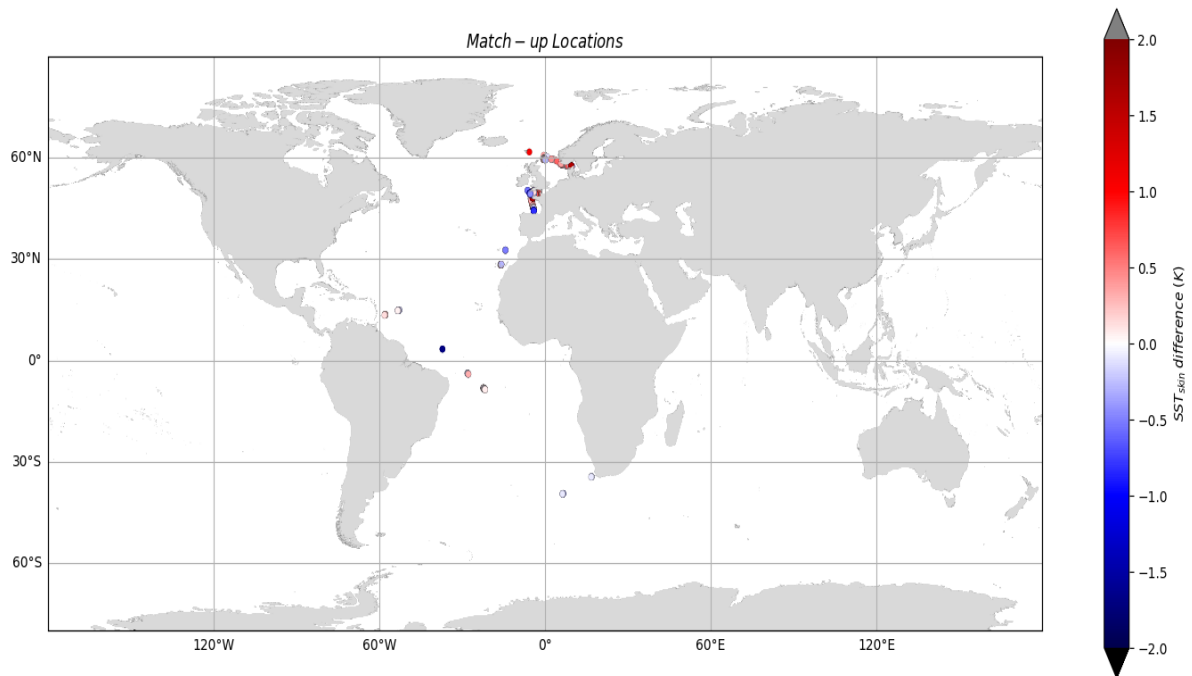


Figure 6: Location plot for the SLSTR 3A - ships4sst match-ups in 2020

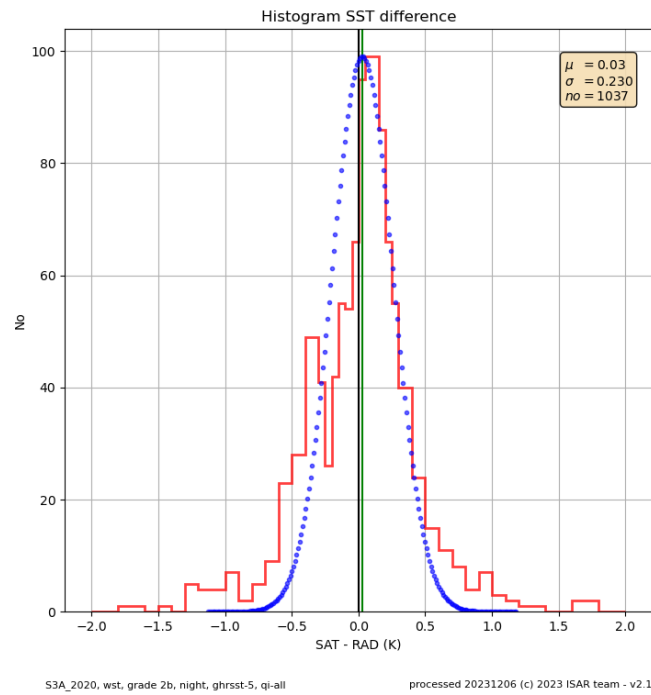


Figure 7: Histogram for SLSTR 3A - ships4sst match-ups for grade 2b match-up window in 2020.

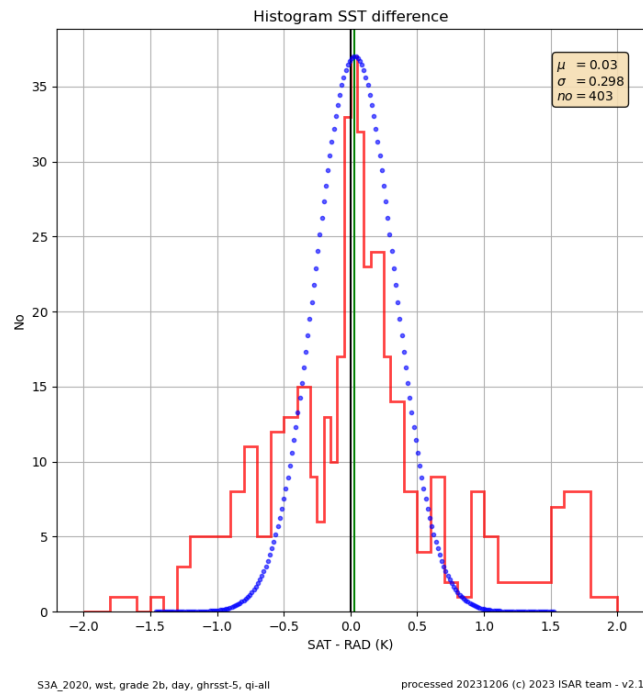


Figure 8: Histogram for SLSTR 3A - ships4sst daytime match-ups for grade 2b match-up window in 2020.

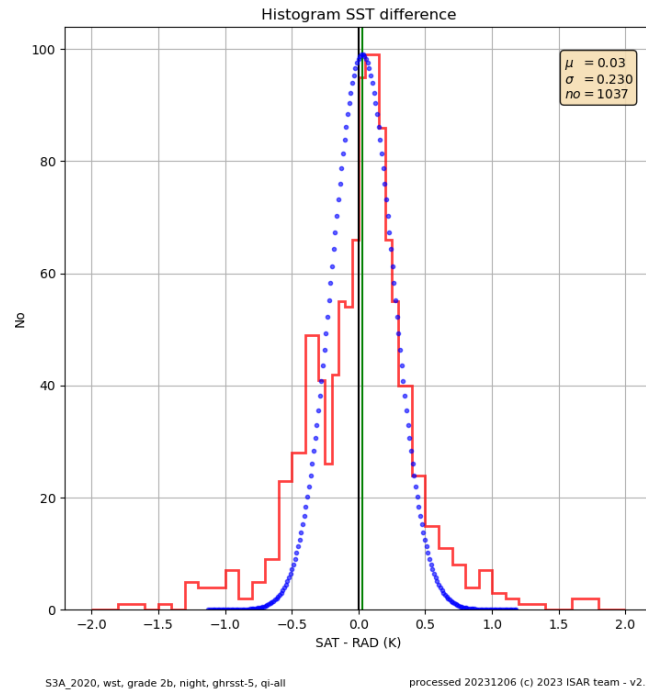


Figure 9: Histogram for SLSTR 3A - ships4sst nighttime match-ups for grade 2b match-up window in 2020.

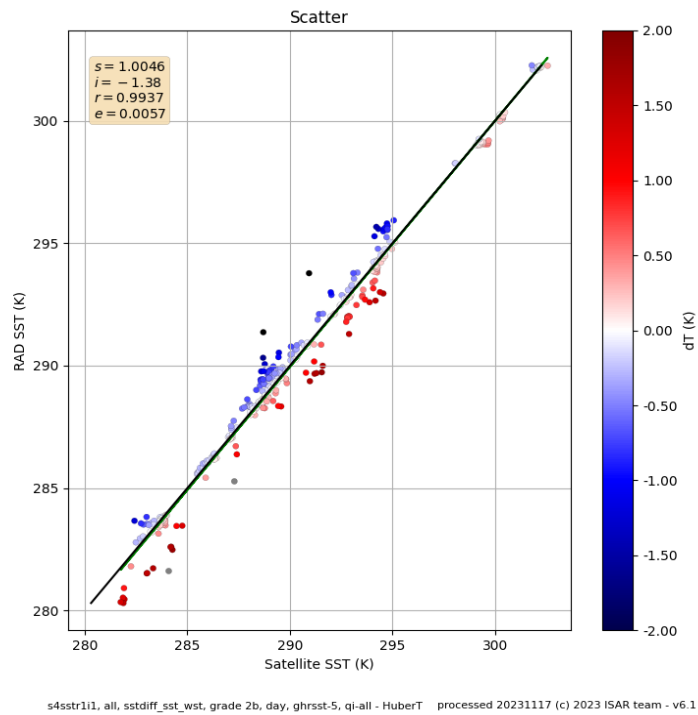


Figure 10: Scatter plot for SLSTR 3A - ships4sst match-ups for daytime grade 2b match-up window in 2020.

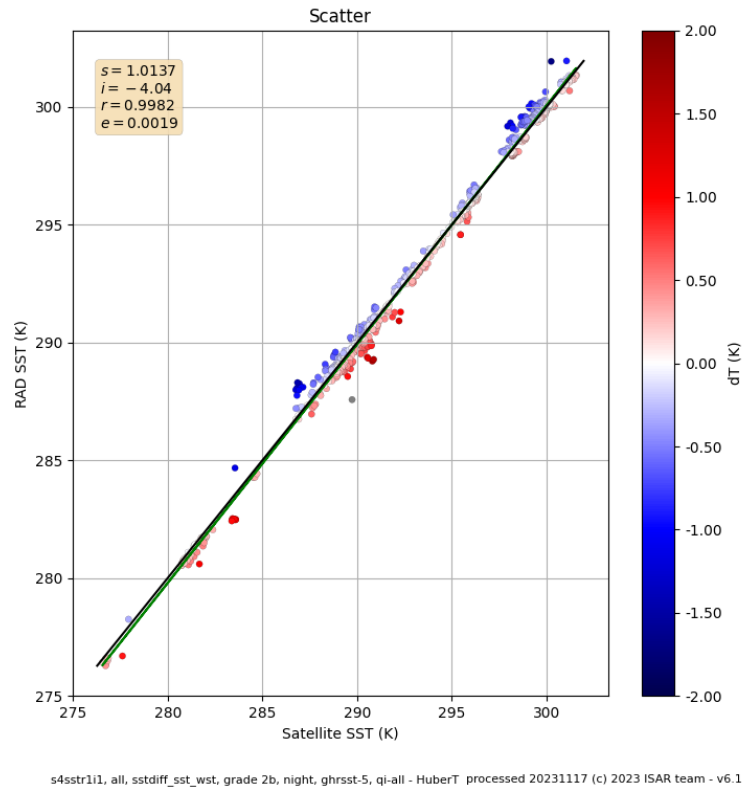


Figure 11: Scatter plot for SLSTR 3A on Sentinel 3A - ships4sst match-ups for nighttime grade 2b match-up window in 2020.

Table 2: Match-up statistics for SLSTR 3A - ships4sst in 2020

WST						
ALL						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.05	0.23	393	50	277.93	302.56
2a	0.08	0.37	1224	90	276.62	304.09
2b	0.03	0.24	1440	73	276.56	302.56
3	0.08	0.38	4661	116	276.55	304.14
4	0.07	0.40	12436	164	275.67	304.98

WST						
Day						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	-0.05	0.26	96	19	281.83	302.56
2a	0.17	0.42	538	44	279.12	304.09
2b	0.03	0.30	403	31	281.83	302.56
3	0.22	0.45	2005	57	279.12	304.14
4	0.20	0.48	5528	103	279.12	304.98

WST						
Night						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.08	0.20	297	32	277.93	301.45
2a	0.01	0.32	686	49	276.62	301.45
2b	0.03	0.23	1037	43	276.56	301.57
3	-0.01	0.34	2656	62	276.55	301.75
4	-0.02	0.34	6908	106	275.67	303.42

3.3 Results for 2020 for SLSTR on Sentinel 3B

As with section 3.2, all plots for the SLSTR 3B results show the GHRSSST 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.

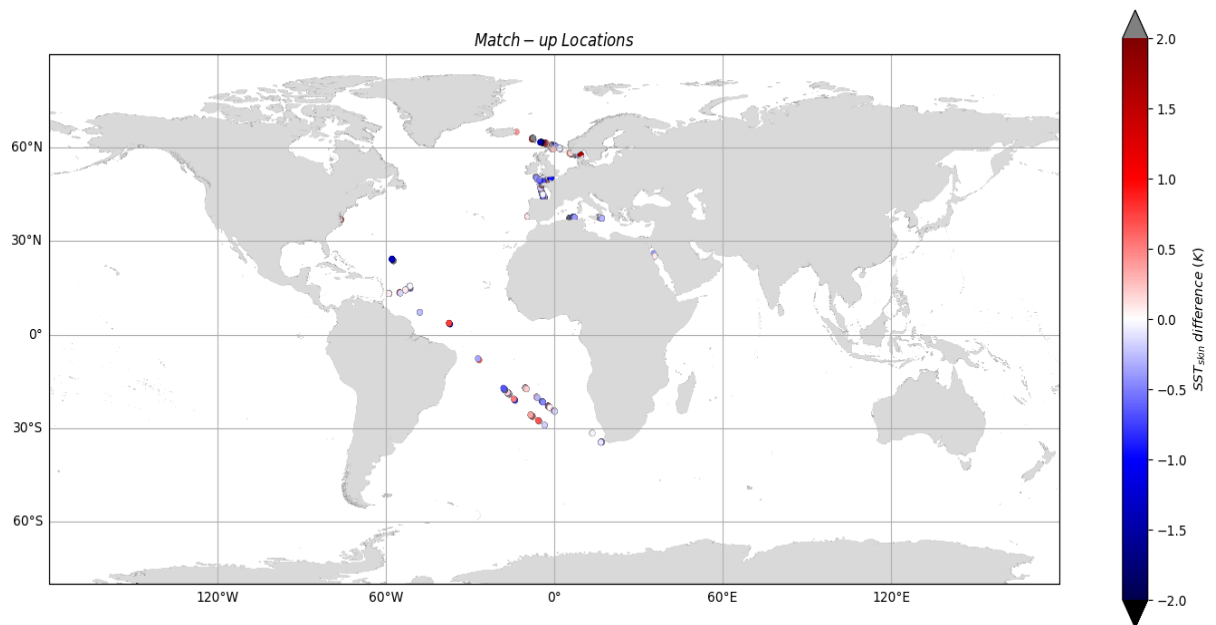


Figure 12: Location plot for the SLSTR 3B - ships4sst match-ups on 2020

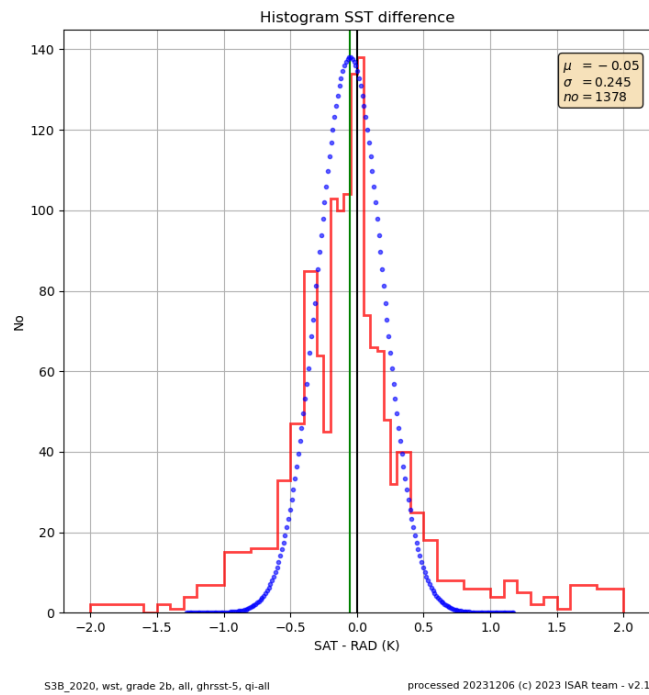


Figure 13: Histogram for SLSTR 3B - ships4sst match-ups for grade 2b match-up window in 2020.

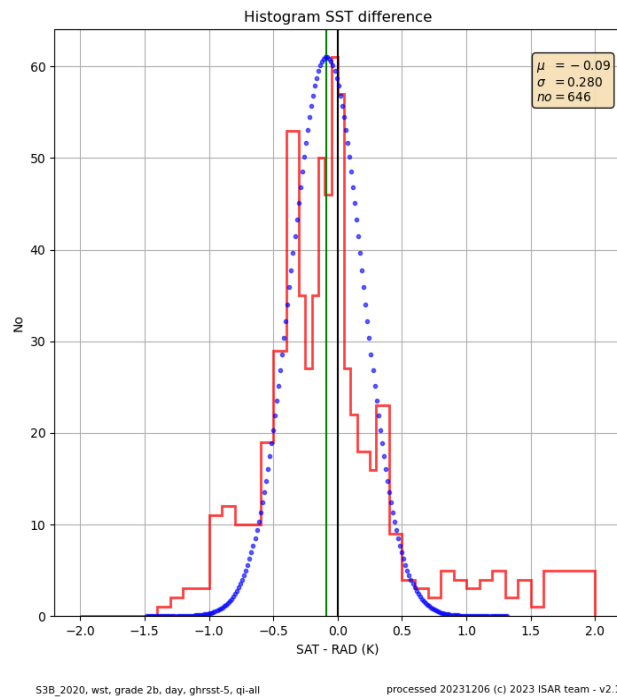


Figure 14: Histogram for SLSTR 3B - ships4sst day time match-ups for grade 2b match-up window in 2020.

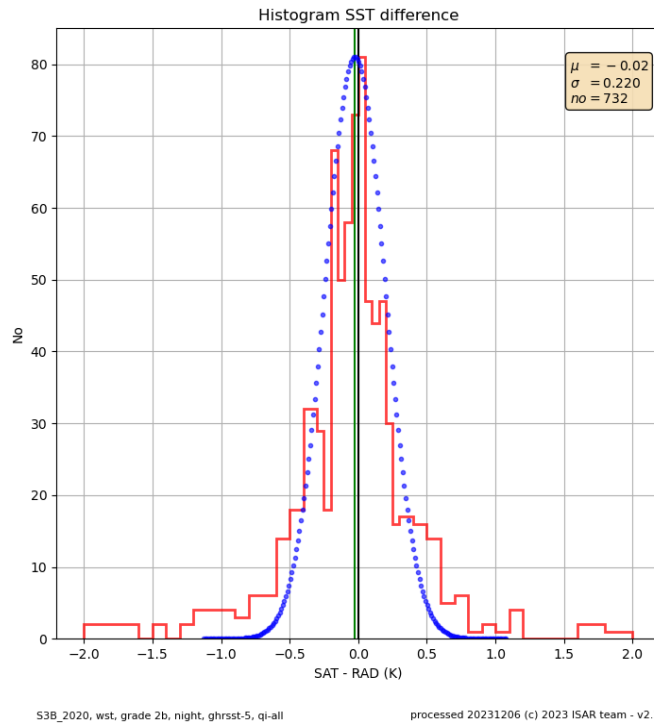


Figure 15: Histogram for SLSTR 3B - ships4sst nighttime match-ups for grade 2b match-up window in 2020

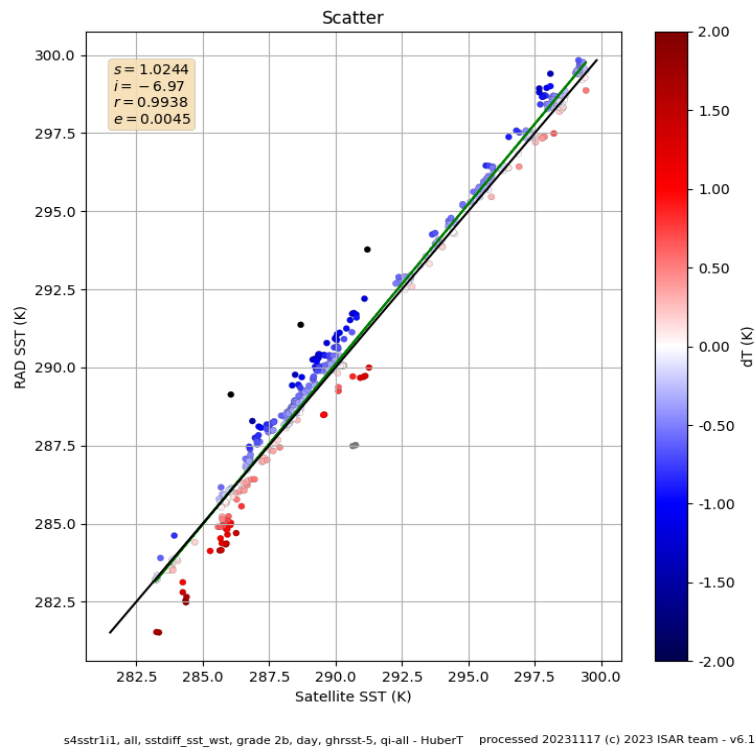


Figure 16: Scatter plot for SLSTR 3B - ships4sst match-ups for daytime grade 2b match-up window in 2020

Table 3: Match-up statistics for SLSTR 3B - ships4sst in 2020

WST						
All						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	-0.04	0.19	359	46	280.73	301.07
2a	-0.01	0.29	1110	95	278.64	303.63
2b	-0.05	0.25	1378	72	276.69	303.05
3	-0.03	0.31	4364	117	276.64	303.93
4	-0.03	0.34	12611	156	276.64	304.17

WST						
Day						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	-0.12	0.22	167	19	283.30	299.22
2a	0.02	0.36	530	42	278.64	300.63
2b	-0.09	0.28	646	31	283.30	299.48
3	0.02	0.38	1978	54	278.64	303.02
4	0.03	0.40	6163	107	278.64	304.17

WST						
Night						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.02	0.19	192	28	280.73	301.07
2a	-0.04	0.23	580	54	279.80	303.63
2b	-0.02	0.22	732	43	276.69	303.05
3	-0.07	0.25	2386	65	276.64	303.93
4	-0.08	0.30	6448	109	276.64	303.93

3.4 Results for 2021 for SLSTR on Sentinel 3A

As with the previous sections, all plots for the SLSTR 3A results show the GHRSSST 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.

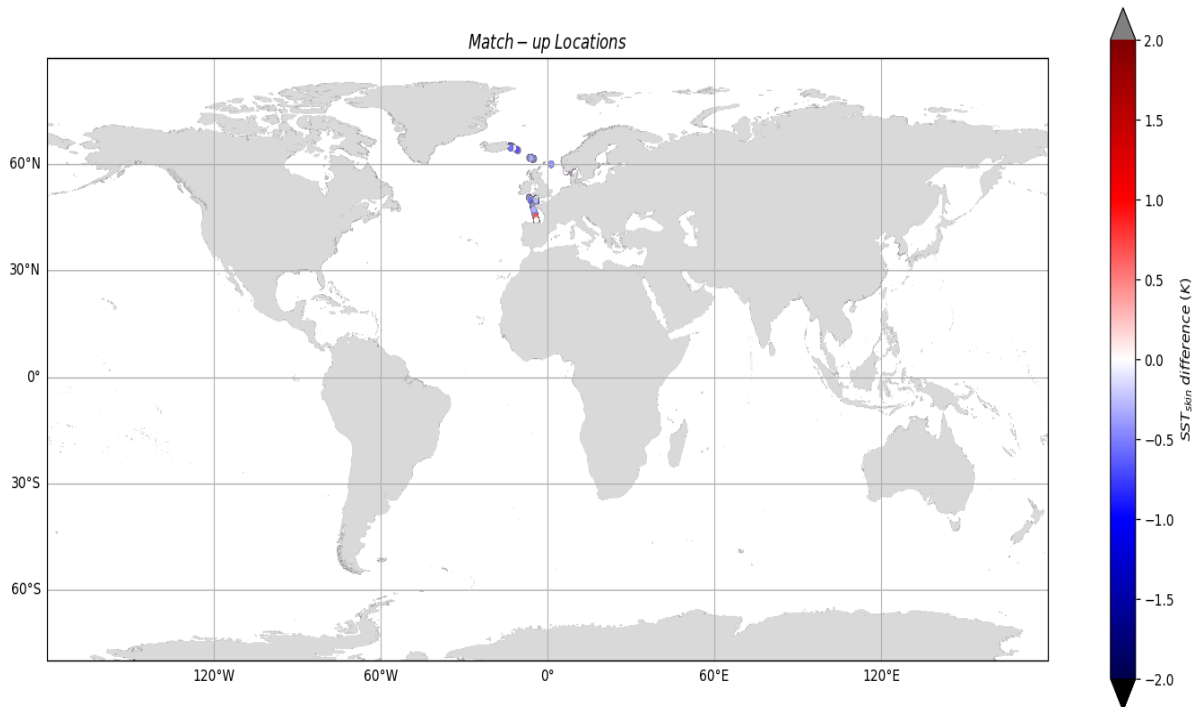


Figure 17: Location plot for the SLSTR 3A - ships4sst match-ups in 2021

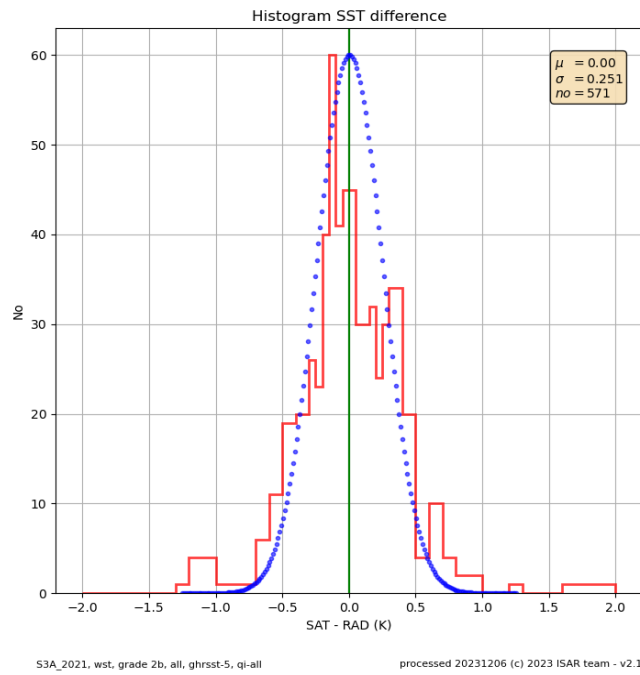


Figure 18: Histogram for SLSTR 3A - ships4sst match-ups for grade 2b match-up window in 2021.

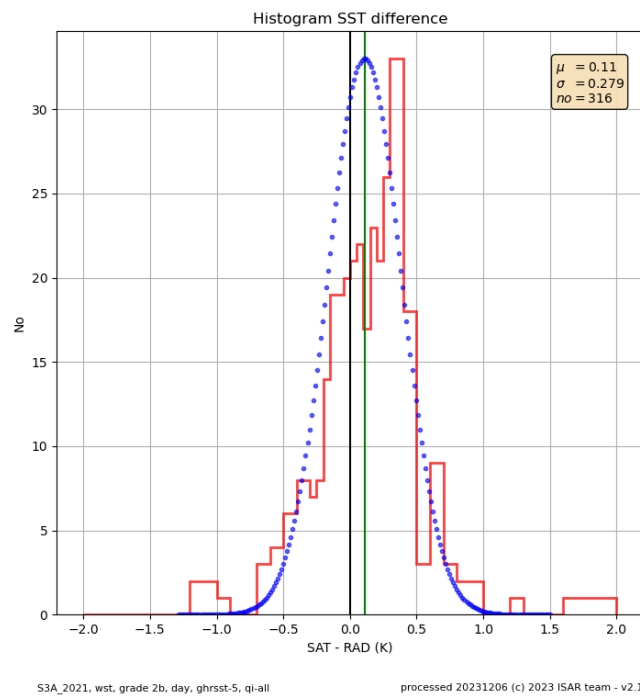


Figure 19: Histogram for SLSTR 3A - ships4sst daytime match-ups for grade 2b match-up window in 2021.

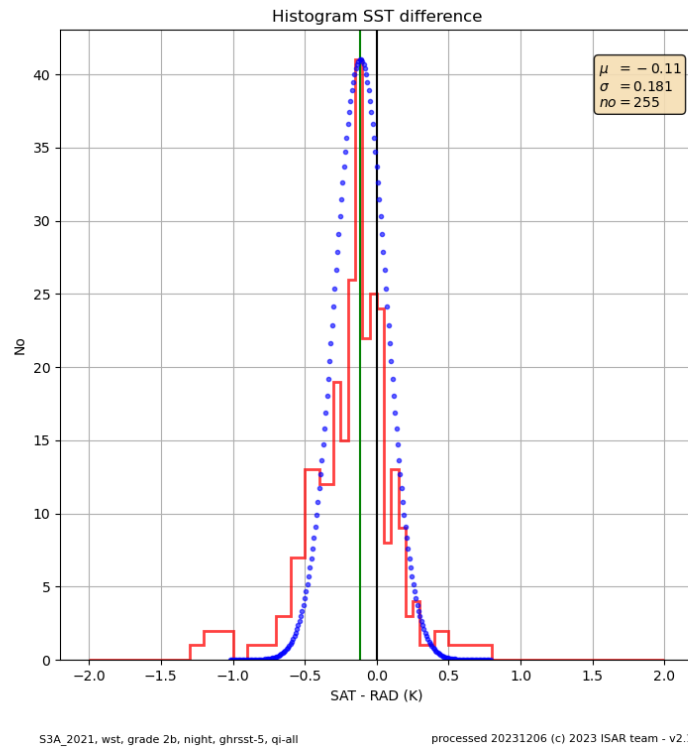


Figure 20: Histogram for SLSTR 3A - ships4sst nighttime match-ups for grade 2b match-up window in 2021.

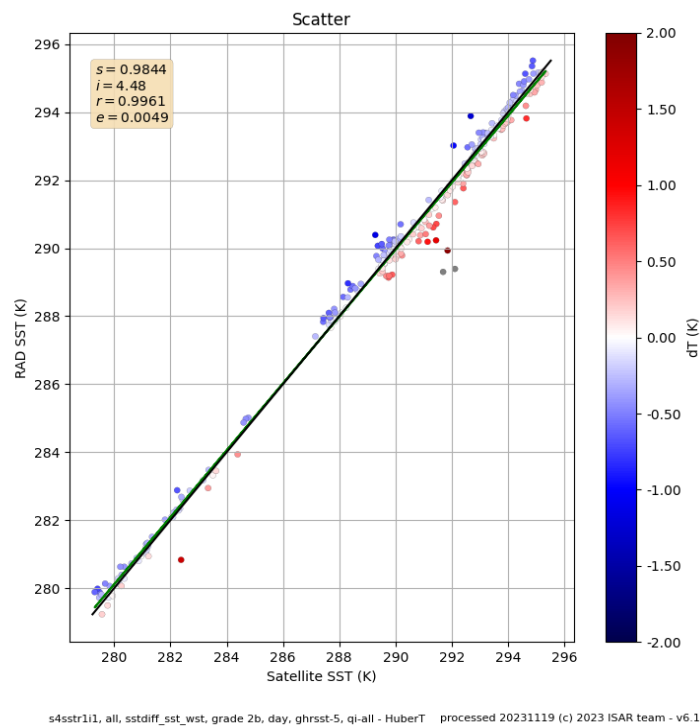


Figure 21: Scatter plot for SLSTR 3A - ships4sst match-ups for day time grade 2b match-up window in 2021.

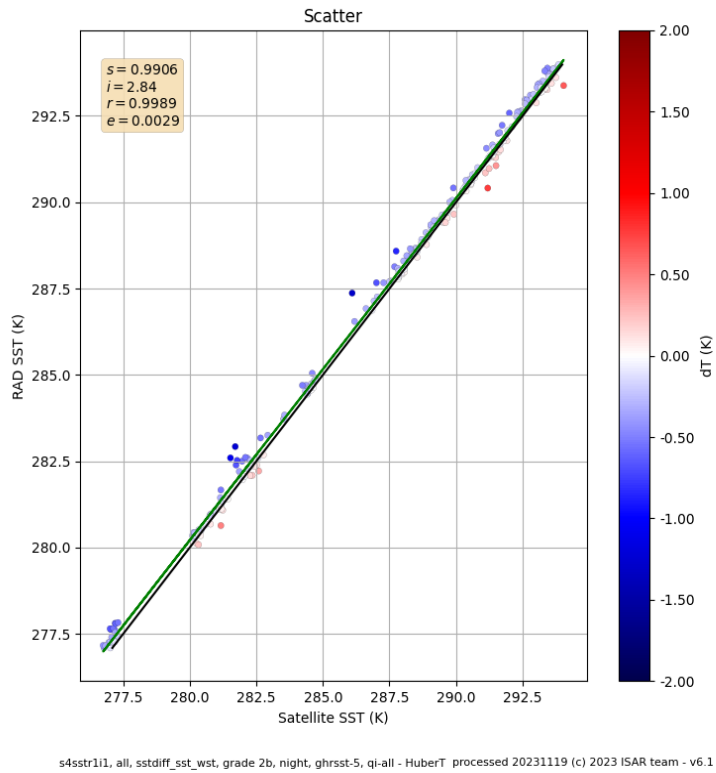


Figure 22: Scatter plot for SLSTR 3A - ships4sst match-ups for nighttime grade 2b match-up window in 2021.

Table 4: Match-up statistics for SLSTR 3A - ships4sst in 2021

WST						
All						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.00	0.23	157	25	276.77	295.35
2a	0.02	0.31	329	42	276.66	295.43
2b	0.00	0.25	571	40	276.77	295.35
3	0.01	0.38	1260	56	275.85	295.43
4	-0.01	0.54	3326	79	273.71	295.50

WST						
Day						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.07	0.21	87	13	279.33	295.35
2a	0.09	0.30	189	24	279.25	295.43
2b	0.11	0.28	316	24	279.33	295.35
3	0.06	0.43	729	33	275.85	295.43
4	-0.01	0.60	1979	56	273.71	295.50

WST						
Night						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	-0.08	0.18	70	13	276.77	293.77
2a	-0.07	0.28	140	20	276.66	293.81
2b	-0.11	0.18	255	18	276.77	294.06
3	-0.05	0.30	531	26	276.32	294.06
4	-0.06	0.39	1347	46	276.22	294.60

3.5 Results for 2021 for SLSTR on Sentinel 3B

As with the previous sections, all plots for the 2021 SLSTR 3B results show the GHRSSST 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.

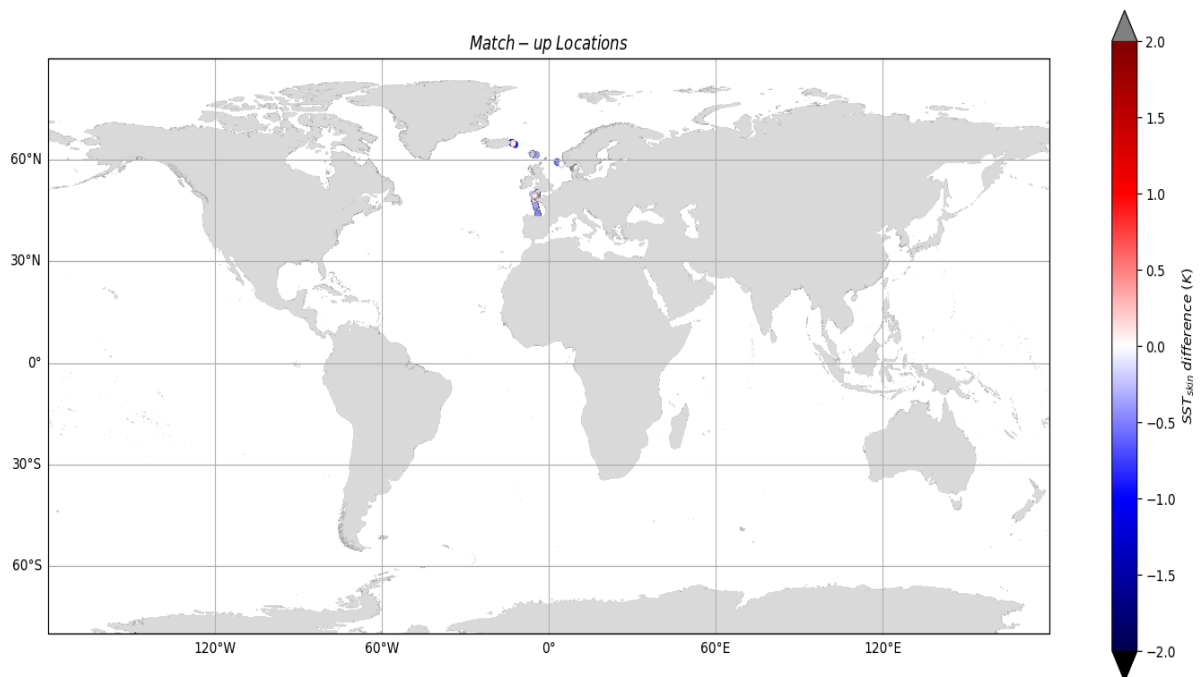


Figure 23: Location plot for the SLSTR 3B - ships4sst match-ups on 2021

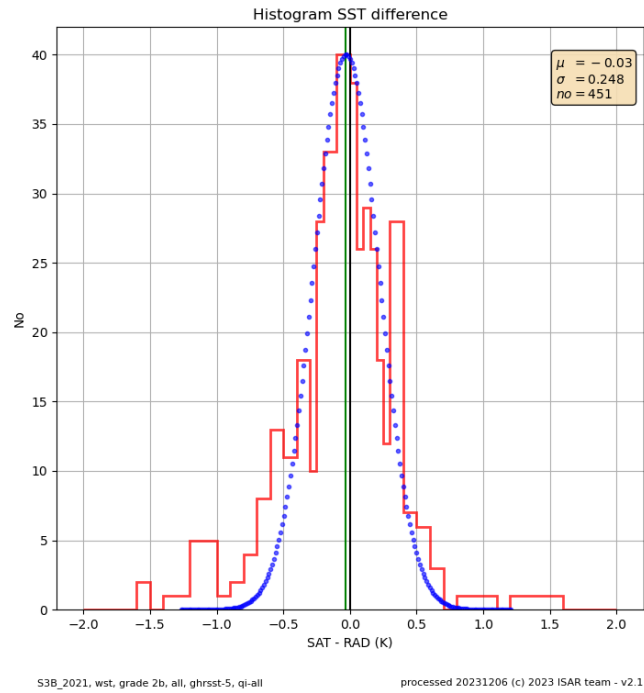


Figure 24: Histogram for SLSTR 3B - ships4sst match-ups for grade 2b match-up window in 2021.

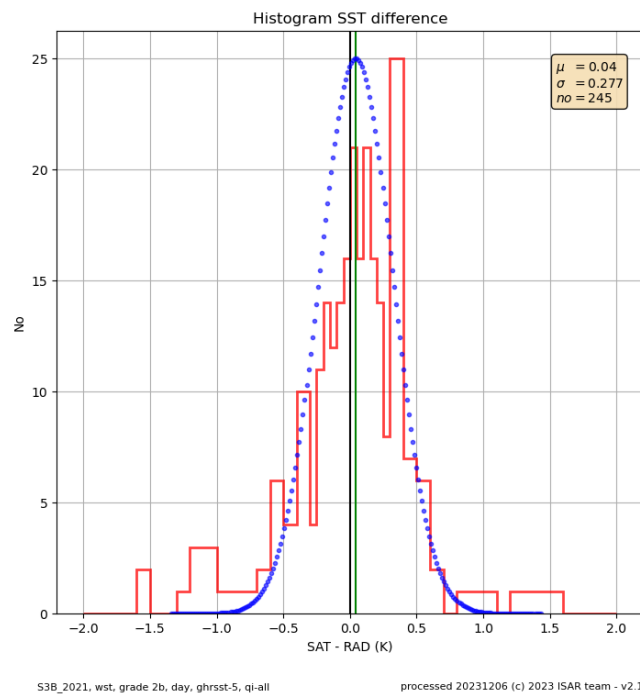


Figure 25: Histogram for SLSTR 3B - ships4sst daytime match-ups for grade 2b match-up window in 2021.

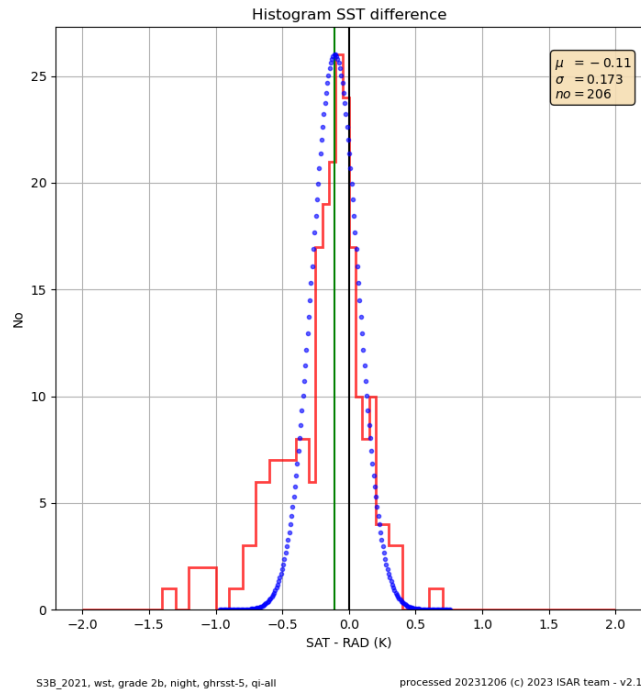


Figure 26: Histogram for SLSTR 3B - ships4sst nighttime match-ups for grade 2b match-up window in 2021.

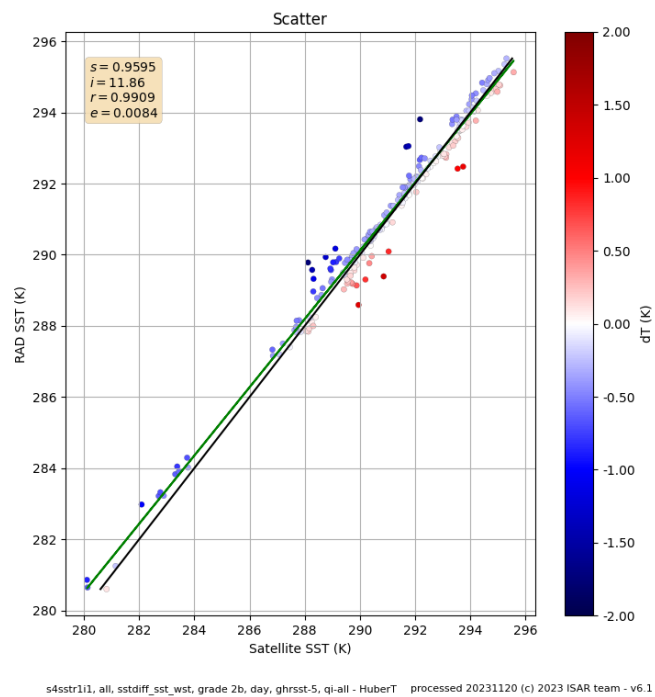
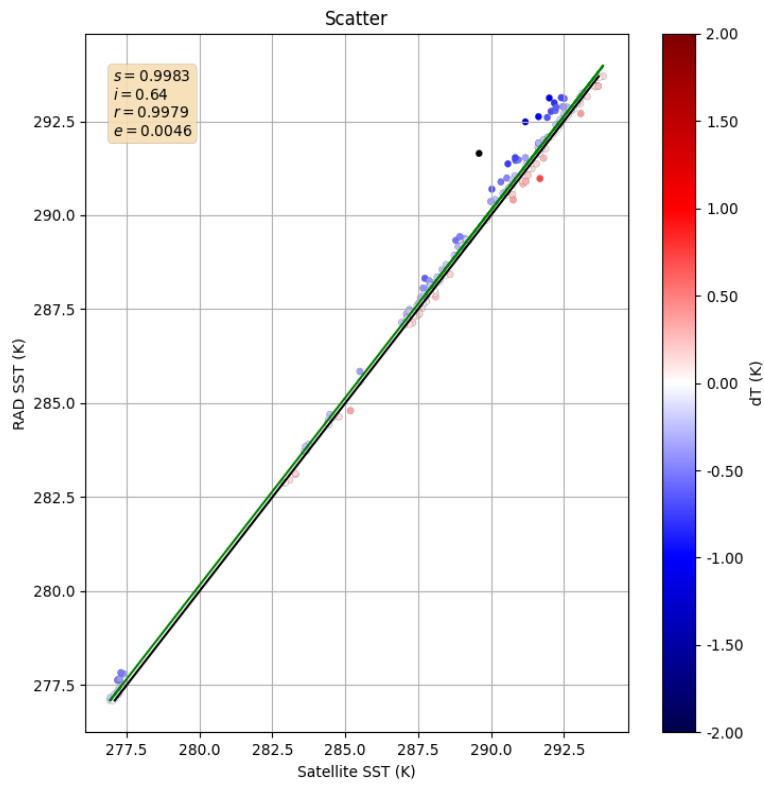


Figure 27: Scatter plot for SLSTR 3B - ships4sst match-ups for daytime grade 2b match-up window in 2021.



s4sstr1i1, all, sstdiff_sst_wst, grade 2b, night, ghrsst-5, qi-all - HuberT processed 20231120 (c) 2023 ISAR team - v6.1

Figure 28: Scatter plot for SLSTR 3B - ships4sst match-ups for nighttime grade 2b match-up window in 2021.

Table 5: Match-up statistics for SLSTR 3B - ships4sst in 2021

WST						
All						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	-0.06	0.18	135	24	277.10	295.69
2a	-0.14	0.36	284	45	277.10	296.05
2b	-0.03	0.25	451	40	276.92	295.69
3	-0.12	0.44	1076	59	276.92	296.41
4	-0.17	0.59	2951	77	274.33	296.41

WST						
Day						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	-0.02	0.22	82	11	281.27	295.69
2a	-0.11	0.38	168	25	277.12	296.05
2b	0.04	0.28	245	21	280.23	295.69
3	-0.08	0.51	592	36	277.02	296.41
4	-0.13	0.68	1685	52	275.90	296.41

WST						
Night						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	-0.10	0.14	53	13	277.10	293.07
2a	-0.19	0.28	116	21	277.10	293.28
2b	-0.11	0.17	206	20	276.92	293.84
3	-0.17	0.37	484	26	276.92	294.14
4	-0.22	0.42	1266	48	274.33	294.68

3.6 Results for 2022 for SLSTR on Sentinel 3A

As with the previous sections, all plots for the 2022 SLSTR 3A results show the GHRSSST 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 day and night time only data. Next are the scatter plots for day and night time 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.

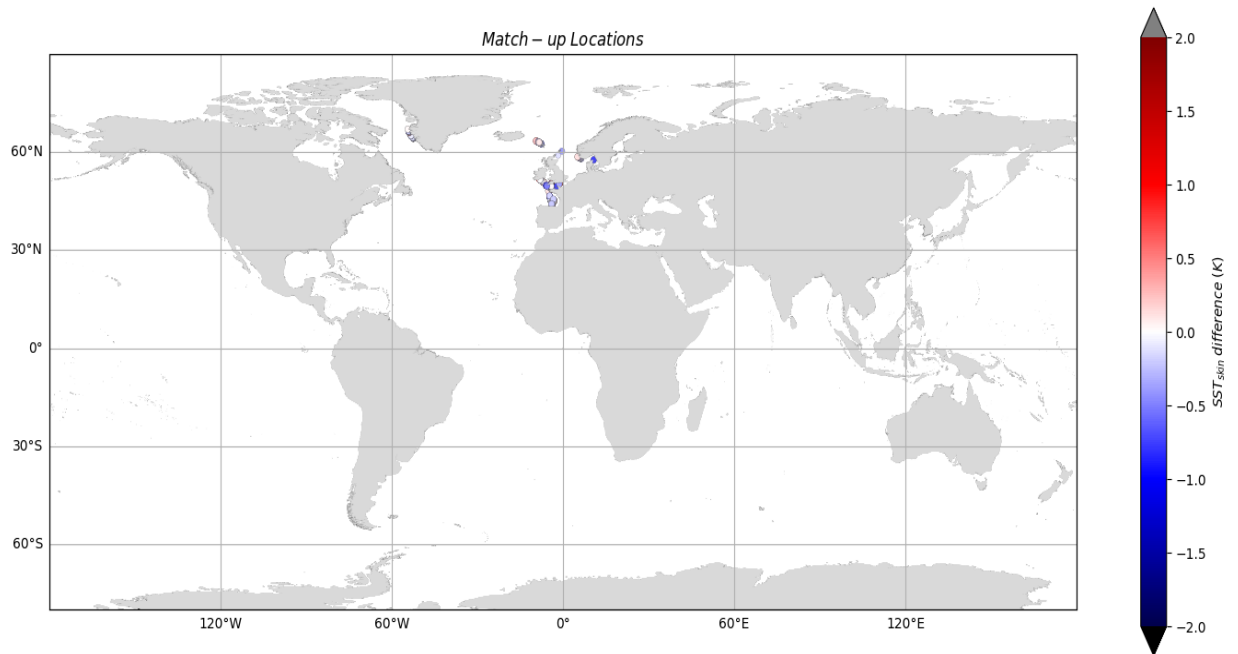


Figure 29: Location plot for the SLSTR 3A - ships4sst match-ups in 2022

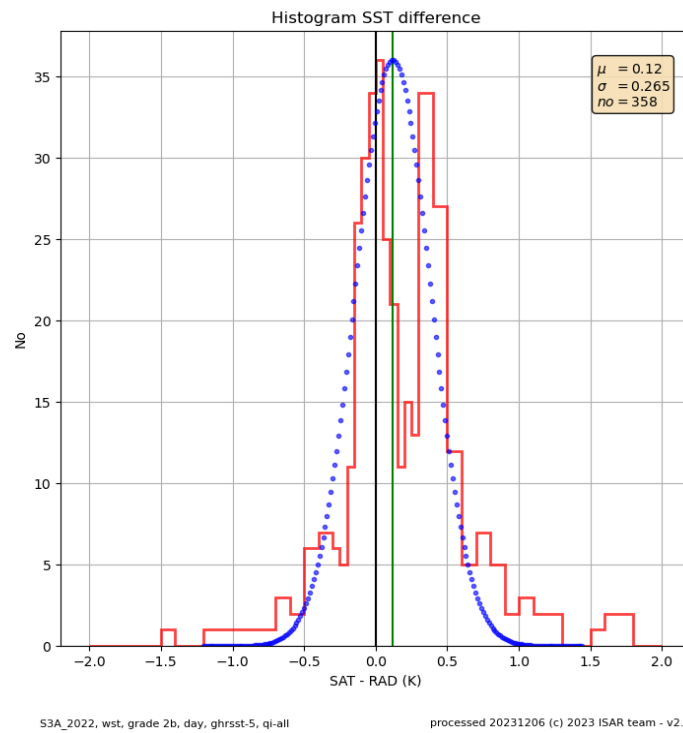


Figure 30: Histogram for SLSTR 3A - ships4sst match-ups for grade 2b match-up window in 2022.

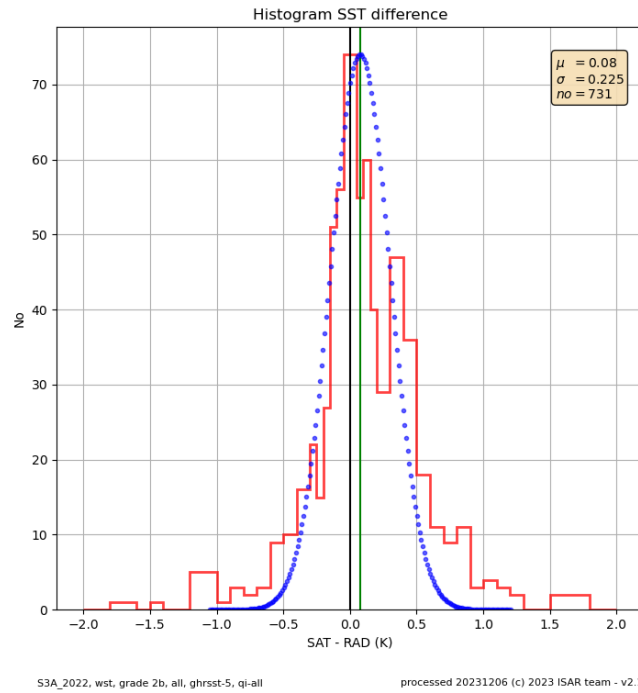


Figure 31: Histogram for SLSTR 3A - ships4sst daytime match-ups for grade 2b match-up window in 2022.

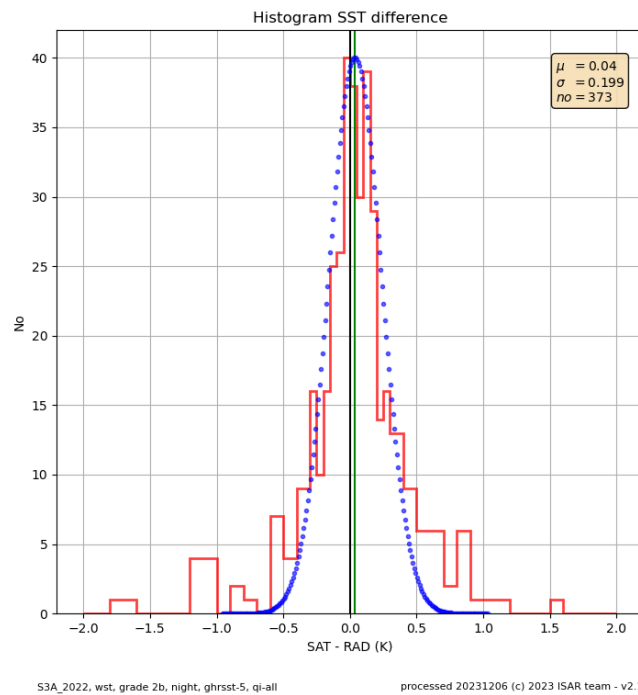


Figure 32: Histogram for SLSTR 3A - ships4sst nighttime match-ups for grade 2b match-up window in 2022.

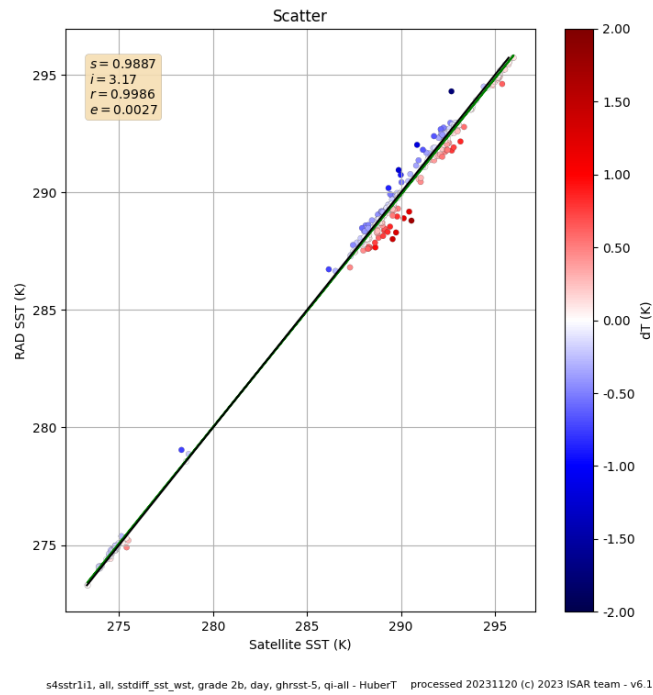


Figure 33: Scatter plot for SLSTR 3A - ships4sst match-ups for daytime grade 2b match-up window in 2022.

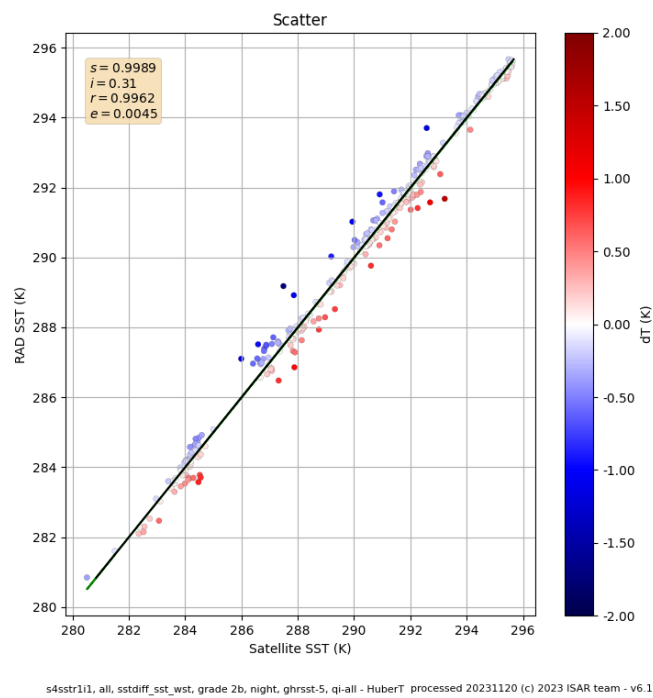


Figure 34: Scatter plot for SLSTR 3A - ships4sst match-ups for nighttime grade 2b match-up window in 2022.

Table 6: Match-up statistics for SLSTR 3A - ships4sst in 2022

WST						
All						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.04	0.17	223	37	273.96	296.09
2a	0.05	0.30	488	69	273.95	296.09
2b	0.08	0.23	731	54	273.33	296.15
3	0.04	0.42	1765	91	273.21	299.04
4	-0.01	0.55	4916	135	273.21	299.04

WST						
Day						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.06	0.18	108	19	273.96	296.09
2a	0.06	0.36	286	43	273.95	296.09
2b	0.12	0.26	358	33	273.33	296.15
3	0.11	0.51	1051	61	273.21	299.04
4	0.04	0.59	3056	93	273.21	299.04

WST						
Night						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.03	0.18	115	19	281.52	295.67
2a	0.04	0.25	202	28	276.22	295.67
2b	0.04	0.20	373	24	280.55	295.67
3	-0.03	0.31	714	34	275.29	295.67
4	-0.07	0.48	1860	70	275.06	297.82

3.7 Results for 2022 for SLSTR on Sentinel 3B

As with the previous sections, all plots for the 2022 SLSTR 3B results show the GHRSSST 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.

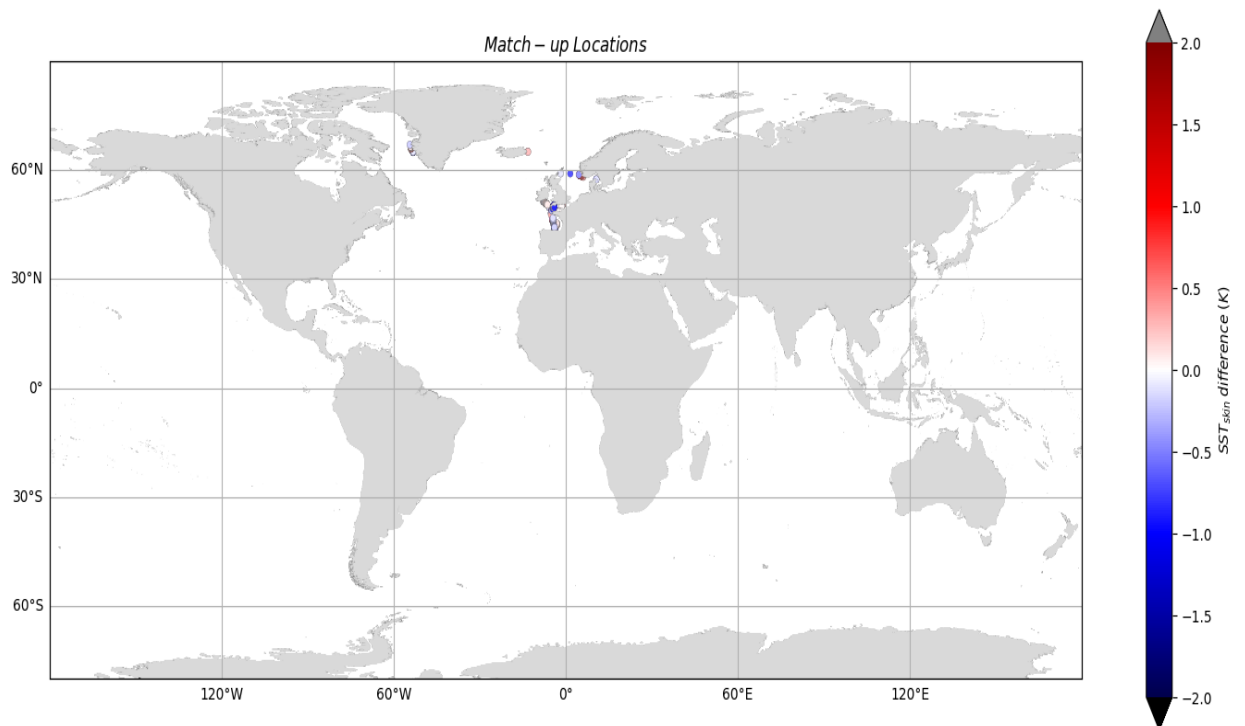


Figure 35: Location plot for the SLSTR 3B - ships4sst match-ups in 2022

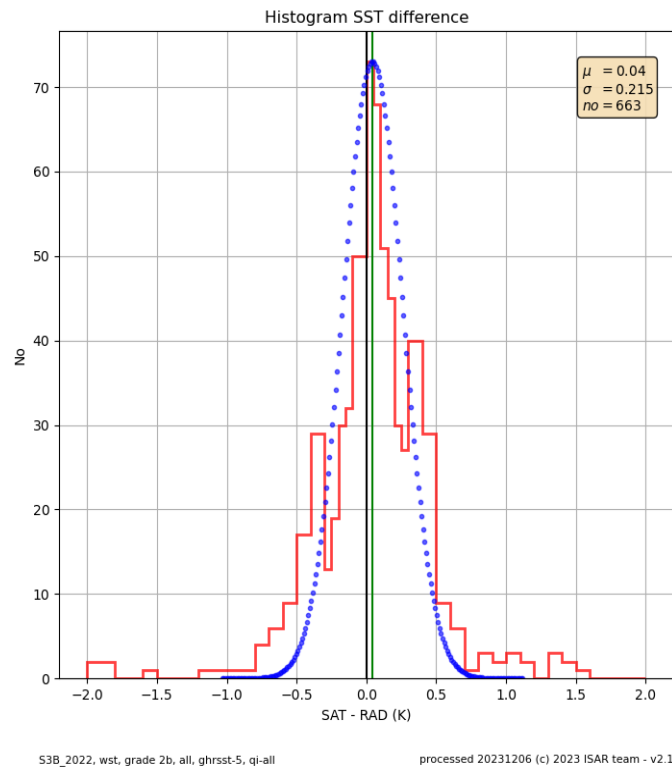


Figure 36: Histogram for SLSTR 3B - ships4sst match-ups for grade 2b match-up window in 2022.

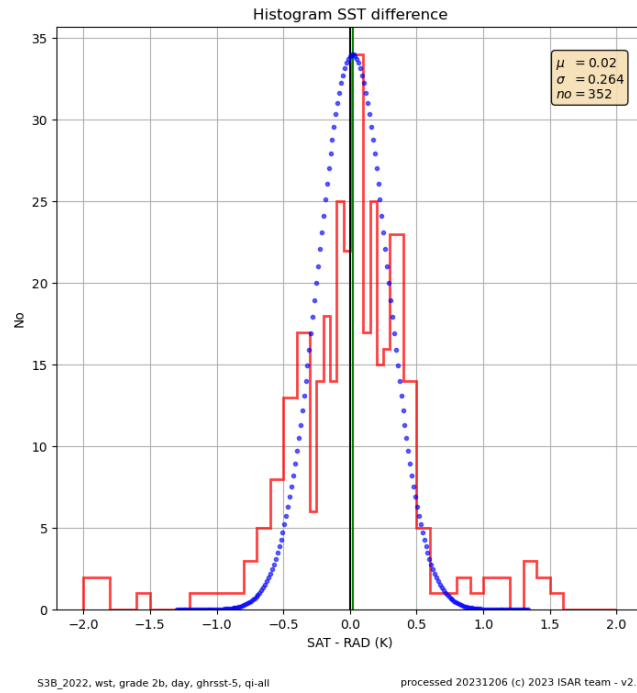


Figure 37: Histogram for SLSTR 3B - ships4sst daytime match-ups for grade 2b match-up window in 2022.

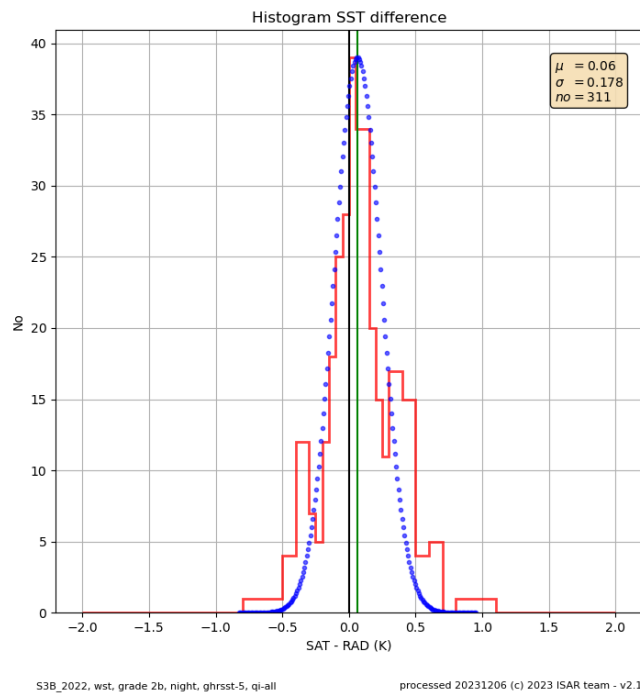


Figure 38: Histogram for SLSTR 3B - ships4sst nighttime match-ups for grade 2b match-up window in 2022.

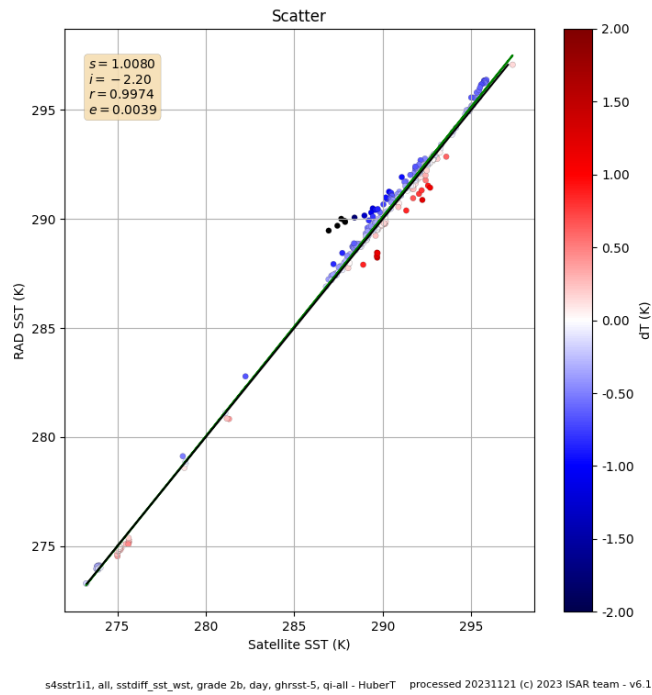


Figure 39: Scatter plot for SLSTR 3B - ships4sst match-ups for daytime grade 2b match-up window in 2022.

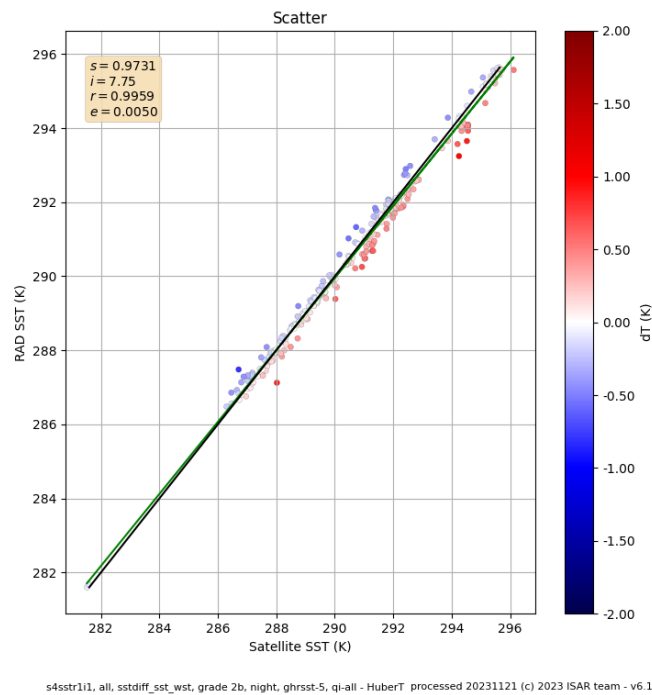


Figure 40: Scatter plot for SLSTR 3B - ships4sst match-ups for nighttime grade 2b match-up window in 2022.

Table 7: Match-up statistics for SLSTR 3B - ships4sst in 2022

WST						
All						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.03	0.21	182	29	273.35	295.94
2a	0.00	0.44	411	64	273.15	295.94
2b	0.04	0.21	663	46	273.35	297.45
3	0.03	0.44	1625	87	273.15	298.00
4	0.04	0.52	4618	132	273.15	298.00

WST						
Day						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	-0.04	0.19	96	16	273.35	295.94
2a	-0.05	0.52	255	41	273.35	295.94
2b	0.02	0.26	352	29	273.35	297.45
3	0.02	0.58	970	51	273.35	298.00
4	0.04	0.68	2805	81	273.35	298.00

WST						
Night						
Grade	MDiff	RSD	No	Overpass	Min Temp	Max Temp
1	0.10	0.20	86	13	281.51	295.72
2a	0.08	0.32	156	24	273.15	295.72
2b	0.06	0.18	311	18	281.51	296.14
3	0.08	0.32	655	36	273.15	296.14
4	0.05	0.37	1813	83	273.15	296.32

4. CONCLUSION

The validation of SLSTR WST 2020, 2021 and 2022 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 2020 show a very small mean difference of 0.03 K for daytime and nighttime data and a robust standard deviation (RSD) of 0.3 K for daytime data and 0.23 K for nighttime data. For 2021 the statistics are a mean difference of 0.11K for daytime data and -0.11K for nighttime data with a RSD of 0.28K for daytime data and 0.18K for nighttime data. Finally, in 2022, the statistics are a mean difference of 0.12K for daytime data and 0.04K for nighttime data with a RSD of 0.26 K for daytime data and 0.20K for nighttime data.

For SLSTR on Sentinel 3B in 2020, the statistics show again a small mean difference of -0.09 K for daytime data and -0.02K for nighttime data and a robust standard deviation of 0.28 K for daytime data and 0.22 K for nighttime data. For 2021, the statistics are a mean difference of 0.04K for daytime data and -0.11K for nighttime data with a RSD of 0.28K for daytime data and 0.17K for nighttime data. Finally, in 2022 the statistics are a mean difference of 0.02K for daytime data and 0.06K for nighttime data with a RSD of 0.26 K for daytime data and 0.18K for nighttime data.

Overall, the SLSTR on Sentinel 3A and 3B perform very similar, with slightly better statistics in 2020 and 2022 than in 2021. This is partly due to the reduced ships4sst data in the database due to COVID and the reduction in available shipping routes and ship time, and partly because of the D2 data which performed slightly less well than the ships4sst data available. 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
GHRSSST	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>

Werenfrid Wimmer, Ian S. Robinson, Craig J. Donlon, Long-term validation of AATSR SST data products using shipborne radiometry in the Bay of Biscay and English Channel, *Remote Sensing of Environment*, Volume 116, 2012, Pages 17-31, ISSN 0034-4257, <https://doi.org/10.1016/j.rse.2011.03.022>.