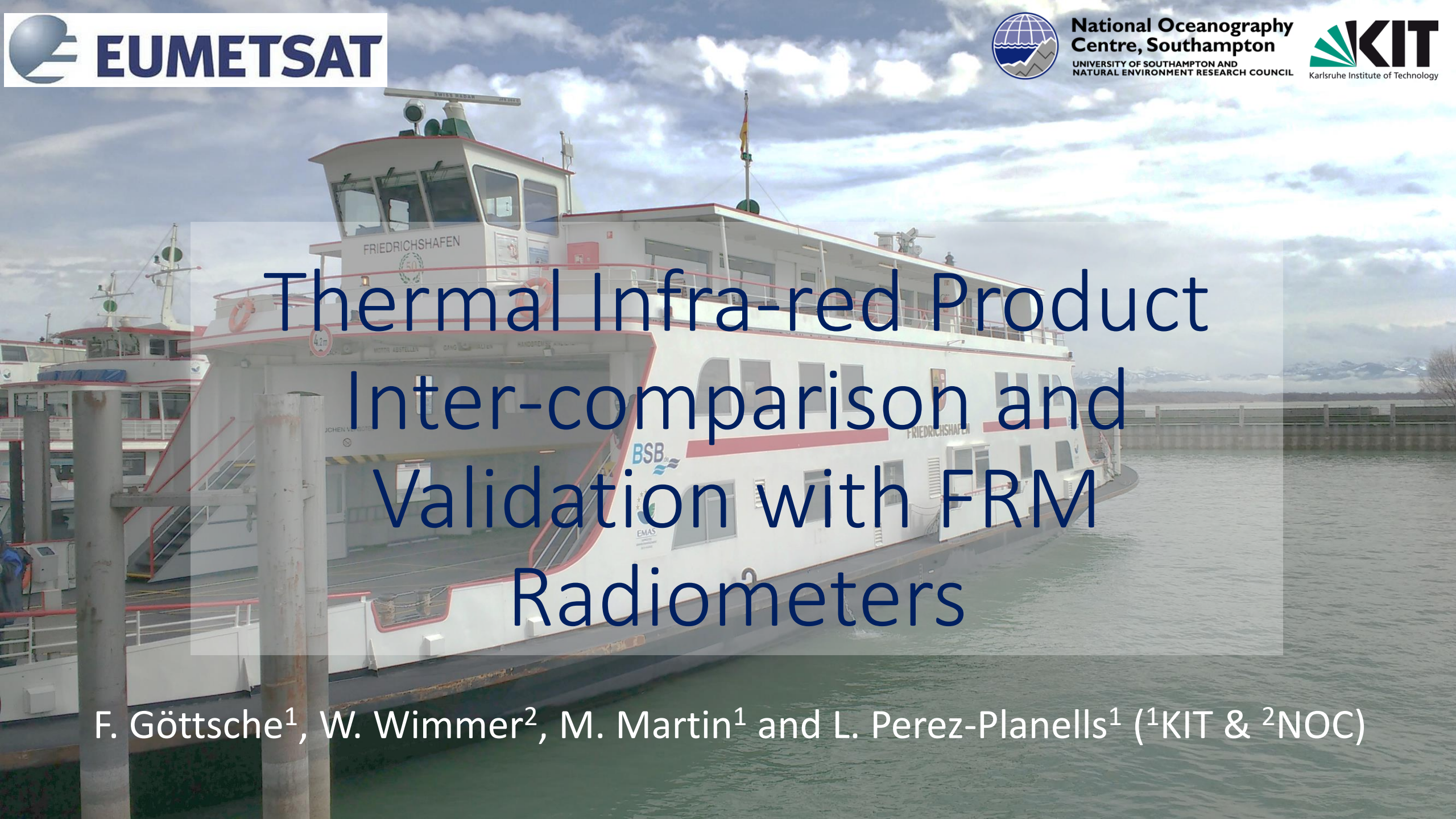


Thermal Infra-red Product Inter-comparison and Validation with FRM Radiometers

F. Göttsche[1], W. Wimmer[2], M. Martin[1] and L. Perez-Planells[1] ([1]KIT & [2]NOC)

Fiducial Reference Measurements (FRM)

Sentinel-3 Validation Team:

"The suite of independent ground measurements that provide the maximum return on investment for a satellite mission by delivering, to users, the required confidence in data products, in the form of independent validation results and satellite measurement uncertainty estimation, over the entire end-to-end duration of a satellite mission"

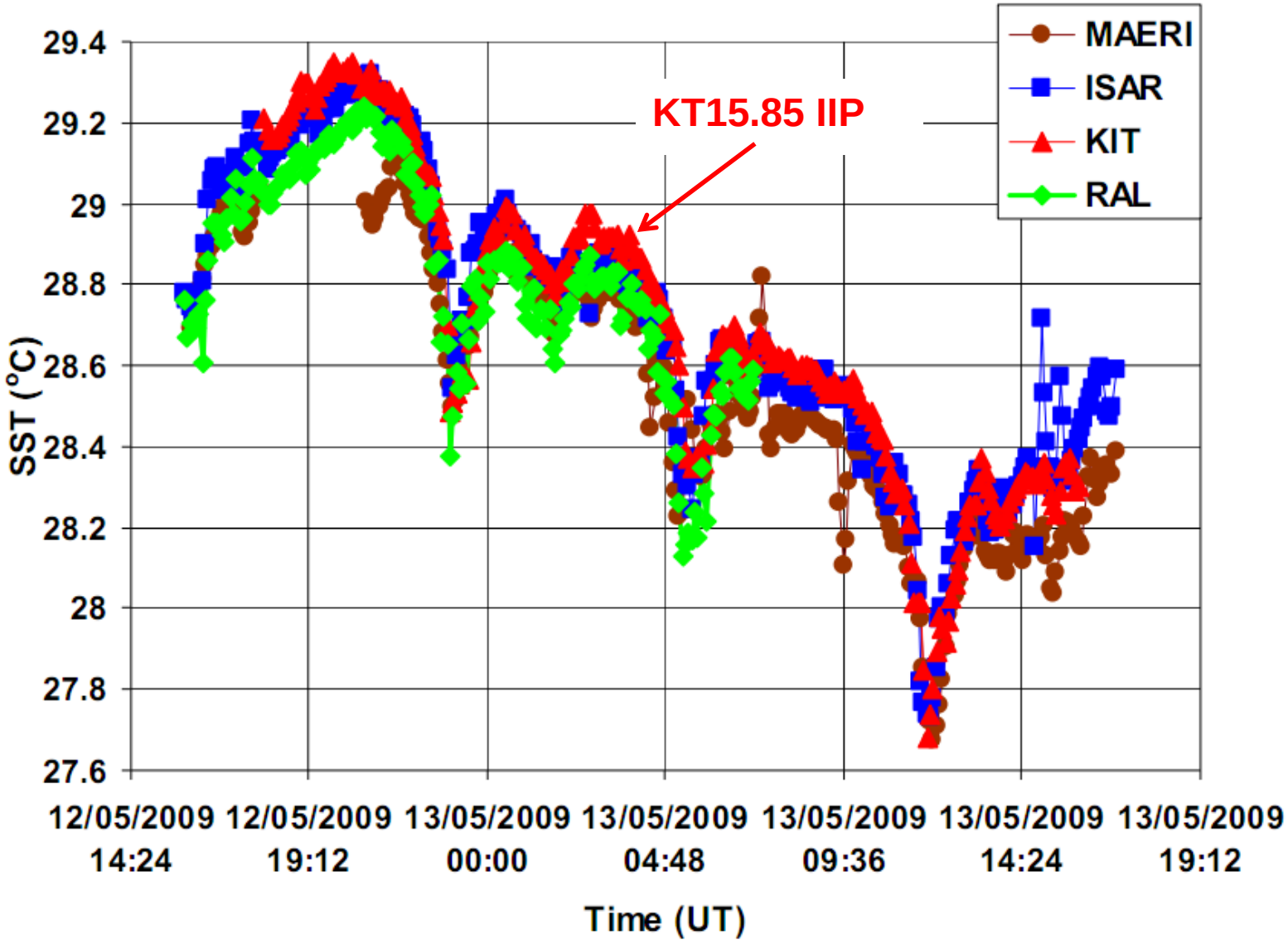
FRM must (at least):

1. Document evidence of its traceability to SI
2. Be independent from the satellite geophysical retrieval process
3. Detail an uncertainty budget for the instrumentation and measurement process for the range of conditions it is used over.
4. Adhere to community agreed measurement protocols & management practises.

KIT's main validation instrument: Heitronics KT15.85 IIP

- **chopped**, precision radiometer:
  stability better than **0.12% per year**
- narrow band 9.6µm -11.5µm
- better than **±0.3K** absolute accuracy
- narrow view angle: 8.5°
- separate KT15 for each end-member
  additional KT15 for **sky radiance**

Sea Surface Temperature at 2009 CEOS Inter-Comparison, Miami



Laboratory & Field Inter-comparisons: ESA FRM4STS

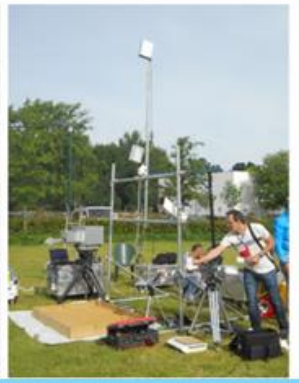
Laboratory Intercomparison

For the Laboratory Intercomparisons there were three types of validation:

- Controlled laboratory testing (blackbody and radiometer comparisons,
- Water Surface Temperature (WST), and
- Land Surface Temperature measurements (LST)

Phase1: Laboratory Intercomparison Exercise

Phase 1: CEOS Laboratory IR intercomparison, NPL, Hampton UK



Field intercomparison experiments (FICE)

Phase 2A: Shipborne Comparison

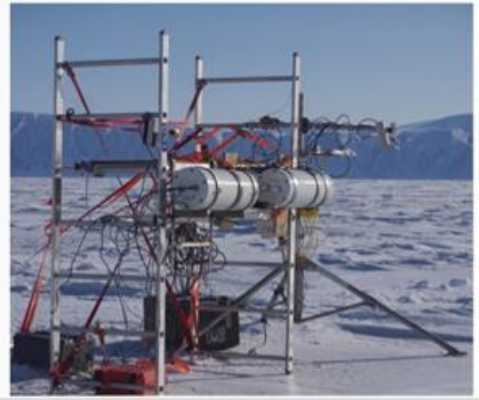
Phase 2A: Ship based Sea Surface Temperature (SST) Comparison

Phase 2B: Land Surface Temperature, Gobabeb

Phase 2B: Land surface Temperature comparison (Gobabeb, Namibia)

Phase 2C: Ice Surface Temperature, Greenland

Phase 2C: Ice surface Temperature measurements, Greenland, Arctic



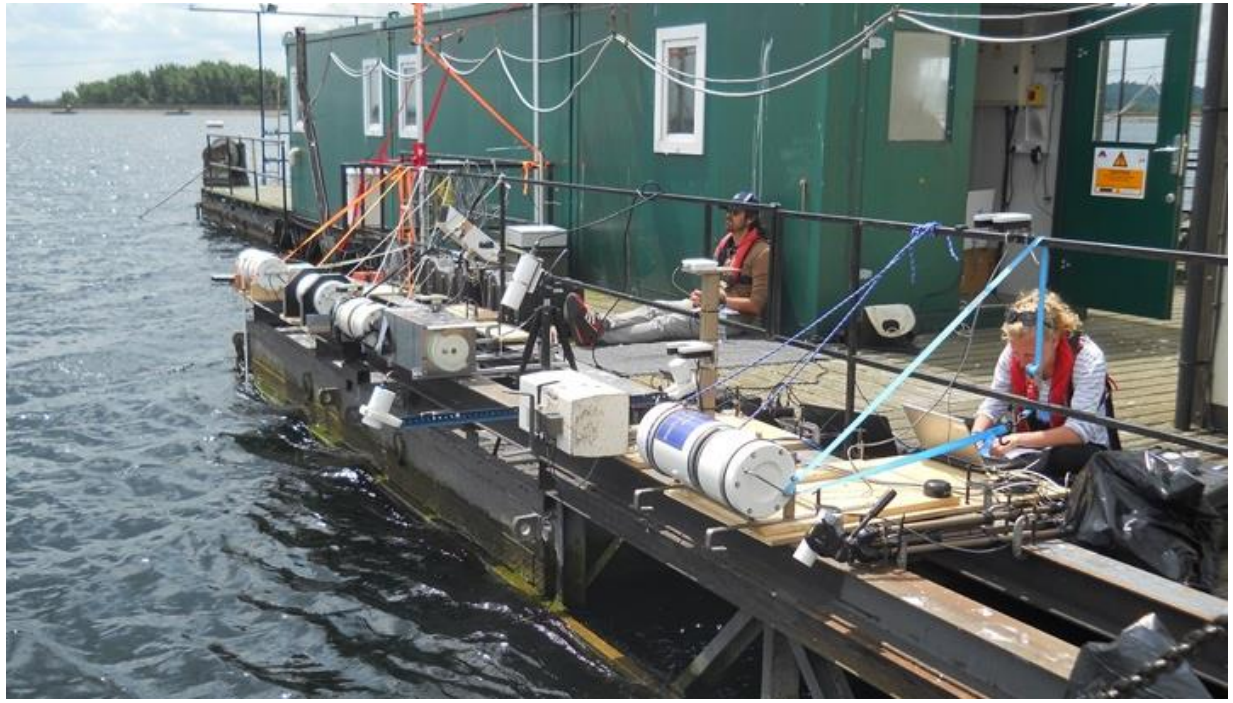
Source: **www.frm4sts.org**

KT15.85 IIP LWST Uncertainty

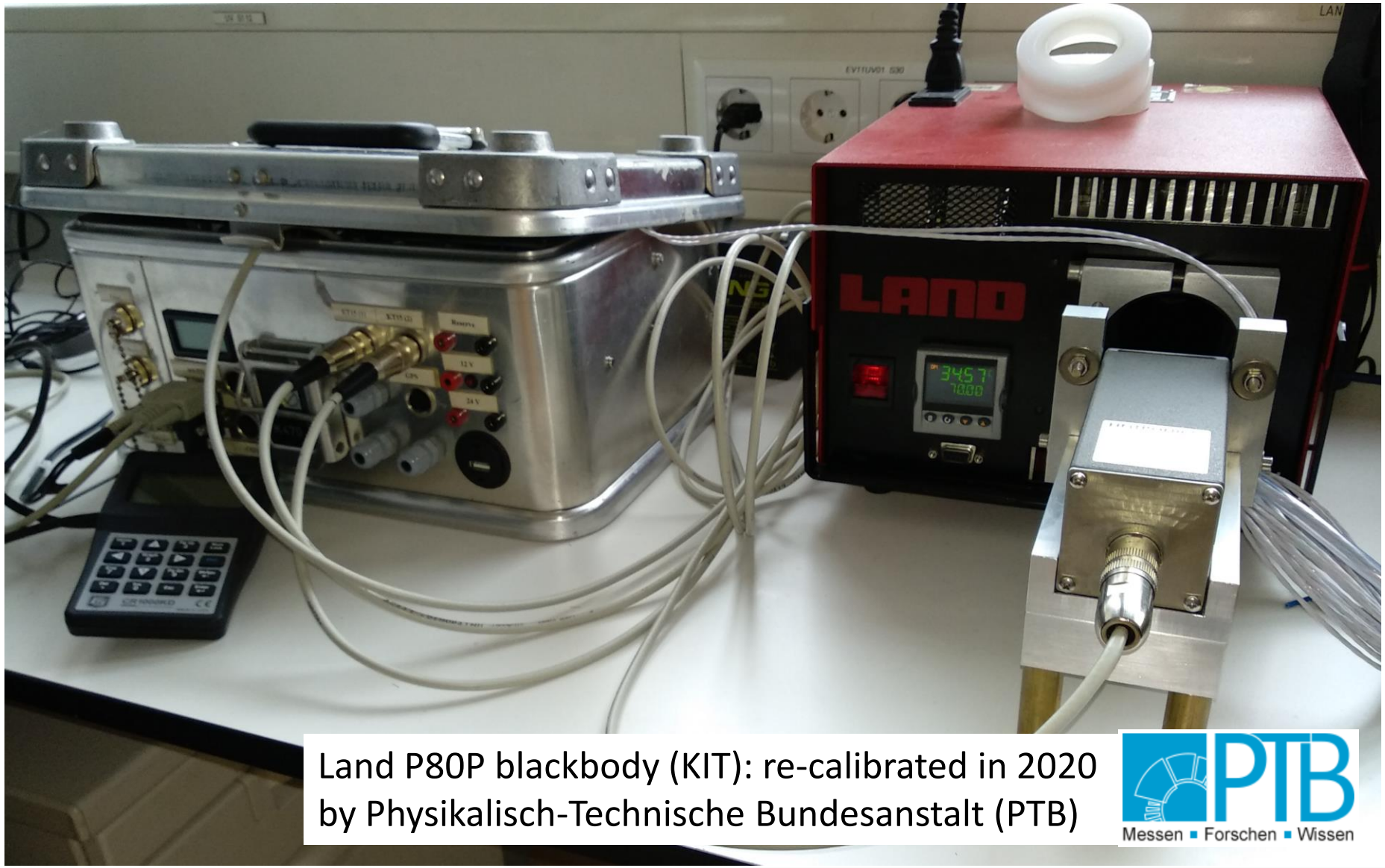
Uncertainty Contribution	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature K
Repeatability of measurement	0.12		0.024
Reproducibility of measurement	0.12		0.024
Primary calibration		0.250 K	0.250
Water emissivity		0.1%	0.067
Water surface "roughness"		2.0 m/s	0.033
Angle of view to nadir		2.5 °	0.117
Linearity of radiometer		0.053 K	0.053
Drift since last calibration		0.176 K	0.176
Temperature resolution		0.035 K	0.035
Ambient temperature fluctuations		0.035 K	0.035
Atmospheric absorption/emission		0.035 K	0.035
Down-welling sky radiance		0.004 K	0.004
RMS total	0.173		0.347

Left: estimates from FRM4STS inter-comparison experiment on Wraysbury reservoir, Heathrow, UK.

ISAR: self-calibrating radiometer with two internal reference blackbody cavities to maintain radiance calibration with an accuracy of ±0.1 K.



KT15.85 IIP radiometer calibration against Land P80P Blackbody



Land P80P blackbody (KIT): re-calibrated in 2020
by Physikalisch-Technische Bundesanstalt (PTB)

Thermal Infra-red Product Inter-comparison and Validation with FRM Radiometers

BSB Bodensee-Schiffsbetriebe

BSB ferry *Friedrichshafen*

- One-way distance: 13.4 km
- One-way travel time: 43 min
- Up to 8 round trips per day (03:41 UTC to 19:21 UTC)
- Measurements since 2015

Project Objectives

- Perform inter-comparison experiment with Heitronics **KT15.85 IIP** and Infrared Sea Surface Temperature Autonomous Radiometer (**ISAR**) on Lake Constance
- Extend previous campaigns and contribute to the ‘Fiducial Reference Measurements For Surface Temperature from Satellite’ (FRM4STS) project
- Acquire an in-situ data set of Lake Water Surface Temperature (LWST) & Sea Surface Temperature (SST) from two FRM radiometers operating in parallel
- Inter-compare in-situ surface temperatures and FRM radiometers’ uncertainties
- Compare infra-red satellite ST products (focus on Sentinel-3) with in-situ LWST

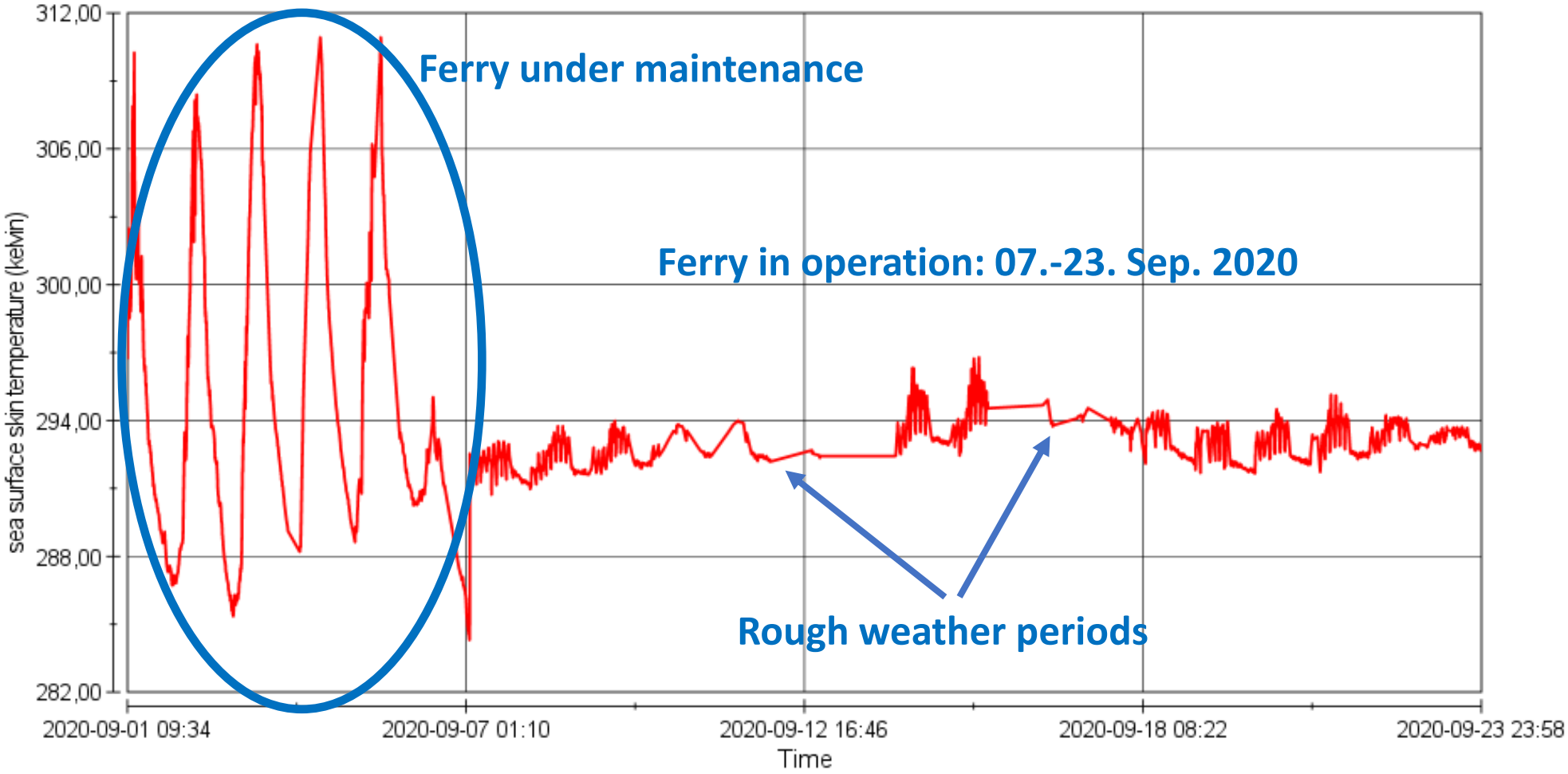
FRM Radiometer Inter-comparison Experiment on Lake Constance

01.-23. September 2020

National Oceanography Centre, Southampton
UNIVERSITY OF SOUTHAMPTON AND NATURAL ENVIRONMENT RESEARCH COUNCIL

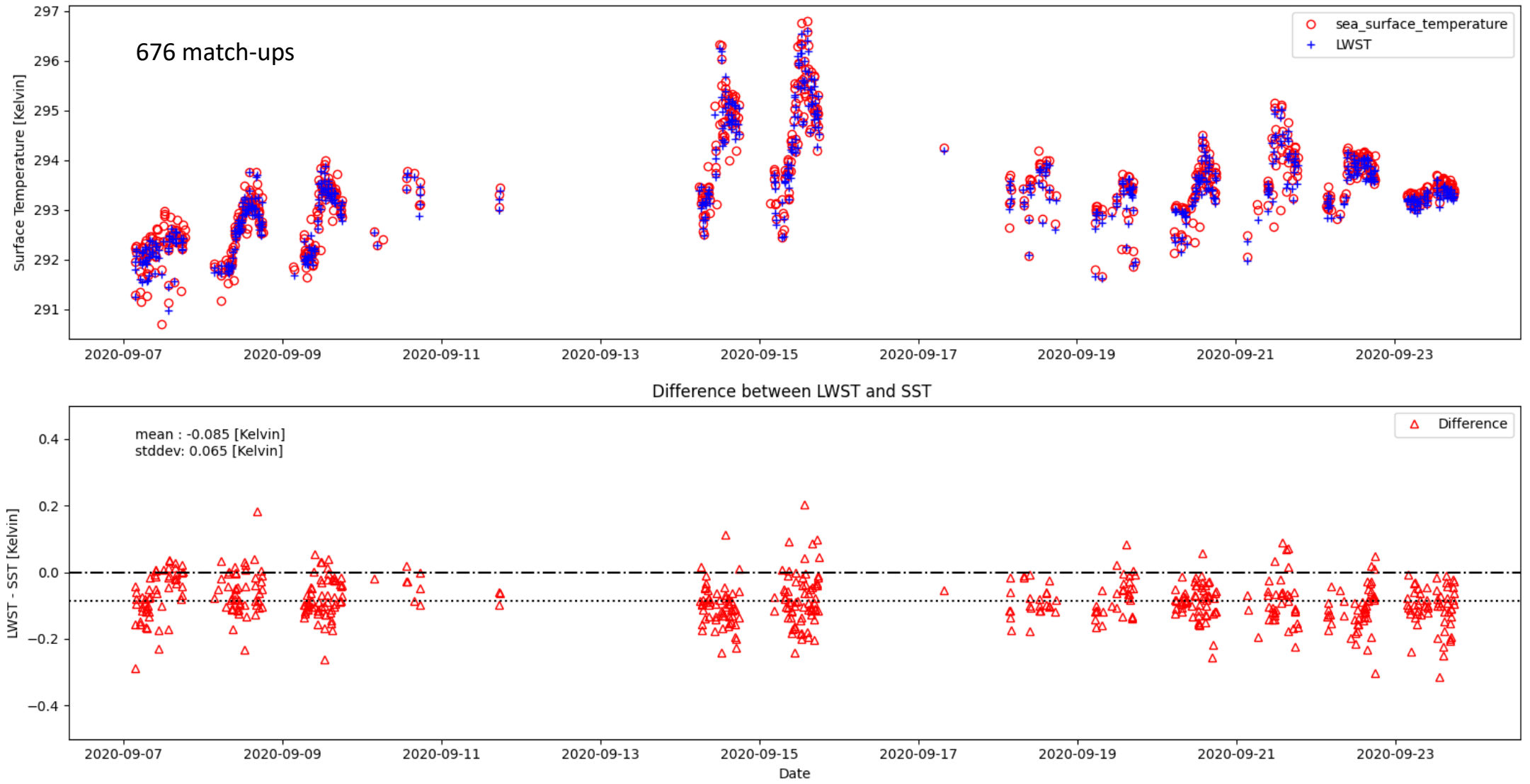
EUMETSAT

ISAR SST during Lake Constance Campaign (01.-23. Sep. 2020)

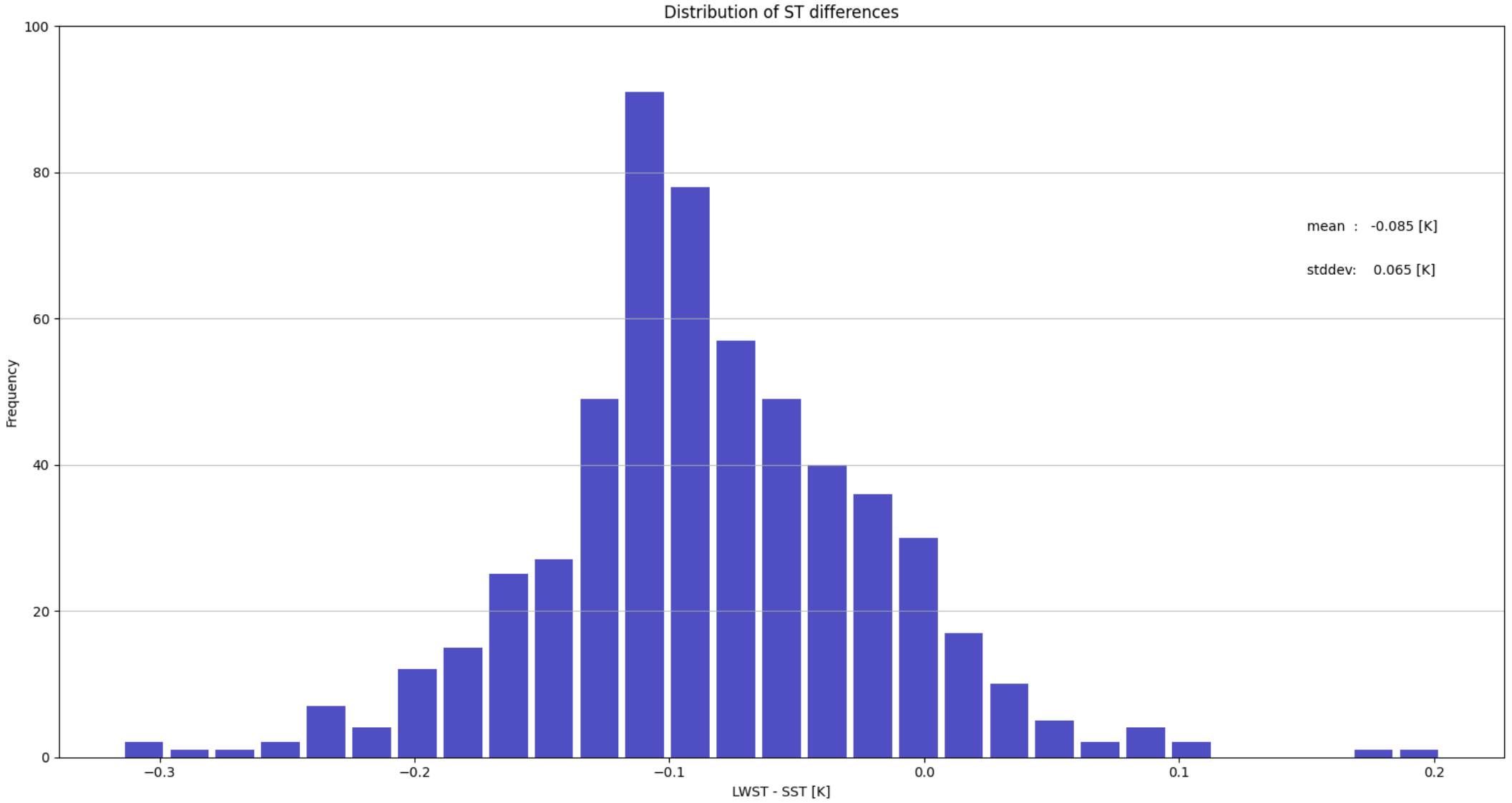


In-situ measurements, meta data and obtained ST delivered as netCDF files

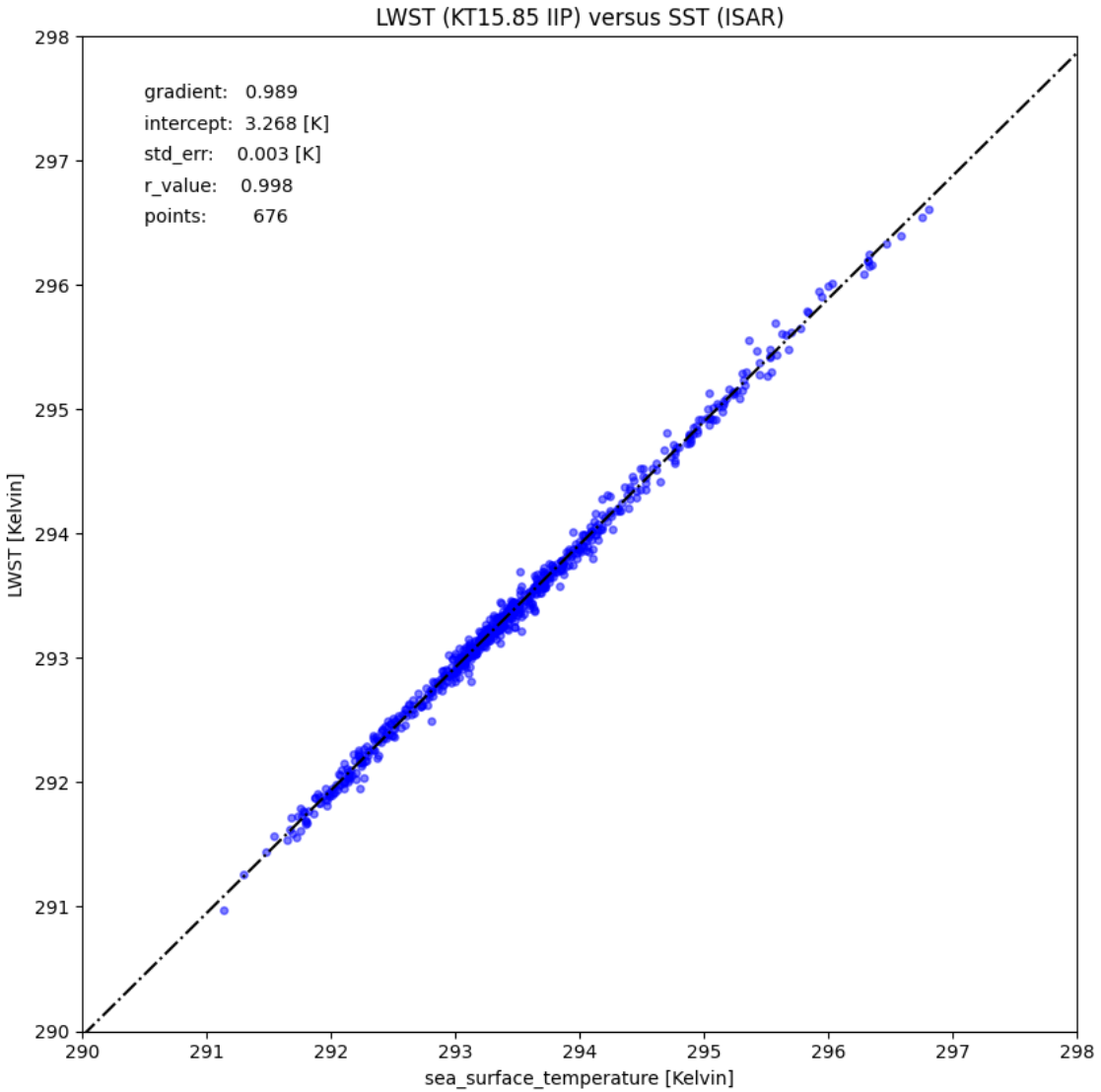
In-situ SST (ISAR) and LWST (KT15.85 IIP) for Lake Constance Campaign



Distribution of ST differences between KT15.85 IIP and ISAR



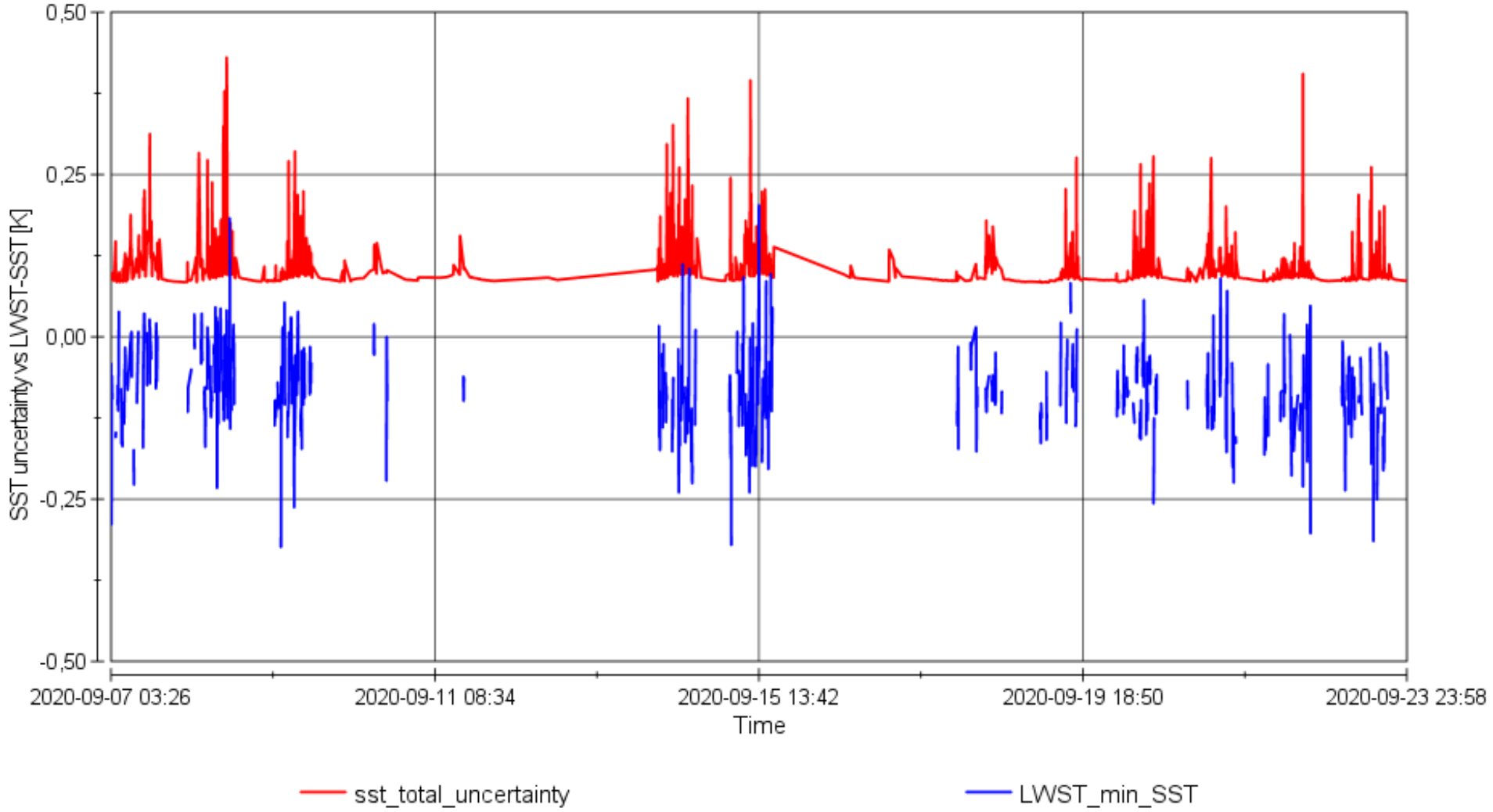
Relationship between LWST (KT15.85 IIP) and SST (ISAR)



- Excellent agreement between the two time-series of in-situ surface temperatures
- Differences well within uncertainty range of ±0.3 K estimated for KT15.85 IIP (LWST)
- 676 valid matchups (07.-23. Sep. 2020)
- Average ST deviation between KT15.85 IIP and ISAR was -0.085 K ± 0.065 K

ISAR total SST uncertainty and comparison with KT15.85 IIP

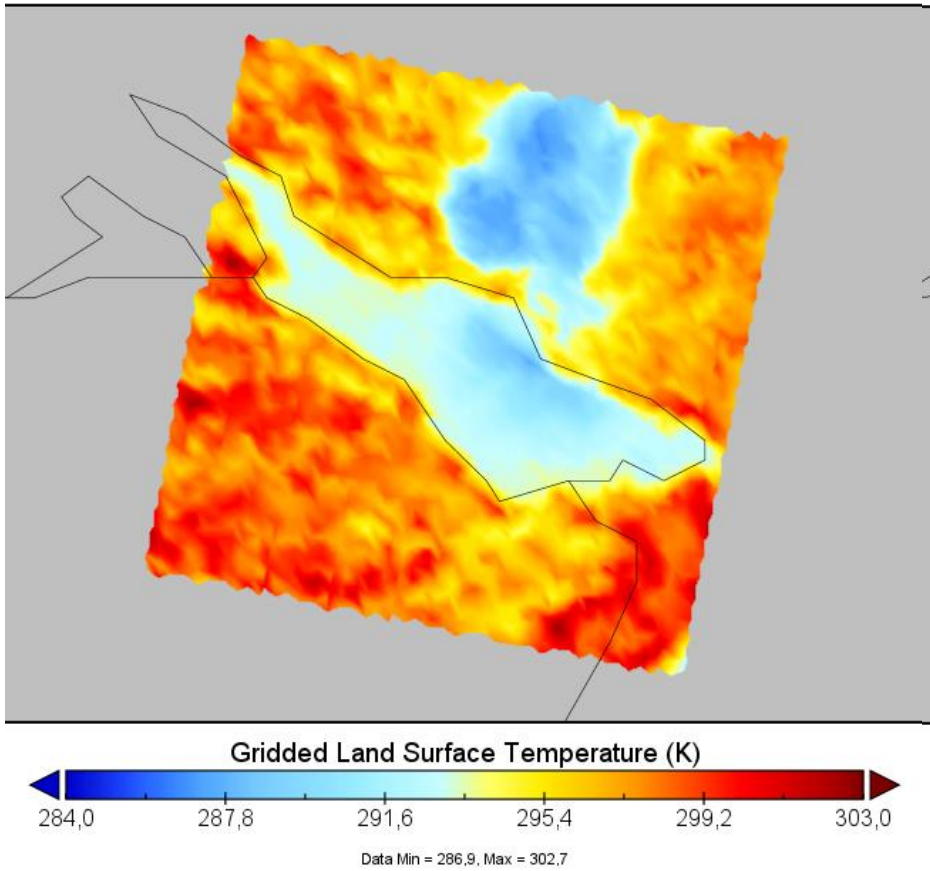
Matchups for ferry speed > 9.0 m/s (32.4 km/h)



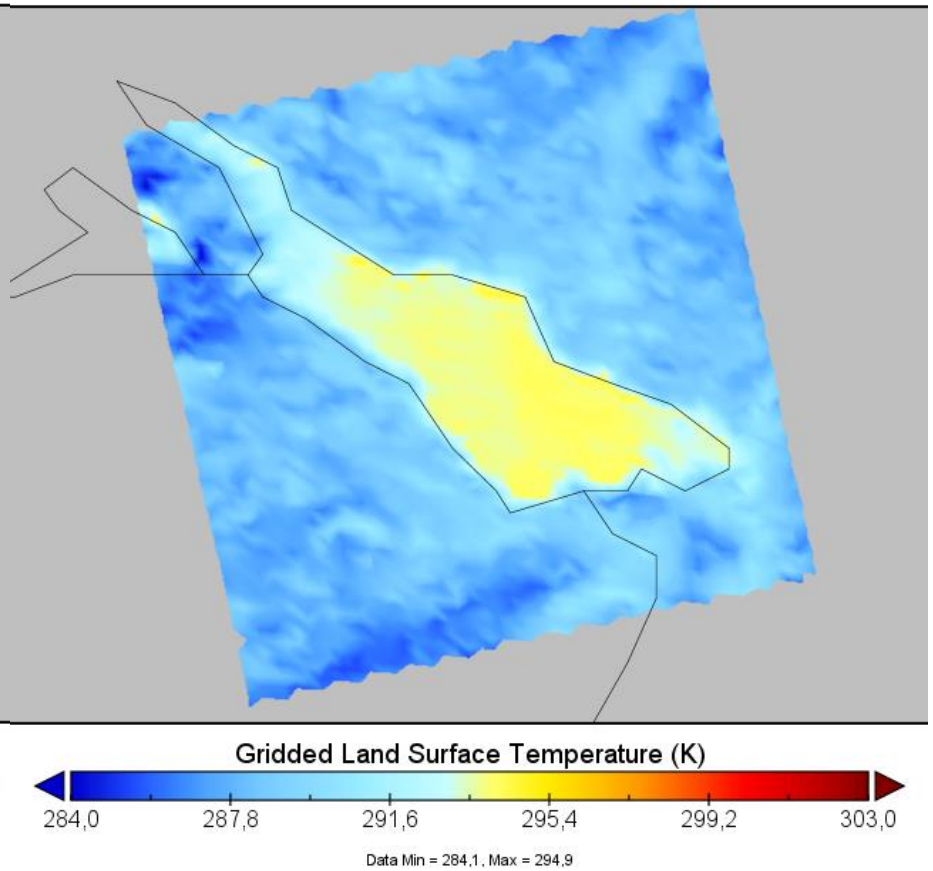
Preparation of satellite ST product subsets into netCDF files

51 x 51 pixel subsets of ESA operational SLSTR Level-2 LST product

S3A_SL_2_LST_20200909T**093541**



S3A_SL_2_LST_20200909T**205835**



SST and LST satellite products compared against in-situ LWST

Sensor ST product(s)	**Satellite(s)**	**Spatial resolution** Data format	**Satellite operator** Data source
SLSTR WCT WST SL_2_LST	**Sentinel-3 (A,B)**	**1 km** netCDF netCDF netCDF	**Copernicus / ESA** EUMETSAT (internal) EUMETSAT (CODA) Scihub (Uni Leicester)
MODIS LST (MOD21) SST (MODIST/A)	**Terra / Aqua**	**1 km** HDF-EOS netCDF	**NASA** Earthdata Earthdata
AVHRR SST (OSI-204) LST (LSA-002)	**MetOp (B,C)**	**1 km** netCDF HDF-5	**EUMETSAT** OSI SAF LSA SAF
VIIRS SST LST (VNP21)	**Suomi NPP**	**1 km** netCDF (GHRSST) netCDF	**NOAA / NASA** Earthdata Earthdata

The Sentinel-3 SLSTR WCT product

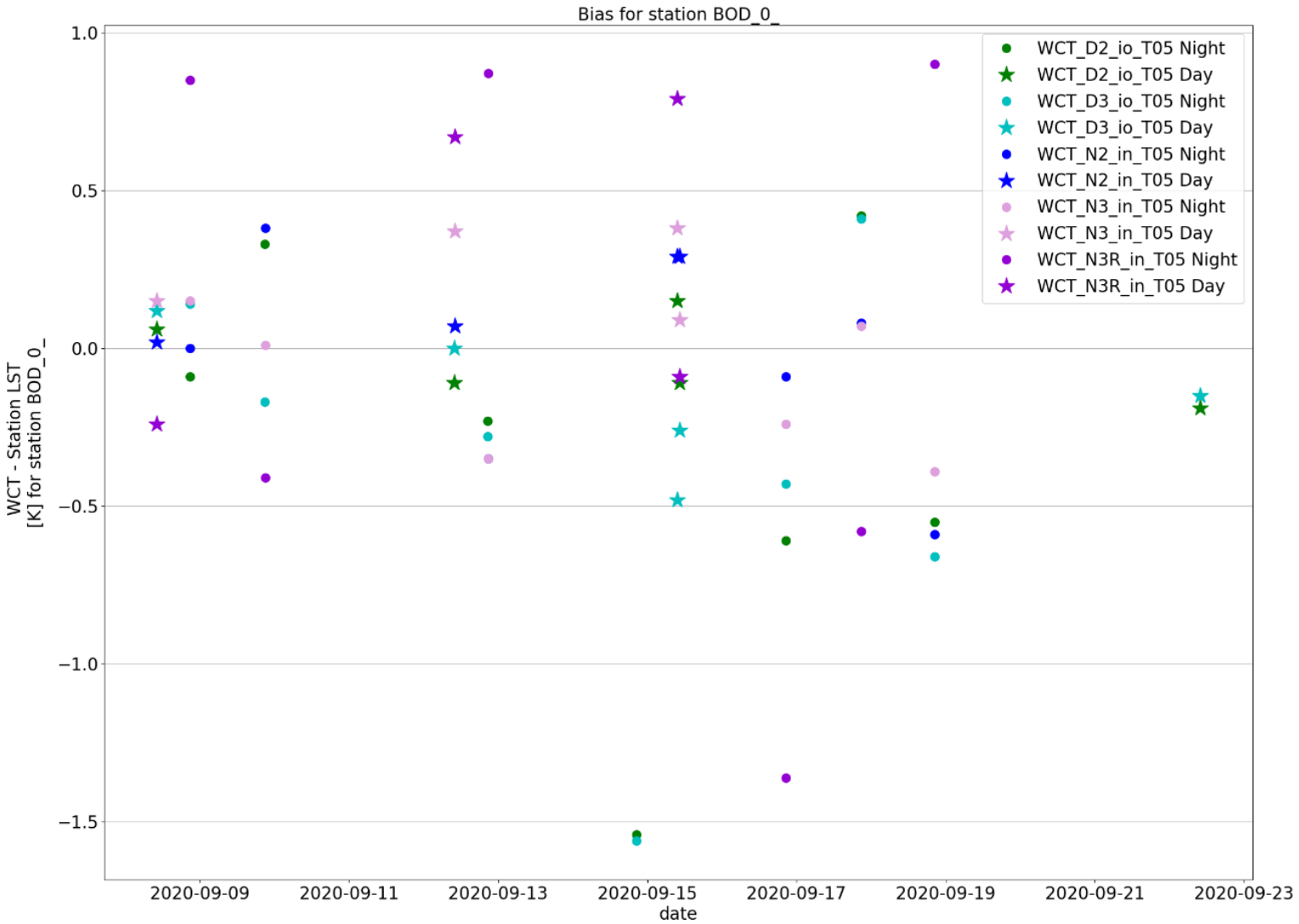
WCT is an **internal** SST product consisting of five SST datasets:

- N2: day-time, nadir single view, two thermal channels
- N3: night-time, across track single view, three thermal channels
- N3R: similar to N3, but with “aerosol robustness“
- D2: similar to N2, but dual view
- D3: similar to N3, but dual view

Day-time channels: S8 (10.85 µm) and S9 (12 µm)

Night-time channels: day-time channels plus S7 (3.7 µm)

Sentinel-3 SLSTR **WCT** versus in-situ LWST over Lake Constance



In-situ LWST averaged over 1 km

Matched-up at lake centre

Stars: daytime
Circles: night-time

T05: required cloud probability < 0.5

- io: probability_cloud_single_io
- in: probability_cloud_single_in

WCT product validation over Lake Constance

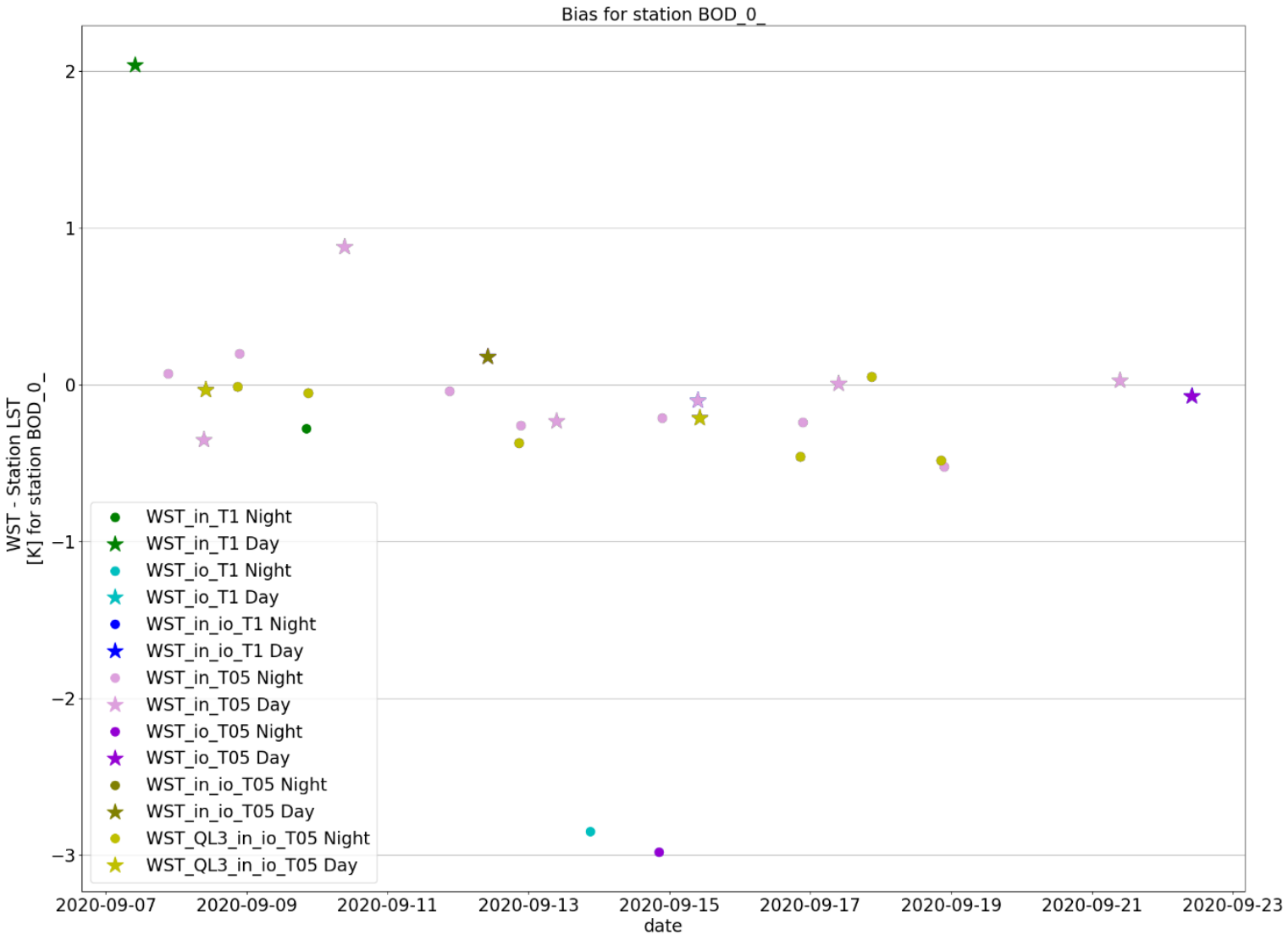
WCT	Quality Flag	Threshold	Day			Night		
			Median [K]	RSTD [K]	points	Median [K]	RSTD [K]	points
D2	probability_cloud_single_io	0.5	-0.11	0.32	12	-0.23	0.56	7
D3	probability_cloud_single_io	0.5	-0.15	0.22	5	-0.28	0.56	7
N2	probability_cloud_single_in	0.5	0.18	0.16	4	-0.04	0.32	6
N3	probability_cloud_single_in	0.5	0.26	0.17	4	-0.12	0.31	6
N3R	probability_cloud_single_in	0.5	0.29	0.65	4	0.22	0.99	6

- Small number of match-ups after cloud filtering
- Still some absolute temperature differences > 1 K

Robust statistics for all five **WCT** data sets yield:

- Median bias < 0.3 K
- RSTD < 1 K
- Night-time RSTD > daytime RSTD

Sentinel-3 SLSTR **WST** versus in-situ LWST over Lake Constance



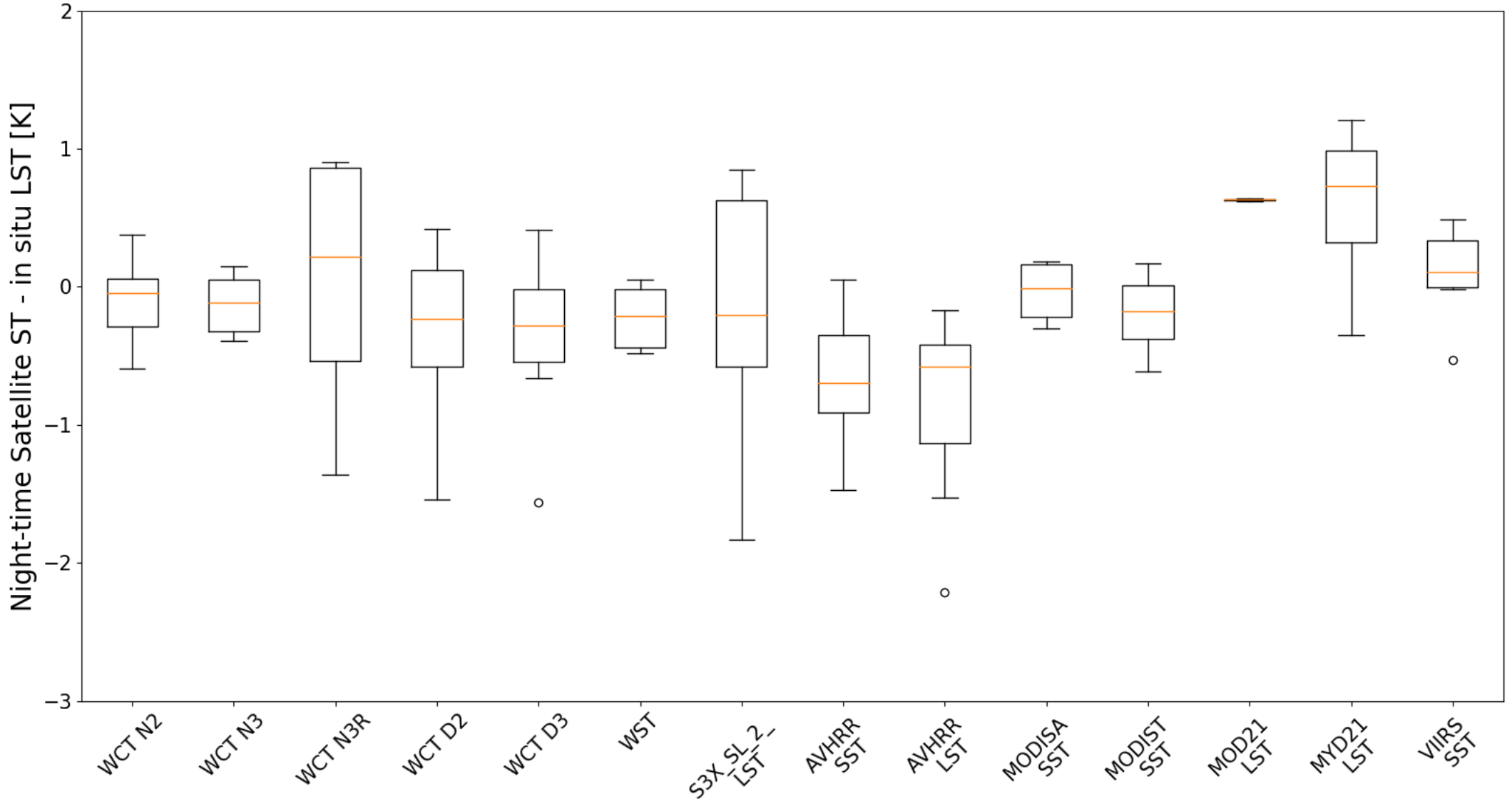
WST product:

- ‘Best’ single SST field selected from the five WCT fields
- WST products are disseminated to the EUMETSAT users

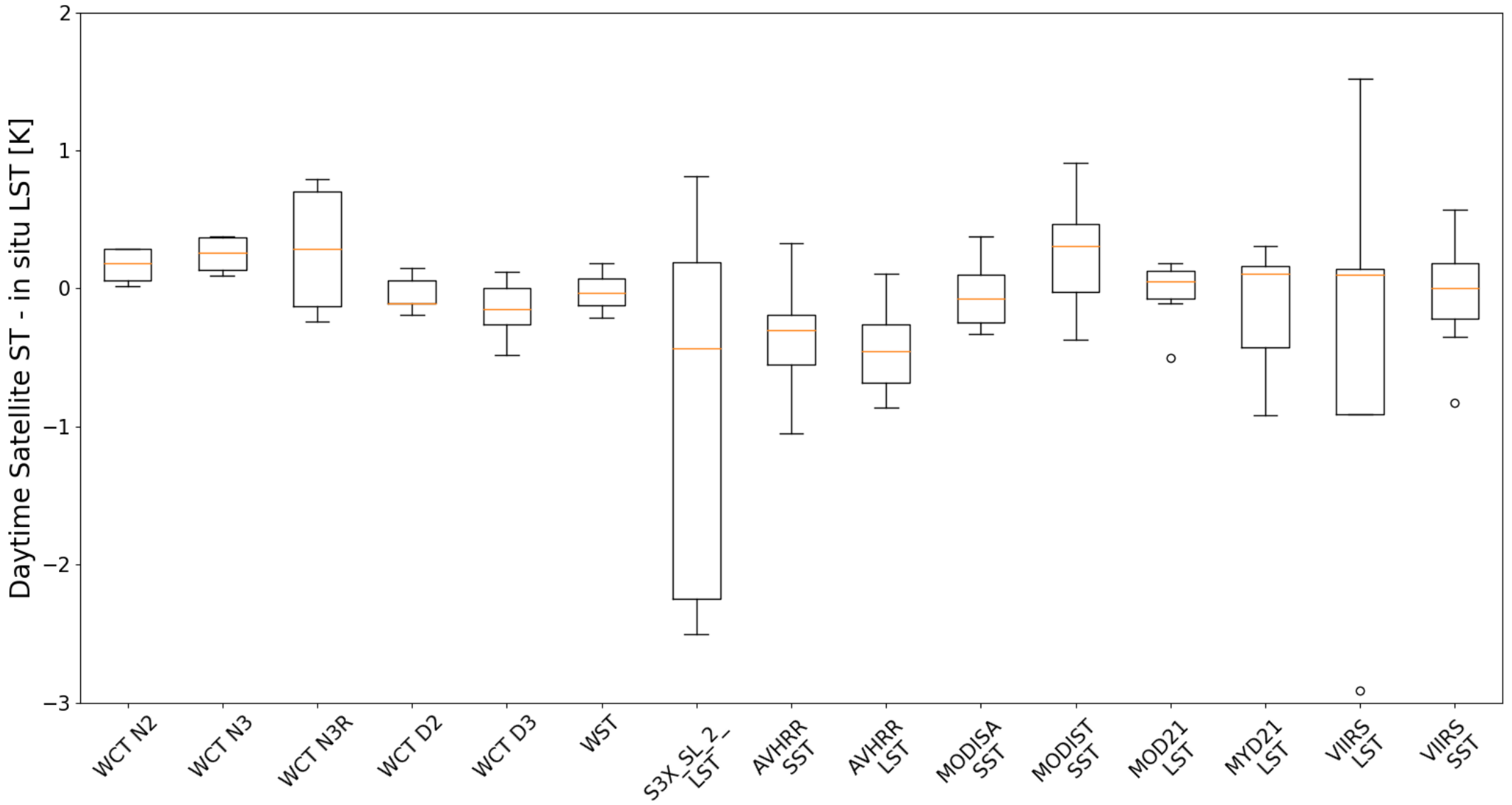
SLSTR WST product validation over Lake Constance

Data set	Quality Flag	Threshold	Day			Night		
			Median [K]	RSTD [K]	points	Median [K]	RSTD [K]	points
WST	probability_cloud_single_io	1	-0.07	0.06	5	-0.41	0.57	8
WST	probability_cloud_single_in	1	-0.03	0.27	11	-0.23	0.30	14
WST	probability_cloud_single_in **and** probability_cloud_single_io	1	-0.07	0.06	5	-0.21	0.33	6
WST	probability_cloud_single_io	0,5	-0.05	0.13	4	-0.37	0.47	7
WST	probability_cloud_single_in	0,5	-0.03	0.27	9	-0.21	0.30	13
WST	probability_cloud_single_in **and** probability_cloud_single_io	0,5	-0.03	0.27	3	-0.21	0.33	6
WST	probability_cloud_single_in, probability_cloud_single_io **and** quality level	0,5 0,5 4	-0.11	0.13	2	-0.21	0.33	6

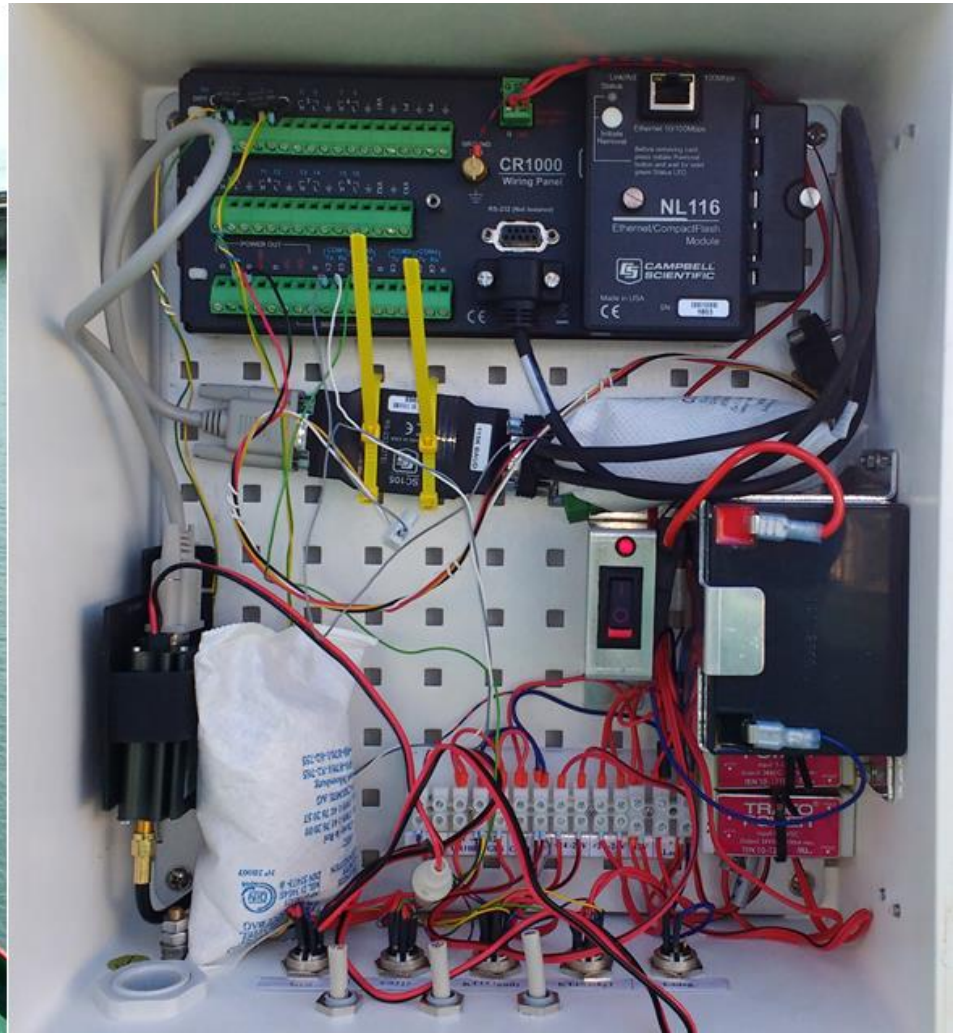
Nighttime validation results for investigated SST & LST products



Daytime validation results for investigated SST & LST products



Permanently installed instruments on the BSB *Friedrichshafen*

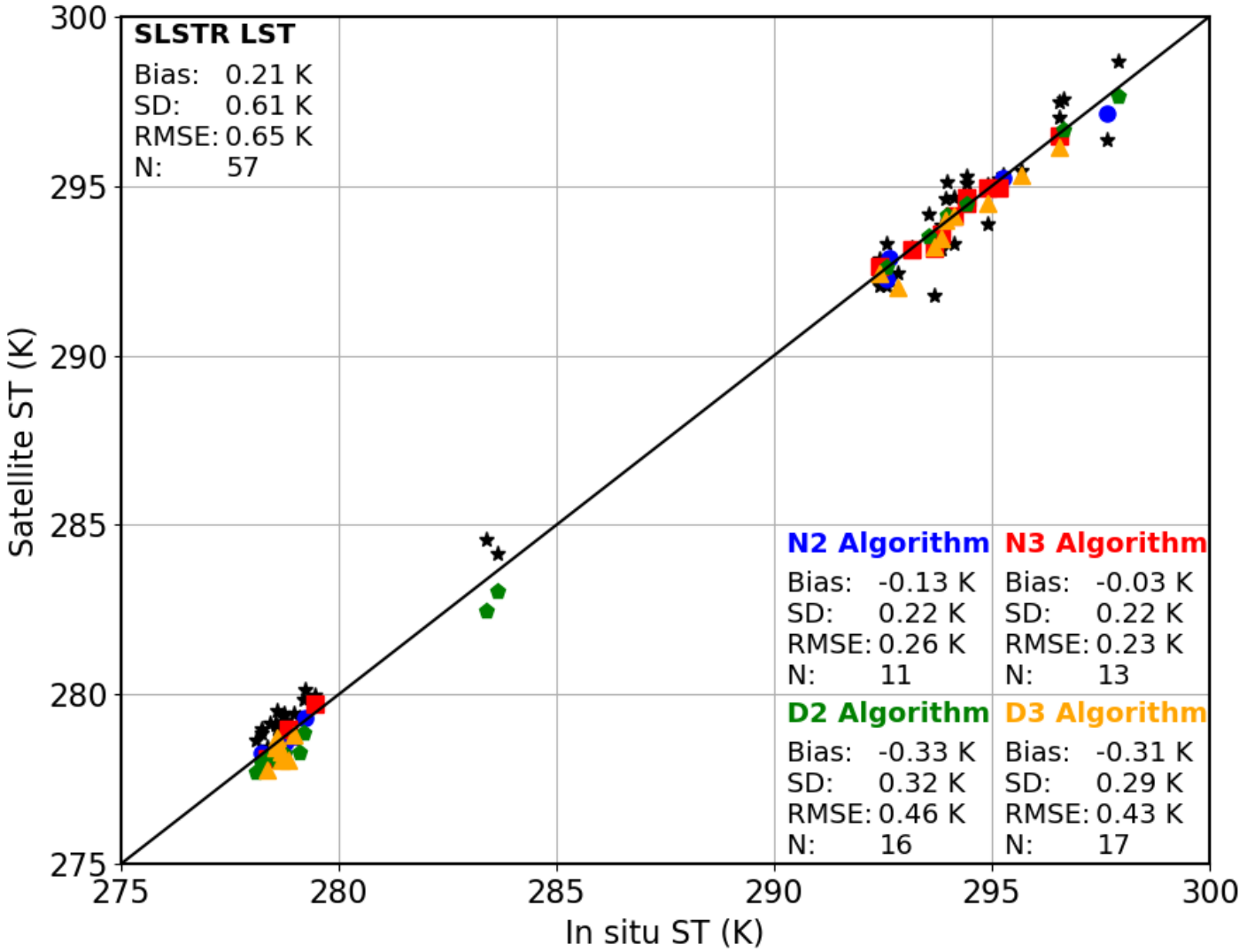


Extended SLSTR WST & LST validation for June 2020 to April 2021

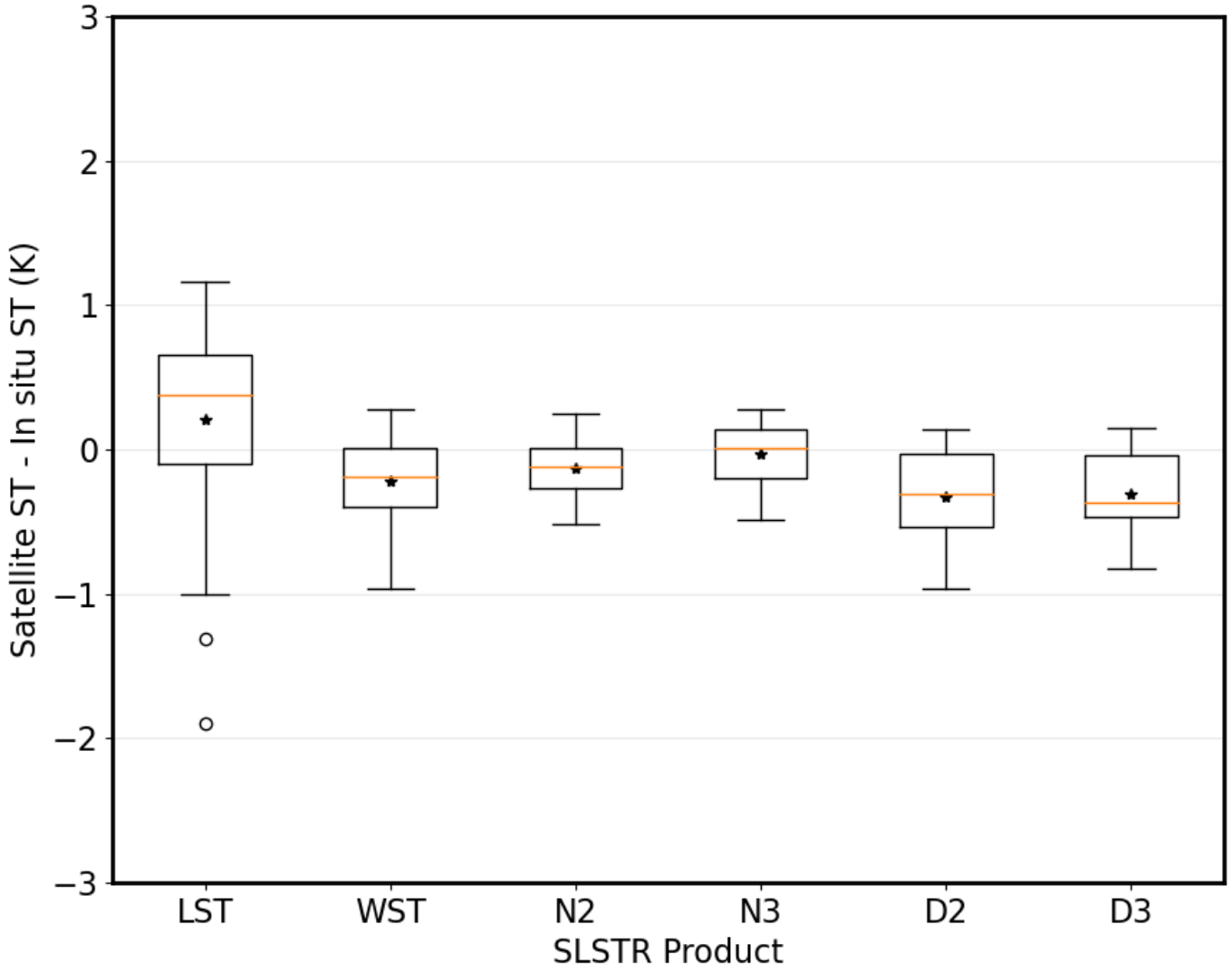
339 match-ups between Sentinel-3 SLSTR WST and LST with in-situ LWST

WST match-ups by WCT field:
N2: 67
N3: 46
D2: 122
D3: 104

Filter	LST	WST			
		N2	N3	D2	D3
Cloud Probability	82	13	20	20	29
Cloud Probability + cloud bit	57	11	13	16	17



SLSTR LST & SST product validation results for extended period



In-situ LWST obtained from KT15.85 IIP measurements, June 2020 to April 2021

Legend:

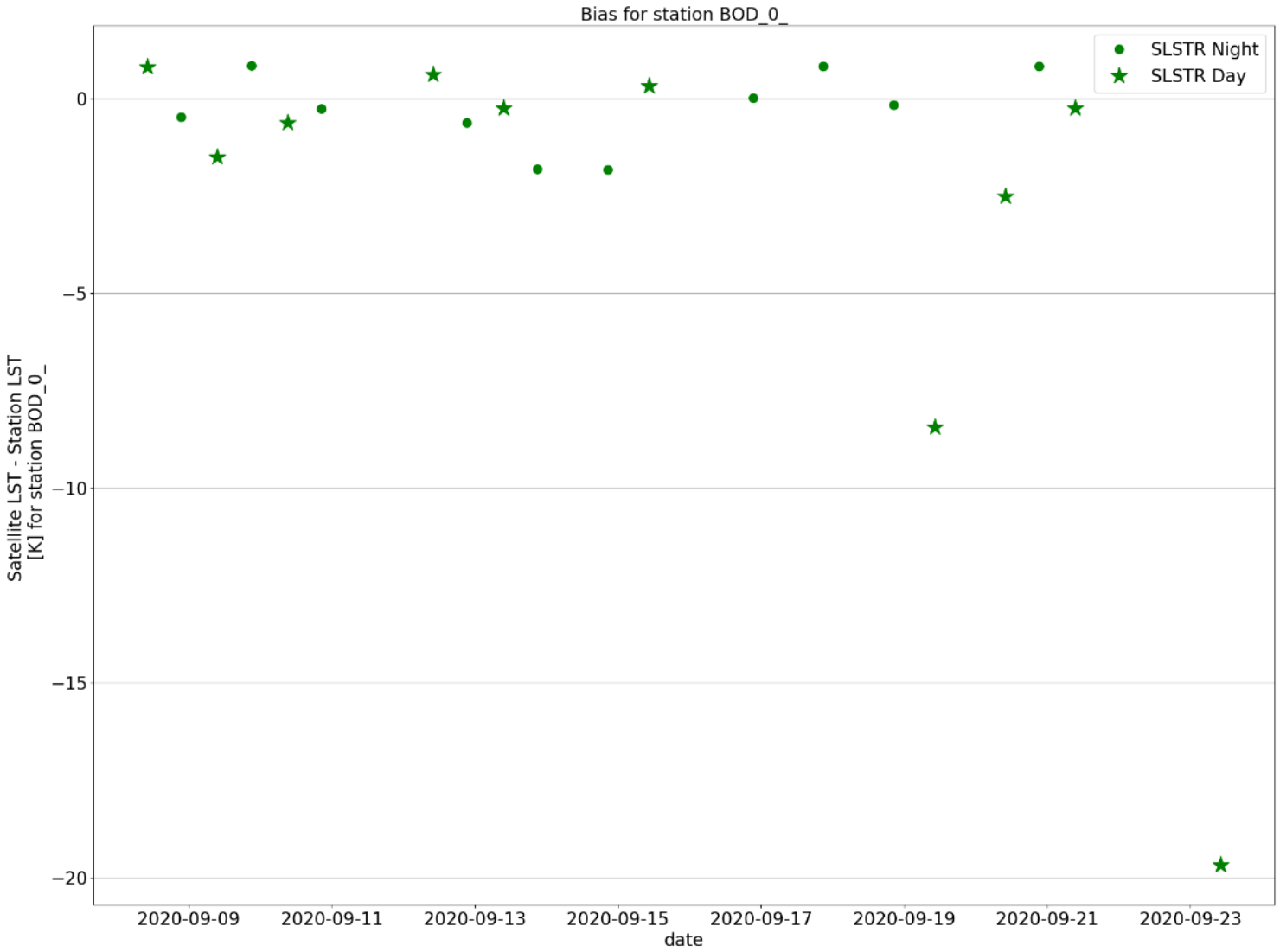
- Lower (upper) whiskers: minima (maxima)
- Orange lines: median
- Stars: mean
- Box: lower & upper quartile ranges
- Circles: outliers (high VZA of about 50°)

Thank you for your attention!

SST and LST validation results for inter-comparison experiment

Data set	Quality Flag	Threshold	Day			Night		
			Median [K]	RSTD [K]	points	Median [K]	RSTD [K]	points
VIIRS SST	qual_sst	> 1	0.00	0.33	11	0.11	0.30	6
VNP21 LST	QC	Nominal quality	0.10	1.50	5	-	-	-
MODISA SST	qual_sst	> 1	-0.08	0.26	8	-0.01	0.28	5
MODIST SST	qual_sst	> 1	0.31	0.43	12	-0.18	0.32	6
MOD21 LST	QC	bit [0-1] > 0	0.05	0.12	7	0.63	0.01	2
MYD21 LST	QC	bit [0-1] > 0	0.10	0.26	12	0.73	0.49	4
AVHRR SST	quality_level	>= 3	-0.30	0.37	9	-0.70	0.46	16
AVHRR LST	LST uncertainty	> 2 K	-0.45	0.36	10	-0.58	0.52	13
S3X_SL_2_LST	confidence_in	"summary_ cloud" set	-0.43	1.57	10	-0.20	1.07	10
S3X_SL_2_LST	probability_ cloud_single_in	=1	0.05	0.64	6	-0.07	0.70	8

Sentinel-3 SLSTR **LST** versus in-situ LWST over Lake Constance



SLSTR LST were cloud-filtered using the product's quality flag "confidence_in"

Daytime median difference:
-0.43 ± 1.57 K (10 data points)

Night-time median difference:
-0.20 ± 1.07 K (10 data points)

Cloud probability: impact on SLSTR LST product