

FIELD EVALUATION OF SENSORS FOR PRECIPITATION TYPE DISCRIMINATION: AN UPDATE

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ABSTRACT

This document provides an update on the previously reported KNMI field evaluation of present weather sensors (Wauben et al, 2016), for the succeeding period of August 1, 2016 to February 12, 2017. The instruments participating in this field test were the Vaisala FD12P, Vaisala PWD22, Biral VPF750, Biral SWS250, Campbell Scientific PWS100, Ott Parsivel², Thies LPM, and Optical Scientific OWI430. Results of the precipitation amount and intensity are compared to the KNMI precipitation gauge, visibility is compared to a transmissometer, and temperature to an automatic weather station. In other situations the results of the PWS are compared to that of the FD12P.

1. INTRODUCTION

The Royal Netherlands Meteorological Institute (KNMI) uses the Vaisala FD12P present weather sensor for the automated determination of visibility and of the type, intensity and duration of precipitation in its national meteorological observation network. Replacement of the FD12P is required in the near future due to discontinuation of support by the manufacturer. In preparation of the upcoming European Tender, a field evaluation was conducted using several instruments, which have been selected in order to cover various techniques with respect to precipitation type discrimination.

The full evaluation period was from February 18, 2016 to February 12, 2017. The results on the first half of this period, up to July 31, 2016, have already been reported in Wauben et al. (2016). More information about the background of this field test and the participating instruments can be found in this previous report.

In the current document an update of the results of the field test is given, reporting results from August 1, 2016 onwards, following the same structure of the previous report. Here we restrict ourselves to presenting the data, without any in depth discussion or analysis.

2. SELECTED PRESENT WEATHER SENSORS, FIELD SETUP AND EVALUATION PERIODS

The field evaluation for precipitation type discrimination included the following sensors:

- Vaisala **FD12P** present weather sensor (firmware 1.92S). The FD12P is currently used operationally by KNMI. All other sensors are compared against this sensor when a suitable reference is not available. The FD12P was removed from the test field for repair from November 12 to November 21, 2016.
- Vaisala **PWD22** present weather detector (firmware 2.07).
- Biral **SWS250** present weather sensor (firmware SI100245.06A). A remote upgrade onsite regarding the precipitation threshold and intensity calibration factors was performed on November 18, 2016. The SWS250 was erroneously reporting continuous precipitation between November 21 and December 1, 2016 due to interference with the neighboring VPF750 after a relocation of the sensors on the test field. The data of the SWS250 for that particular period is flagged invalid.

- Biral **VPF750** present weather sensor (firmware SI100245.06A, firmware version reported in Wauben et al, 2016 was incorrect). The VPF750 was removed from the test field from October 21 to November 20, 2016 for an upgrade at the manufacturer. Visibility was recalibrated, precipitation threshold parameters were updated to allow lower levels of precipitation to be reported, and a new calibration factor for the precipitation amount was introduced.
- Thies **LPM** laser precipitation monitor (firmware V2.53). Two LPM instruments (**LPM1** and **LPM2**) were already available at the test site from a previous test.
- Ott Parsivel² (**PAR2**) present weather sensor (firmware 2.02.5, upgraded to 2.10.1 on August 15, 2016 and upgraded to 2.11.1 on January 9, 2017). The PAR2 was removed from the test field for repair at the manufacturer from August 23, 2016 to January 9, 2017.
- Campbell Scientific **PWS100** present weather sensor (firmware 007628-07). A visibility recalibration and update software (OS7a) to reduce the number of occasions of unidentified precipitation reports and increase reporting of solid precipitation, especially in conditions of low intensity was performed onsite on November 18, 2016.
- Optical Scientific **OWI430** & HIPS weather identifier and visibility sensor (firmware WIVDS63S 08/16/2016). The OWI430 was not yet operational in the previous evaluation period and started to operate on October 25, 2016. Data became unavailable from February 8, 2017 due to a problem with the data acquisition.

Figure 1 displays an overview of the data availability (specifically of the precipitation type) of the instruments during the course of the full evaluation period. The first reported period (February 18, 2016 to July 31, 2016) had a high amount of data availability (the OWI430 being not yet available). In the present period data availability was much less for a couple of instruments, partly due to upgrades made at the manufacturer triggered by the results of the first period. Therefore the last part of the present period (from December 1, 2016 onwards), in which the data availability was high (except for the PAR2), is evaluated separately. This period also contained a significant amount of solid precipitation and low visibility (fog) events.

The test field is also equipped with a standard Automatic Weather Station (**AWS**) so that meteorological information of for example air temperature, humidity and wind is available. A Vaisala Mitras transmissometer (**TMM**) is available on the test field and serves as the reference for MOR values up to 2 km. A rain gauge of in-house design serves as the reference for the precipitation amount and intensity reported by the present weather sensors under evaluation. For high visibility values and for precipitation type no reference is available, but the selected present weather sensors will be compared against the results obtained with the FD12P since the characteristics and the strong and weak points of the FD12P are known by KNMI after years of operational use.

In the remainder of the document results are presented for August 1, 2016 to February 12, 2017 denoted as evaluation period (a), and December 1, 2016 to February 12, 2017 denote as evaluation period (b). An overview of the results for precipitation type, precipitation intensity, visibility (Meteorological Optical Range) and temperature are given in sections 3, 4, 5 and 6, respectively. The order and the content of the tables and figures is more or less the same as the previous report (Wauben et al, 2016), although in some cases non-essential data is left out. In addition, boxplots are presented for visibility, focusing on the performance of visibility up to 1.5 km.

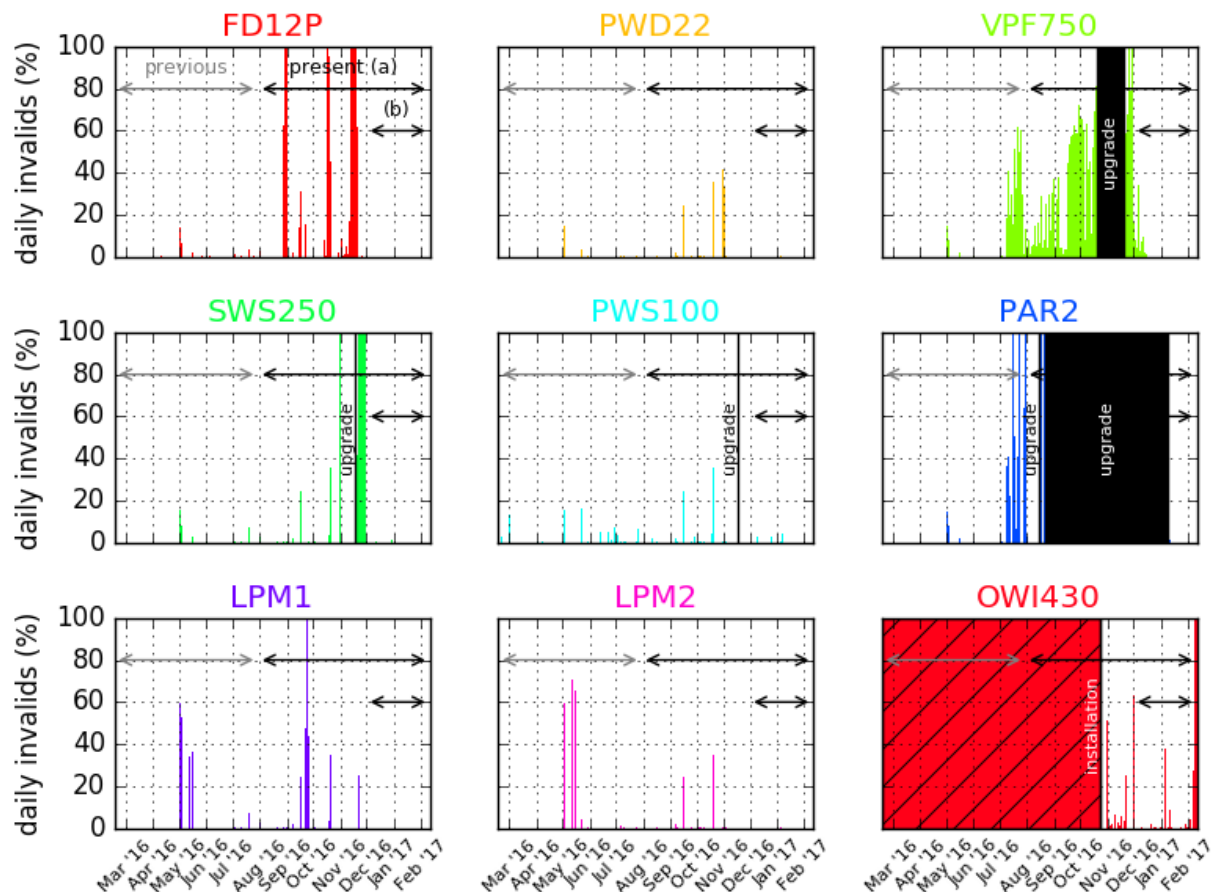


Figure 1: The daily percentage of invalid 1-minute PW values for the time that spans both the previous evaluation period (February 18, 2016 to July 31, 2016) and the present evaluation period (August 1, 2016 to February 12, 2017). Note that the entire present period (a) and the last winter (b) are considered.

3. PRECIPITATION TYPE

In this section an overview of the results for the 1-minute precipitation type reported by the PWSs under evaluation is given. The instantaneous precipitation type is reported by the sensor in the so-called NWS code of the National Weather Service, the METAR weather code of the ICAO or the wawa weather code of the WMO. In terms of the NWS code the following cases can be distinguished: “C” means clear or no precipitation; “P” for unidentified precipitation; “L” for drizzle; “ZL” for freezing drizzle; “LR” for a mixture of drizzle and rain; “ZL” for freezing drizzle; “R” for rain; “ZR” for freezing rain; “RS” for a mixture of rain and snow; “S” for snow; “IP” for ice pellets; “SG” for snow grains; “IC” for ice crystals; “SP” for snow pellets; and “A” for hail. The precipitation type can also be divided in classes: unidentified (P), liquid (L, LR or R), freezing (ZL and ZR) and solid (RS, S, IP, SG, IC, SP or A).

The relative occurrence of the precipitation types and classes reported by all present weather sensors in the evaluation period is given in **Table 1**. Here the row indicated by “NA” gives the percentage of 1-minute intervals in the evaluation period with unavailable data or when the sensor reported an invalid precipitation type. The line indicated by “C” denotes the percentage of valid cases that the sensor reported that there was no precipitation, whereas “precipitation” gives the percentage of valid cases that the sensor reported any type of precipitation. Note that the above results apply when no intensity threshold is used for reporting precipitation and precipitation type.

The corresponding contingency matrices of the PWSs versus the FD12P, and LPM1 versus LPM2, are given in **Table 11** in Appendix A. **Table 2** give the agreement between the FD12P and the other PWSs in terms of presence of precipitation (“correct y&n”), precipitation type (“correct type”) and precipitation class (“correct class”). **Table 3** give a comparison between the FD12P and the other PWSs in terms of the Probability of Detection (POD), False Alarm Rate (FAR), and BIAS for precipitation classes. Finally, in **Table 4** the precipitation classes occurrence and POD, FAR and BIAS w. r. t. the FD12P using the WMO 0.02 mm/h threshold on the precipitation intensity is considered.

Table 1 (a): The relative occurrence of the 1-minute precipitation type reported by the selected present weather sensors during the evaluation period (a).

NWS	METAR	wawa	FD12P	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
NA	NA	NA	9.443%	1.399%	33.453%	1.739%	0.831%	73.546%	2.006%	0.525%	47.578%
C	-	0	91.2%	91.0%	93.6%	89.2%	88.6%	87.5%	87.6%	88.0%	92.2%
precipitation	any	>0	8.8%	9.0%	6.4%	10.8%	11.4%	12.5%	12.4%	12.0%	7.8%
P	UP	40	6.51%	0.02%	0.00%	0.00%	10.56%	0.00%	0.51%	0.57%	13.81%
L	DZ	50	26.75%	25.79%	29.94%	22.02%	25.73%	23.83%	41.28%	41.06%	2.36%
ZL	FZDZ	55	0.00%	0.30%	2.41%	0.00%	0.99%	0.00%	0.00%	0.00%	0.00%
LR	DZRA	57	0.00%	0.00%	0.00%	0.00%	0.00%	25.70%	14.52%	14.61%	0.00%
R	RA	60	43.62%	61.33%	57.06%	32.90%	58.90%	37.46%	35.38%	35.74%	76.73%
ZR	FZRA	65	0.00%	0.31%	0.00%	0.00%	0.19%	0.00%	0.00%	0.00%	0.00%
RS	RASN	67	5.57%	0.00%	4.88%	25.82%	0.00%	0.09%	0.46%	0.42%	0.00%
S	SN	70	9.44%	11.02%	1.28%	17.79%	3.36%	9.77%	4.55%	4.60%	7.09%
IP	PL	75	0.34%	1.22%	0.00%	0.00%	0.00%	0.00%	0.20%	0.24%	0.00%
SG	SG	77	7.70%	0.00%	4.18%	1.42%	0.27%	0.00%	3.09%	2.75%	0.00%
IC	IC	78	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SP	GS	87	0.00%	0.00%	0.08%	0.01%	0.00%	2.44%	0.00%	0.00%	0.00%
A	GR	89	0.00%	0.00%	0.18%	0.05%	0.00%	0.72%	0.01%	0.01%	0.00%
unidentified			6.51%	0.02%	0.00%	0.00%	10.56%	0.00%	0.51%	0.57%	13.81%
liquid			70.36%	87.12%	87.00%	54.92%	84.63%	86.99%	91.18%	91.41%	79.10%
freezing			0.00%	0.61%	2.41%	0.00%	1.17%	0.00%	0.00%	0.00%	0.00%
solid			23.13%	12.24%	10.59%	45.08%	3.64%	13.02%	8.31%	8.02%	7.09%

Table 1 (b): The relative occurrence of the 1-minute precipitation type reported by the selected present weather sensors during the evaluation period (b).

NWS	METAR	wawa	FD12P	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
NA	NA	NA	0.038%	0.013%	3.478%	0.117%	0.212%	53.248%	0.017%	0.017%	8.145%
C	-	0	87.7%	88.6%	91.6%	91.6%	87.0%	88.6%	85.5%	85.8%	93.4%
precipitation	any	>0	12.3%	11.4%	8.4%	8.4%	13.0%	11.4%	14.5%	14.2%	6.6%
P	UP	40	8.91%	0.05%	0.00%	0.00%	14.58%	0.00%	0.00%	0.00%	18.04%
L	DZ	50	17.73%	24.15%	34.84%	32.46%	25.69%	14.97%	41.85%	41.64%	2.30%
ZL	FZDZ	55	0.00%	0.62%	3.34%	0.00%	2.26%	0.00%	0.00%	0.00%	0.00%
LR	DZRA	57	0.00%	0.00%	0.00%	0.00%	0.00%	25.41%	14.05%	14.44%	0.00%
R	RA	60	36.77%	49.44%	47.34%	41.69%	48.69%	38.47%	26.02%	26.22%	67.24%
ZR	FZRA	65	0.00%	0.63%	0.00%	0.00%	0.43%	0.00%	0.00%	0.00%	0.00%
RS	RASN	67	6.29%	0.00%	6.77%	14.17%	0.00%	0.14%	1.01%	0.95%	0.00%
S	SN	70	16.30%	22.61%	1.71%	7.09%	7.73%	16.01%	10.09%	10.27%	12.42%
IP	PL	75	0.58%	2.50%	0.00%	0.00%	0.01%	0.00%	0.25%	0.33%	0.00%
SG	SG	77	13.29%	0.00%	5.80%	4.49%	0.61%	0.00%	6.72%	6.14%	0.00%
IC	IC	78	0.12%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SP	GS	87	0.00%	0.00%	0.00%	0.00%	0.00%	3.94%	0.00%	0.00%	0.00%
A	GR	89	0.00%	0.00%	0.20%	0.11%	0.00%	1.05%	0.00%	0.00%	0.00%
unidentified			8.91%	0.05%	0.00%	0.00%	14.58%	0.00%	0.00%	0.00%	18.04%
liquid			54.51%	73.59%	82.18%	74.15%	74.38%	78.86%	81.92%	82.30%	69.54%
freezing			0.00%	1.26%	3.34%	0.00%	2.70%	0.00%	0.00%	0.00%	0.00%
solid			36.58%	25.11%	14.47%	25.85%	8.35%	21.14%	18.08%	17.70%	12.42%

Table 2 (a): Overview of several quantities indicating the agreement between the 1-minute precipitation type reported by a PWS and the FD12P during the evaluation period (a).

Quantity	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
correct type	61.5%	51.2%	52.2%	55.3%	50.1%	48.3%	48.8%	50.3%
correct class	87.8%	82.1%	84.2%	79.3%	90.0%	83.9%	84.2%	72.9%
correct y&n	98.2%	96.1%	90.4%	97.1%	95.3%	96.5%	96.7%	96.0%

Table 2 (b): Overview of several quantities indicating the agreement between the 1-minute precipitation type reported by a PWS and the FD12P during the evaluation period (b).

Quantity	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
correct type	54.3%	43.7%	45.8%	47.1%	45.9%	43.3%	43.1%	50.1%
correct class	83.8%	75.9%	80.1%	69.7%	84.8%	77.6%	77.7%	72.7%
correct y&n	97.4%	95.4%	93.3%	96.4%	95.5%	95.2%	95.3%	95.2%

Table 3 (a): POD, FAR and BIAS scores for the classes unidentified, liquid, and solid precipitation and precipitation detection of a PWS compared to the FD12P during the evaluation period (a). No freezing precipitation events were reported by the FD12P.

Score	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
POD detection	86.3%	62.7%	57.3%	92.6%	76.4%	92.9%	92.3%	62.9%
FAR	6.6%	1.6%	53.4%	21.8%	9.6%	25.9%	24.6%	5.2%
BIAS	0.924	0.637	1.229	1.185	0.845	1.253	1.225	0.663
POD unidentified	0.0%	0.0%	0.0%	5.6%	0.0%	0.0%	0.0%	11.0%
FAR	100.0%			97.3%		100.0%	100.0%	90.5%
BIAS	0.004	0.000	0.000	2.056	0.000	0.115	0.119	1.155
POD liquid	90.6%	66.9%	60.2%	96.9%	83.4%	97.5%	97.4%	61.8%
FAR	18.5%	18.4%	32.7%	30.6%	20.1%	38.8%	37.5%	17.2%
BIAS	1.111	0.82	0.894	1.396	1.044	1.592	1.56	0.746
POD solid	52.2%	24.7%	25.8%	22.3%	41.5%	40.9%	39.6%	15.9%
FAR	10.9%	6.8%	90.0%	1.7%	8.2%	25.3%	23.5%	36.9%
BIAS	0.586	0.265	2.586	0.226	0.452	0.547	0.518	0.252

Table 3 (b): POD, FAR and BIAS scores for the classes unidentified, liquid, and solid precipitation and precipitation detection of a PWS compared to the FD12P during the evaluation period (b). No freezing precipitation events were reported by the FD12P.

Score	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
POD detection	86.0%	65.1%	57.0%	88.8%	73.4%	89.8%	88.7%	58.3%
FAR	7.8%	1.8%	17.1%	17.5%	4.8%	24.3%	23.2%	3.6%
BIAS	0.932	0.663	0.687	1.077	0.771	1.186	1.155	0.605
POD unidentified	0.0%	0.0%	0.0%	5.9%	0.0%	0.0%	0.0%	12.5%
FAR	100.0%			96.6%				88.6%
BIAS	0.005	0.000	0.000	1.743	0.000	0.000	0.000	1.095
POD liquid	93.8%	74.1%	65.1%	96.8%	83.9%	97.9%	97.6%	59.0%
FAR	25.5%	25.9%	30.2%	34.4%	22.5%	45.1%	44.1%	13.3%
BIAS	1.259	1.00	0.934	1.475	1.083	1.782	1.745	0.68
POD solid	57.0%	24.7%	27.6%	24.1%	41.5%	44.6%	43.2%	16.6%
FAR	10.9%	5.5%	43.2%	1.6%	7.4%	23.9%	22.6%	37.8%
BIAS	0.640	0.262	0.487	0.245	0.448	0.586	0.559	0.267

Table 4 (a): The relative occurrence of the 1-minute precipitation type reported by the selected present weather sensors and scores for precipitation classes using a 0.02 mm/h threshold during the evaluation period (a).

Class / Score	FD12P	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
precipitation	7.4%	7.4%	6.1%	10.3%	6.5%	10.7%	9.4%	9.2%	7.2%
unidentified	4.4%	0.0%	0.0%	0.0%	2.0%	0.0%	0.5%	0.7%	13.7%
liquid	75.9%	91.5%	87.2%	52.9%	91.1%	87.1%	93.6%	93.6%	79.0%
solid	19.7%	7.8%	10.9%	47.1%	5.6%	12.9%	5.9%	5.8%	7.3%
POD detection		81.8%	70.5%	62.2%	72.6%	78.2%	93.3%	93.0%	69.3%
FAR		8.4%	4.1%	55.6%	8.7%	9.5%	16.1%	15.7%	8.2%
BIAS		0.892	0.734	1.401	0.795	0.864	1.112	1.103	0.755
POD liquid		85.3%	70.8%	60.4%	76.1%	80.6%	96.9%	96.8%	62.8%
FAR		19.1%	18.2%	33.4%	18.8%	18.1%	28.2%	27.6%	17.1%
BIAS		1.055	0.865	0.907	0.937	0.985	1.351	1.338	0.758
POD solid		40.9%	34.9%	35.1%	27.6%	49.1%	37.1%	36.3%	22.0%
FAR		5.0%	7.9%	90.2%	1.8%	9.3%	9.8%	9.4%	40.3%
BIAS		0.430	0.379	3.601	0.281	0.541	0.412	0.401	0.369

Table 4 (b): The relative occurrence of the 1-minute precipitation type reported by the selected present weather sensors and scores for precipitation classes using a 0.02 mm/h threshold during the evaluation period (b).

Class / Score	FD12P	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
precipitation	9.9%	8.9%	7.9%	7.8%	7.1%	9.8%	10.4%	10.3%	6.1%
unidentified	6.4%	0.0%	0.0%	0.0%	3.3%	0.0%	0.0%	0.0%	17.5%
liquid	62.2%	81.6%	82.2%	72.8%	80.3%	79.0%	86.4%	86.6%	69.8%
solid	31.4%	17.0%	15.1%	27.2%	13.4%	21.0%	13.6%	13.4%	12.7%
POD detection		80.6%	73.6%	64.3%	68.9%	76.9%	90.3%	89.8%	65.1%
FAR		10.3%	5.1%	18.8%	6.4%	5.3%	14.5%	14.2%	7.9%
BIAS		0.898	0.776	0.792	0.736	0.812	1.057	1.045	0.707
POD liquid		87.8%	76.0%	64.6%	75.3%	80.7%	96.7%	96.5%	59.9%
FAR		25.4%	25.8%	30.1%	20.9%	19.8%	34.1%	33.7%	13.6%
BIAS		1.177	1.025	0.924	0.952	1.007	1.467	1.455	0.694
POD solid		46.3%	34.9%	39.0%	30.9%	49.1%	42.0%	41.1%	24.0%
FAR		5.0%	6.7%	43.5%	1.8%	8.5%	8.0%	7.7%	41.3%
BIAS		0.487	0.374	0.691	0.314	0.536	0.456	0.445	0.409

4. PRECIPITATION INTENSITY

In this section an overview of the results for the 1-minute precipitation intensity reported by the PWSs under evaluation is given. Here the KNMI precipitation gauge serves as the reference. Only situations where either the PWS under consideration or the KNMI gauge or both report precipitation are considered. **Figure 2** gives the relative occurrence of the differences between the 1-minute averaged precipitation intensity of a PWS and the KNMI gauge using a bin width of 1 mm/h.

Table 5 gives some key numbers of these differences and the total precipitation sum obtained by each PWS and the number of precipitation events, and the percentage of precipitation events where PWS and KNMI gauge agree within the WMO limits (± 0.1 mm/h for intensities between 0.2 and 2 mm/h and ± 5 % for intensities exceeding 2 mm/h). The 1-minute precipitation intensity reported by the PWSs can also directly be compared to the 1-minute precipitation intensity of the KNMI gauge. Here again only cases when either sensor reports precipitation are considered. The agreement are expressed in terms of the slope of the linear regression and the correlation coefficient.

Figure 3 shows density plots of the precipitation intensity reported by each PWS versus the KNMI gauge.

Table 6 gives the POD, FAR and BIAS scores for the 1-minute precipitation intensity of a PWS versus the KNMI gauge using the reporting limits for light precipitation (intensity below 2.5 mm/h); moderate precipitation (intensity between 2.5 and 10 mm/h); heavy precipitation (intensity between 10 and 50 mm/h) and violent precipitation (intensity equal to or exceeding 50 mm/h). Furthermore, precipitation detection without (intensity exceeding zero) and with threshold (intensity equal to or exceeding 0.03 mm/h) are considered.

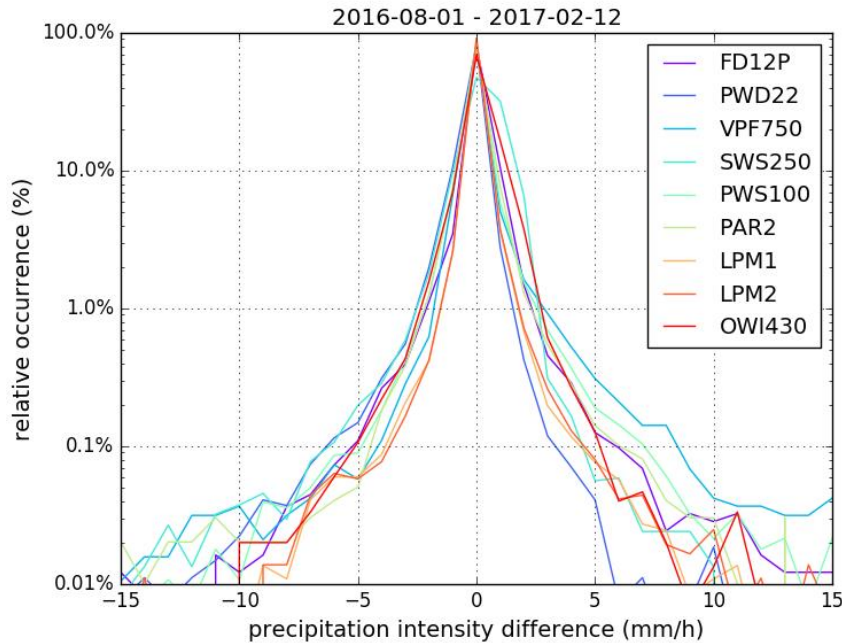


Figure 2 (a): The relative occurrence of the differences between the 1-minute averaged precipitation intensity of a PWS and the KNMI gauge using a bin width of 1 mm/h during the evaluation period (a).

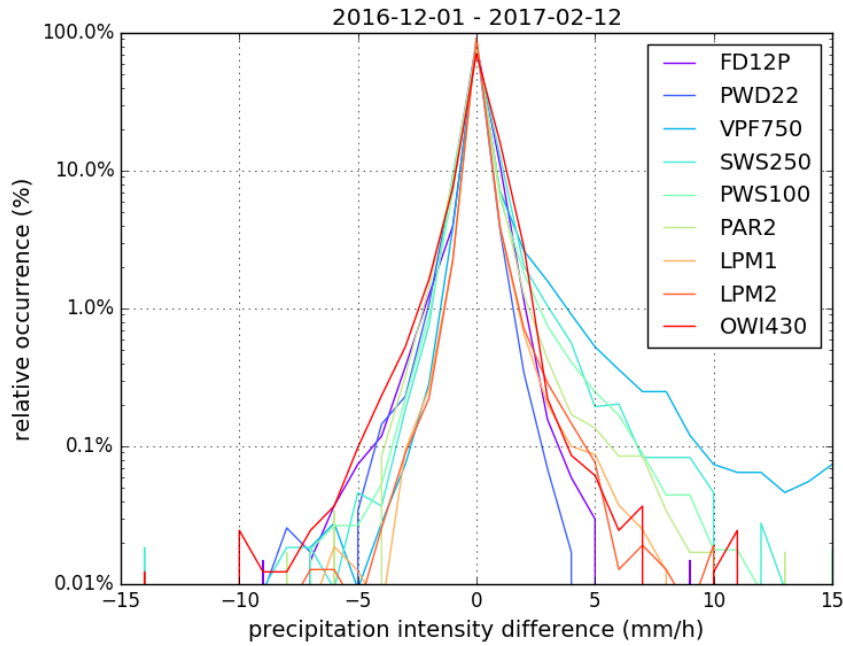


Figure 2 (b): The relative occurrence of the differences between the 1-minute averaged precipitation intensity of a PWS and the KNMI gauge using a bin width of 1 mm/h during the evaluation period (b).

Table 5 (a): Statistics on the differences between the 1-minute averaged precipitation intensity of a PWS and the KNMI gauge (in mm/h) during evaluation period (a). KNMI precipitation gauge total sum of 314.2 mm with 20866 precipitation events.

	FD12P	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
sum (mm)	304.4	232.8	220.9	499.9	304.0	132.1	338.7	344.6	167.9
# precipitation	21691	22123	15362	28934	23102	8090	34066	33538	10715
# either	24621	26936	19030	37340	27913	9886	36637	36166	14996
average	0.121	-0.179	0.060	0.297	0.035	0.028	0.044	0.050	0.150
std. dev.	1.193	0.950	1.545	1.418	2.331	1.350	1.023	1.053	1.019
WMO	44.0%	37.4%	42.3%	17.8%	42.8%	33.6%	59.8%	59.9%	24.3%
slope	0.95	0.69	0.53	0.33	0.81	0.80	0.97	0.96	0.82
corr. coeff.	0.68	0.77	0.43	0.30	0.29	0.57	0.72	0.71	0.44

Table 5 (b): Statistics on the differences between the 1-minute averaged precipitation intensity of a PWS and the KNMI gauge (in mm/h) during evaluation period (b). KNMI precipitation gauge total sum of 96.2 mm with 8064 precipitation events.

	FD12P	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
sum (mm)	115.1	81.7	149.4	118.1	110.3	70.7	111.6	112.2	83.2
# precipitation	12558	10423	9047	8464	9804	4889	15279	14907	5997
# either	13495	11728	10824	10841	11275	5885	16022	15676	8149
average	0.084	-0.075	0.295	0.121	0.11	0.022	0.057	0.061	0.086
std. dev.	0.663	0.548	1.439	1.013	2.878	0.938	0.527	0.54	0.874
WMO	46.6%	39.8%	39.4%	27.4%	42.9%	32.4%	62.6%	62.4%	25.3%
slope	0.78	0.65	0.95	0.63	1.08	0.81	0.94	0.96	0.58
corr. coeff.	0.54	0.65	0.28	0.29	0.09	0.4	0.68	0.69	0.34

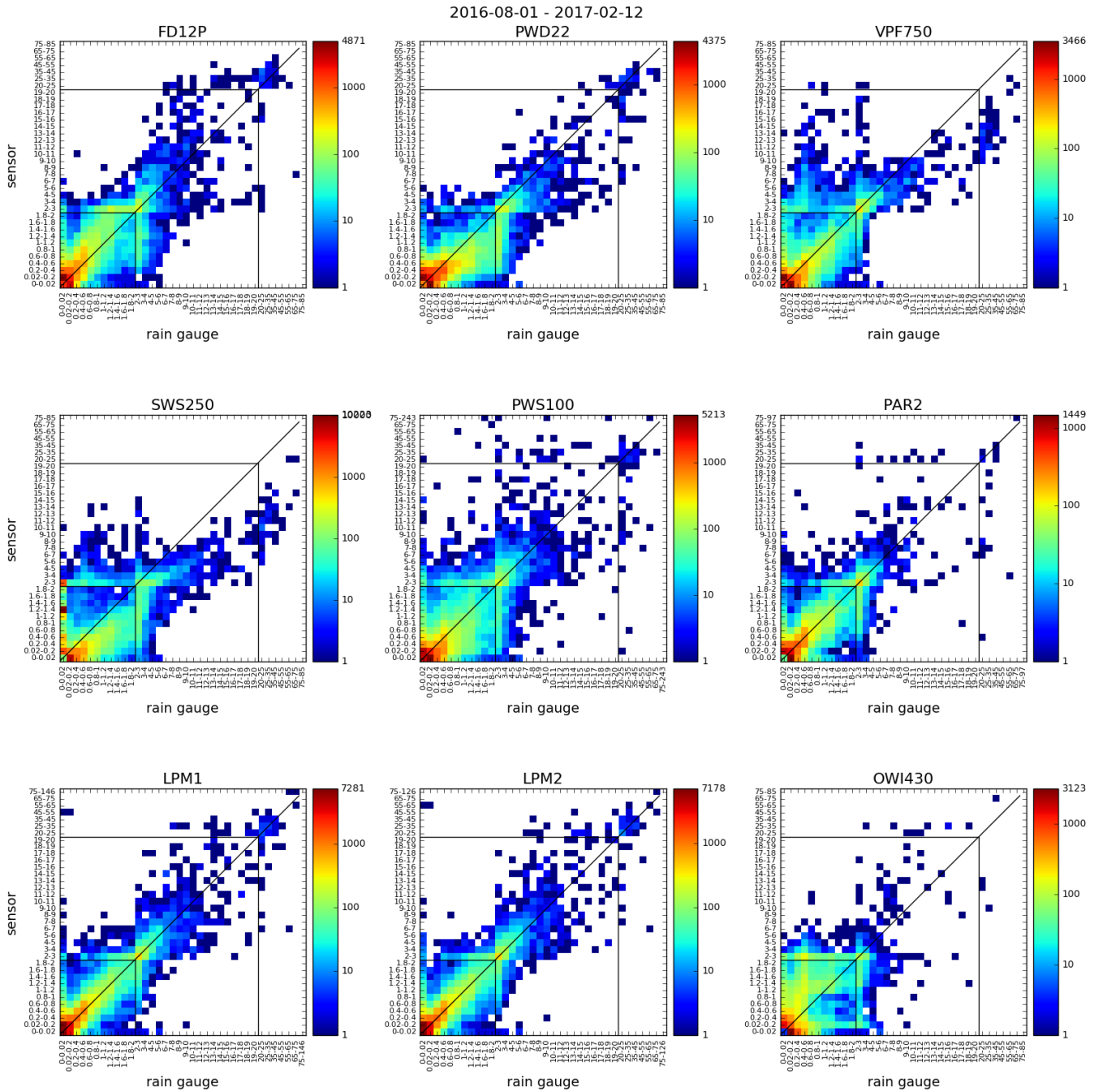


Figure 3 (a): Density plots of the 1-minute precipitation intensity reported by a PWS versus the KNMI gauge during evaluation period (a). The first two bins are 0-0.02 mm/h and 0.02-0.2 mm/h, the succeeding bin width is 0.2 up to 2 mm/h, 1 up to 20 mm/h, 5 up to 75 mm/h, and the final bin contains the higher intensities. Only precipitation events for which either the PWS or the KNMI gauge reported a non-zero precipitation intensity are included.

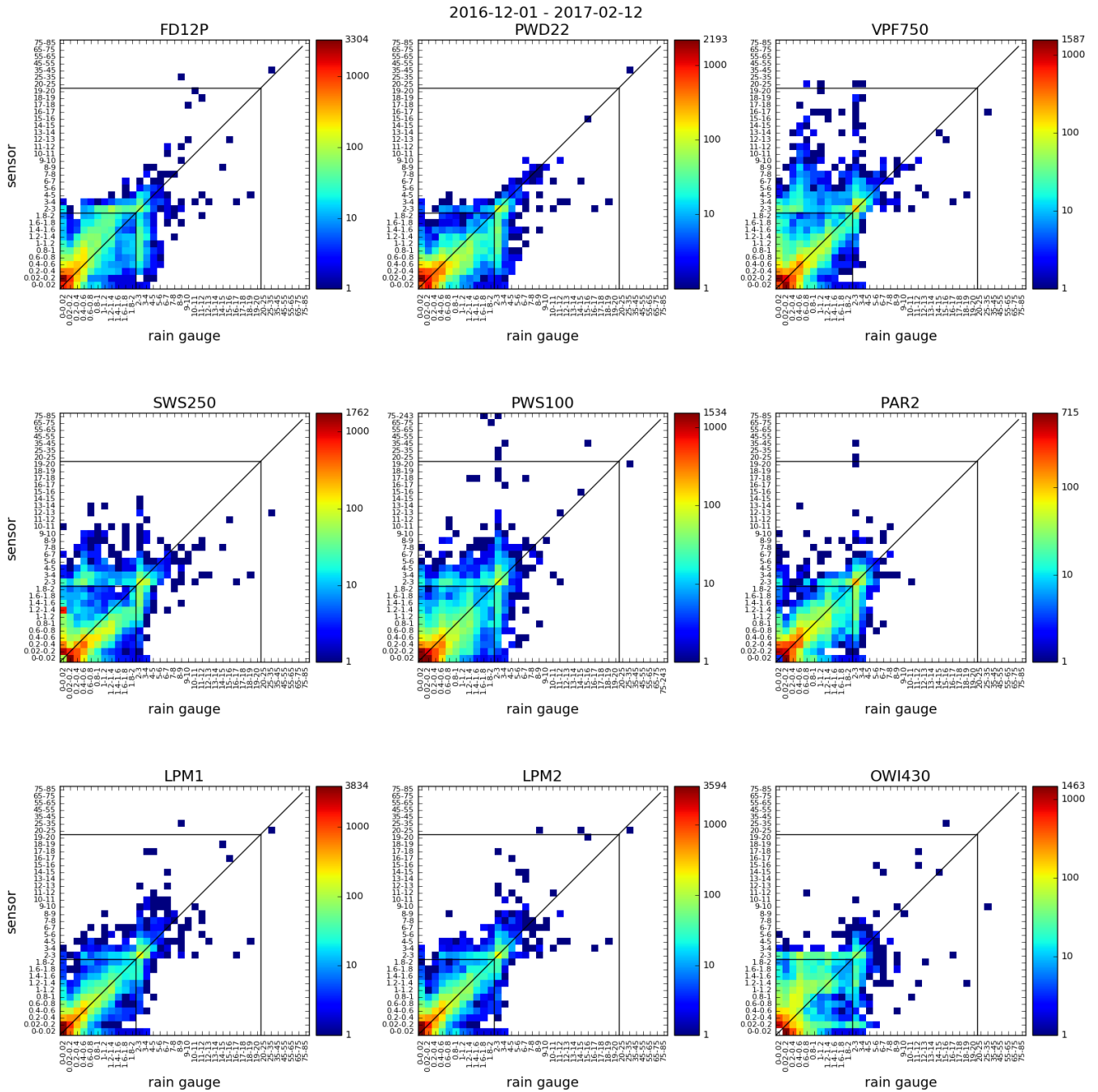


Figure 3 (b): Density plots of the 1-minute precipitation intensity reported by a PWS versus the KNMI rain gauge during evaluation period (b). The first two bins are 0-0.02 mm/h and 0.02-0.2 mm/h, the succeeding bin width is 0.2 up to 2 mm/h, 1 up to 20 mm/h, 5 up to 75 mm/h, and the final bin contains the higher intensities. Only precipitation events for which either the PWS or the KNMI gauge reported a non-zero precipitation intensity are included.

Table 6 (a): POD, FAR and BIAS scores for precipitation detection (without and with threshold) and for precipitation intensity classes corresponding to light, moderate, heavy and violent rain obtained by each PWS versus KNMI precipitation gauge during evaluation period (a).

Score	FD12P	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
POD 0.0005-9999	82.2%	76.3%	72.1%	59.0%	75.4%	78.3%	86.9%	86.7%	63.9%
FAR	37.1%	28.2%	37.8%	57.7%	33.9%	19.7%	46.8%	45.8%	27.2%
BIAS	1.307	1.063	1.159	1.393	1.141	0.974	1.632	1.601	0.878
POD 0.03-9999	79.9%	73.5%	69.0%	57.9%	63.6%	77.3%	81.4%	81.2%	63.7%
FAR	30.0%	25.4%	33.2%	58.0%	24.6%	19.0%	30.6%	30.3%	27.1%
BIAS	1.141	0.985	1.033	1.377	0.843	0.955	1.173	1.164	0.874
POD 0.03-2.5	75.0%	70.9%	61.8%	52.4%	57.7%	72.8%	78.3%	78.0%	59.9%
FAR	34.8%	30.4%	38.2%	63.4%	29.6%	23.8%	34.0%	33.7%	31.9%
BIAS	1.150	1.018	1.000	1.432	0.819	0.956	1.186	1.176	0.879
POD 2.5-10	49.6%	44.6%	73.9%	36.1%	58.8%	53.1%	72.6%	72.4%	16.3%
FAR	49.8%	22.3%	51.8%	51.0%	49.2%	43.7%	28.5%	28.4%	77.7%
BIAS	0.989	0.574	1.532	0.737	1.157	0.943	1.015	1.011	0.728
POD 10-50	69.6%	48.7%	49.0%	25.0%	47.8%	52.3%	62.7%	61.9%	58.3%
FAR	48.6%	19.6%	55.7%	31.0%	61.1%	51.1%	38.9%	41.8%	65.0%
BIAS	1.356	0.606	1.106	0.362	1.228	1.068	1.025	1.062	1.667
POD 50-9999	0.0%	0.0%	0.0%	0.0%	33.3%	50.0%	75.0%	50.0%	0.0%
FAR	100.0%	100.0%	0.0%	0.0%	87.5%	0.0%	25.0%	75.0%	0.0%
BIAS	1.000	0.250	0.000	0.000	2.667	0.500	1.000	2.000	0.000

Table 6 (b): POD, FAR and BIAS scores for precipitation detection (without and with threshold) and for precipitation intensity classes corresponding to light, moderate, and heavy rain obtained by each PWS versus KNMI precipitation gauge during evaluation period (b). No violent rain events (>50 mm/h) were reported.

Score	FD12P	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
POD 0.0005-9999	88.4%	83.8%	77.9%	70.5%	81.3%	80.1%	90.8%	90.5%	66.6%
FAR	43.2%	35.2%	30.6%	32.8%	34.8%	17.8%	52.1%	51.1%	28.3%
BIAS	1.557	1.293	1.123	1.050	1.246	0.975	1.895	1.849	0.930
POD 0.03-9999	85.9%	81.1%	75.6%	69.4%	69.7%	80.1%	86.2%	86.1%	66.3%
FAR	34.1%	30.8%	27.5%	32.6%	23.5%	17.7%	32.7%	32.2%	28.1%
BIAS	1.303	1.171	1.042	1.031	0.911	0.973	1.282	1.271	0.922
POD 0.03-2.5	82.4%	79.5%	66.6%	62.7%	64.0%	75.8%	83.3%	83.0%	63.3%
FAR	38.0%	34.2%	31.6%	37.8%	27.4%	22.7%	35.4%	34.9%	32.7%
BIAS	1.329	1.208	0.974	1.008	0.882	0.981	1.289	1.276	0.940
POD 2.5-10	27.0%	36.1%	75.9%	45.0%	55.3%	43.8%	70.0%	69.5%	23.5%
FAR	67.5%	27.9%	65.4%	68.9%	62.1%	49.2%	39.0%	40.0%	57.4%
BIAS	0.830	0.501	2.194	1.445	1.458	0.862	1.147	1.160	0.551
POD 10-50	36.4%	18.2%	27.3%	18.2%	66.7%	0.0%	27.3%	36.4%	40.0%
FAR	63.6%	0.0%	95.2%	87.5%	81.8%	100.0%	80.0%	75.0%	50.0%
BIAS	1.000	0.182	5.636	1.455	3.667	7.000	1.364	1.455	0.800

5. GENERAL OVERVIEW OF THE RESULTS FOR VISIBILITY

In this section, an overview of the results for the 1-minute visibility (Meteorological Optical Range, MOR) reported by the PWSs under evaluation is given. Here the FD12P serves as the “reference” against which the other sensors are compared since it covers a large visibility range, while the Vaisala Mitras transmissometer (TMM) can only serve as the reference for visibility values up to 1.5 km.

Figure 4 shows the frequency distribution of the 1-minute averaged MOR. **Figure 5** gives the relative occurrence of the difference between the 1-minute averaged MOR of a PWS and the FD12P using a bin width of 1 km. **Table 7** gives some key numbers of these differences, agreement expressed in terms of the slope of the linear regression and the correlation coefficient. Also the percentage of cases in which the PWS and FD12P are in agreement within the WMO limits (± 50 m for MOR up to 600 m; ± 10 % for MOR between 600 and 1500 m and ± 20 % for MOR above 1500 m) is given, replacing MOR values above 20 and 50 km to 20 and 50 km, respectively, to facilitate the intercomparison between PWSs with different MOR ranges.

For the “WMO 0-1.5 km” and “ICAO 0-1.5 km” entries the PWSs are compared with the TMM, selecting only events for which the TMM reported a MOR up to 1.5 km, and for which events with precipitation or inhomogeneous conditions (standard deviation of the MOR in 10-minute interval more than 10%) are filtered out. The ICAO RVR limits are ± 10 m for MOR up to 400 m; ± 25 m for MOR between 400 and 800 m; ± 10 % for MOR above 800 m.

Figure 6 shows the density plots of the MOR reported by each PWS versus the FD12P. **Table 8** give the agreement of specific visibility classes in terms of POD, FAR and BIAS.

Finally, in **Figure 7** boxplots provide a detailed comparison between the PWSs and the TMM for MOR up to 1.5 km. Here the data is processed to 10-minute averages, filtering out precipitation events, inhomogeneous conditions (standard deviation of the MOR in 10 minutes interval more than 10%), and requiring the availability of at least eight 1-minute valid data points with the 10-minute interval.

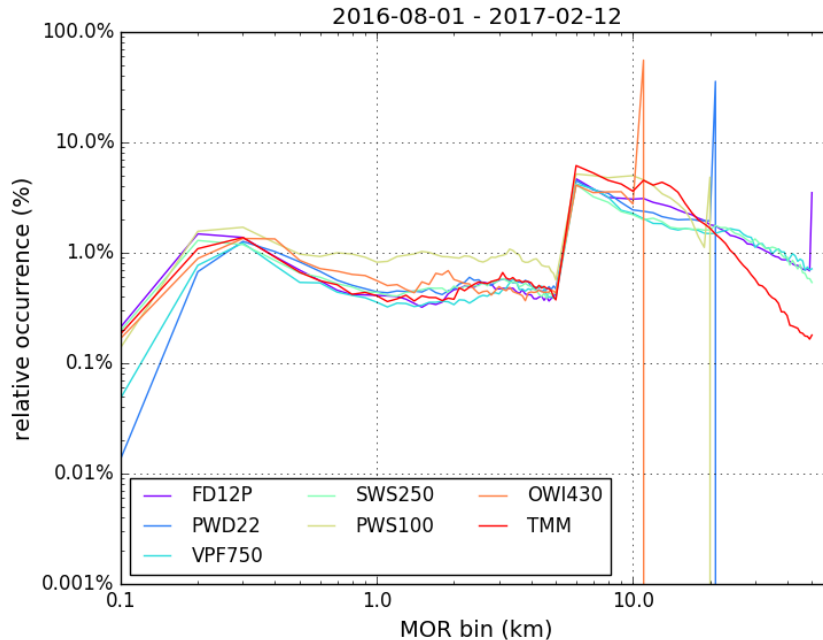


Figure 4 (a): The frequency distribution of the 1-minute averaged MOR reported by the PWSs and TMM using a bin width of 100 m for MOR up to 5 km and 1000 m for higher MOR values during evaluation period (a).

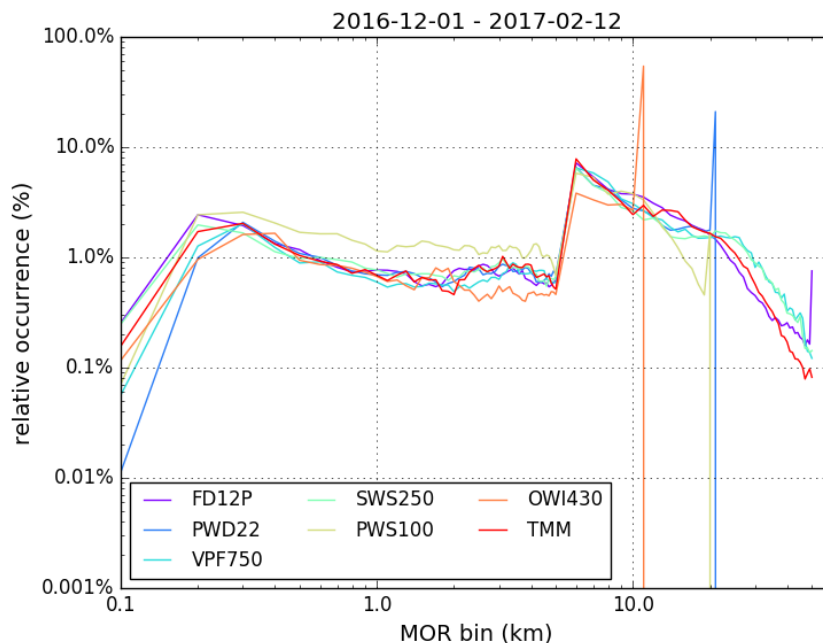


Figure 4 (b): The frequency distribution of the 1-minute averaged MOR reported by the PWSs and TMM using a bin width of 100 m for MOR up to 5 km and 1000 m for higher MOR values during evaluation period (b).

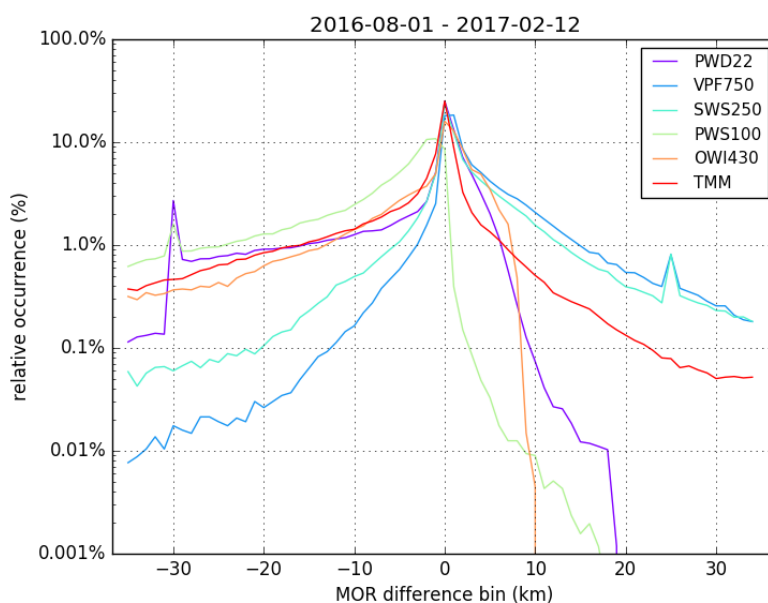


Figure 5 (a): The relative occurrence of the differences between the 1-minute averaged MOR of a PWS and the FD12P using a bin width of 1 km, for the evaluation period (a).

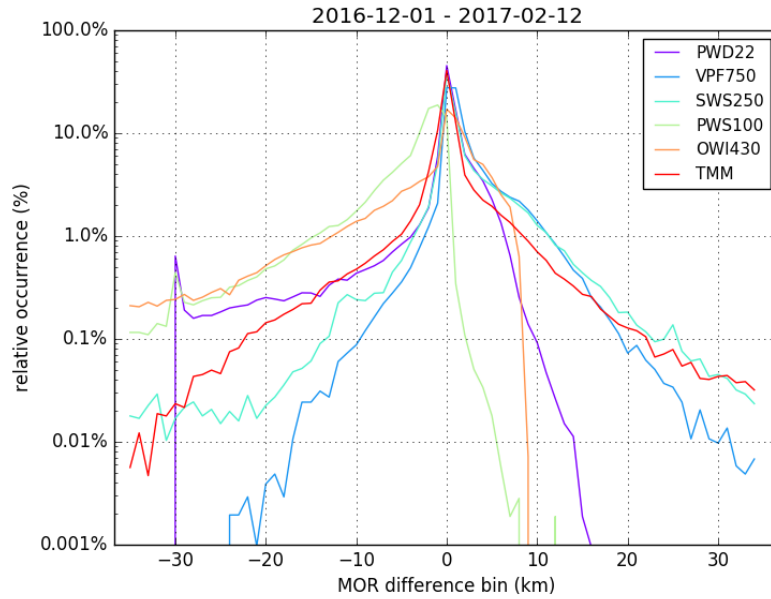


Figure 5 (b): The relative occurrence of the differences between the 1-minute averaged MOR of a PWS and the FD12P using a bin width of 1 km, for the evaluation period (b).

Table 7 (a): Statistics on the differences between the 1-minute averaged MOR of a PWS and the FD12P (in m) for evaluation period (a). The TMM is used as reference for the WMO and ICAO agreement percentage for visibility between 0 and 1.5 km.

	FD12P	PWD22	VPF750	SWS250	PWS100	OWI430
# events	256549	253602	182483	253582	255448	74651
average		-4915	4986	3338	-9666	3637
std. dev.		10320	8608	10518	10266	13348
skew		-1.589	1.662	0.876	-1.252	-0.991
slope		0.374	1.233	1.103	0.314	0.058
corr. coeff.		0.514	0.834	0.695	0.668	0.039
WMO (cut-off 50km)		42.0%	42.0%	48.0%	6.0%	14.0%
WMO (cut-off 20km)		65.0%	63.0%	68.0%	14.0%	36.0%
WMO 0 - 1.5km	48.0%	74.6%	61.3%	75.6%	43.2%	17.4%
ICAO 0 - 1.5km	11.3%	30.3%	21.2%	42.9%	10.8%	5.1%

Table 7 (b): Statistics on the differences between the 1-minute averaged MOR of a PWS and the FD12P (in m) for evaluation period (b). The TMM is used as reference for the WMO and ICAO agreement percentage for visibility between 0 and 1.5 km.

	FD12P	PWD22	VPF750	SWS250	PWS100	OWI430
# events	106520	106511	102864	106484	106299	49819
average		-616	2265	1860	-4995	8856
std. dev.		5343	3964	5829	6731	9691
skew		-3.311	1.838	0.226	-2.573	-1.646
slope		0.617	1.123	1.112	0.376	0.069
corr. coeff.		0.734	0.899	0.791	0.695	0.031
WMO (cut-off 50km)		60.1%	42.6%	53.0%	10.0%	12.2%
WMO (cut-off 20km)		68.4%	52.0%	63.3%	13.1%	19.6%
WMO 0 - 1.5km	46.4%	79.4%	61.3%	73.9%	41.3%	17.0%
ICAO 0 - 1.5km	8.9%	32.8%	21.2%	41.8%	9.0%	4.9%

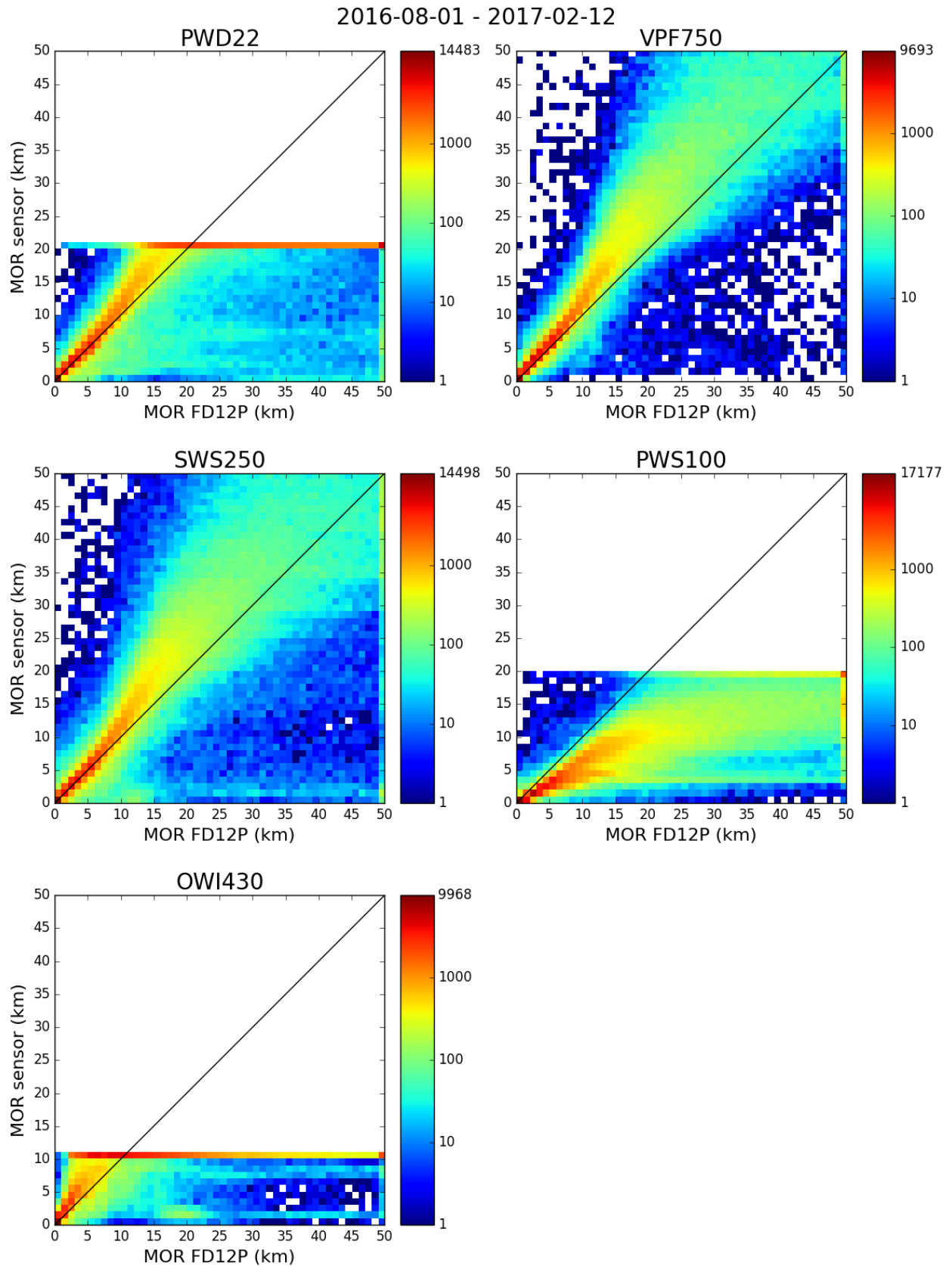


Figure 6 (a): Density plots of the 1-minute MOR reported by each PWS versus FD12P for the evaluation period (a). The bin width is 1 km for the full range.

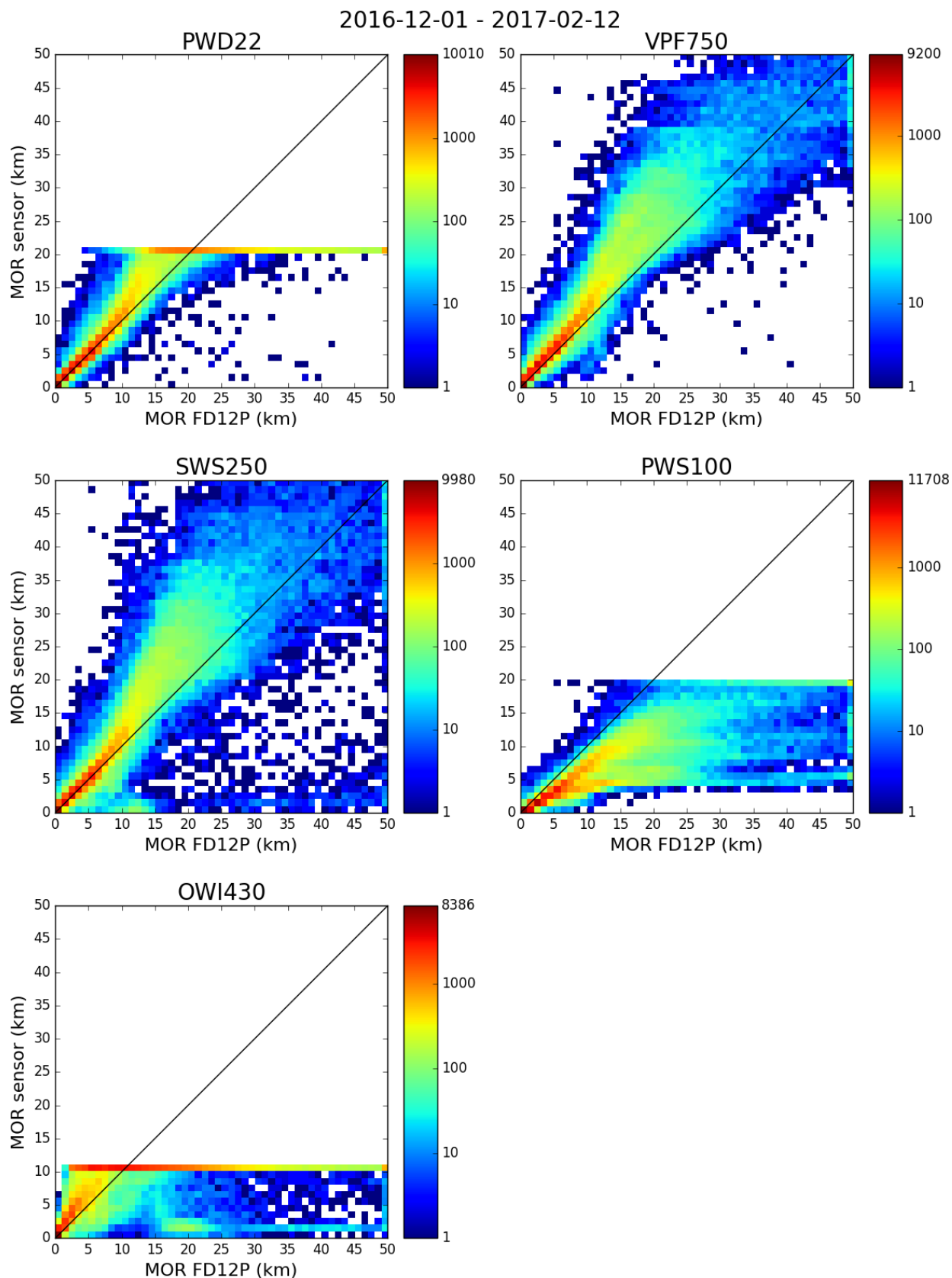


Figure 6 (b): Density plots of the 1-minute MOR reported by each PWS versus FD12P for the evaluation period (b). The bin width is 1 km for the full range.

Table 8 (a): POD, FAR and BIAS scores for MOR in various visibility classes using the TMM as reference when class limits are below 1.5 km and the FD12P otherwise, for the evaluation period (a).

Score	FD12P	PWD22	VPF750	SWS250	PWS100	OWI430
POD 0-800	95.9%	88.0%	84.7%	88.3%	95.7%	79.0%
FAR	10.5%	12.5%	3.1%	15.8%	36.0%	9.2%
BIAS	1.072	1.005	0.874	1.049	1.495	0.87
POD 800-1500	66.4%	65.8%	53.7%	56.9%	18.4%	36.5%
FAR	34.2%	42.6%	34.9%	49.0%	92.2%	60.7%
BIAS	1.009	1.147	0.825	1.116	2.349	0.929
POD 1500-3000		65.1%	48.6%	64.7%	28.6%	24.5%
FAR		39.6%	40.8%	38.5%	85.3%	67.2%
BIAS		1.079	0.821	1.052	1.947	0.746
POD 3000-5000		66.5%	60.7%	66.1%	11.3%	20.0%
FAR		45.1%	43.0%	40.9%	94.6%	75.2%
BIAS		1.21	1.067	1.119	2.081	0.808
POD 5000-8000		63.8%	64.3%	62.2%	8.3%	19.9%
FAR		36.9%	32.3%	30.1%	93.6%	72.0%
BIAS		1.011	0.951	0.89	1.302	0.708
POD 8000-999999		91.6%	98.5%	94.9%	61.3%	89.5%
FAR		4.4%	5.9%	4.6%	0.3%	27.2%
BIAS		0.959	1.047	0.995	0.615	1.228
POD 0-1000	95.8%	88.6%	84.4%	88.0%	96.1%	80.2%
FAR	9.9%	12.9%	2.7%	16.2%	38.7%	9.7%
BIAS	1.063	1.018	0.867	1.051	1.568	0.888

Table 8 (b): POD, FAR and BIAS scores for MOR in various visibility classes using the TMM as reference when class limits are below 1.5 km and the FD12P otherwise, for the evaluation period (b).

Score	FD12P	PWD22	VPF750	SWS250	PWS100	OWI430
POD 0-800	98.0%	90.7%	85.3%	89.8%	98.2%	78.1%
FAR	10.9%	2.7%	2.1%	11.2%	36.2%	5.7%
BIAS	1.099	0.932	0.871	1.011	1.539	0.828
POD 800-1500	72.7%	79.9%	55.4%	65.5%	16.3%	36.8%
FAR	28.9%	22.7%	31.9%	38.4%	91.1%	60.4%
BIAS	1.023	1.033	0.814	1.062	1.834	0.928
POD 1500-3000		73.5%	47.8%	70.1%	32.2%	23.0%
FAR		22.8%	38.4%	31.1%	80.7%	70.7%
BIAS		0.952	0.776	1.017	1.673	0.783
POD 3000-5000		79.5%	62.8%	73.5%	13.5%	18.7%
FAR		29.3%	42.6%	35.2%	92.1%	77.1%
BIAS		1.124	1.094	1.135	1.706	0.814
POD 5000-8000		76.2%	68.9%	68.8%	10.6%	19.2%
FAR		16.4%	30.7%	22.4%	88.1%	69.5%
BIAS		0.911	0.995	0.886	0.889	0.631
POD 8000-999999		98.4%	98.5%	94.3%	50.5%	90.1%
FAR		5.5%	10.7%	6.9%	0.1%	30.0%
BIAS		1.041	1.103	1.013	0.505	1.288
POD 0-1000	97.9%	91.3%	85.2%	90.0%	98.4%	79.3%
FAR	10.2%	2.4%	1.6%	11.8%	36.9%	6.5%
BIAS	1.09	0.936	0.865	1.02	1.56	0.849

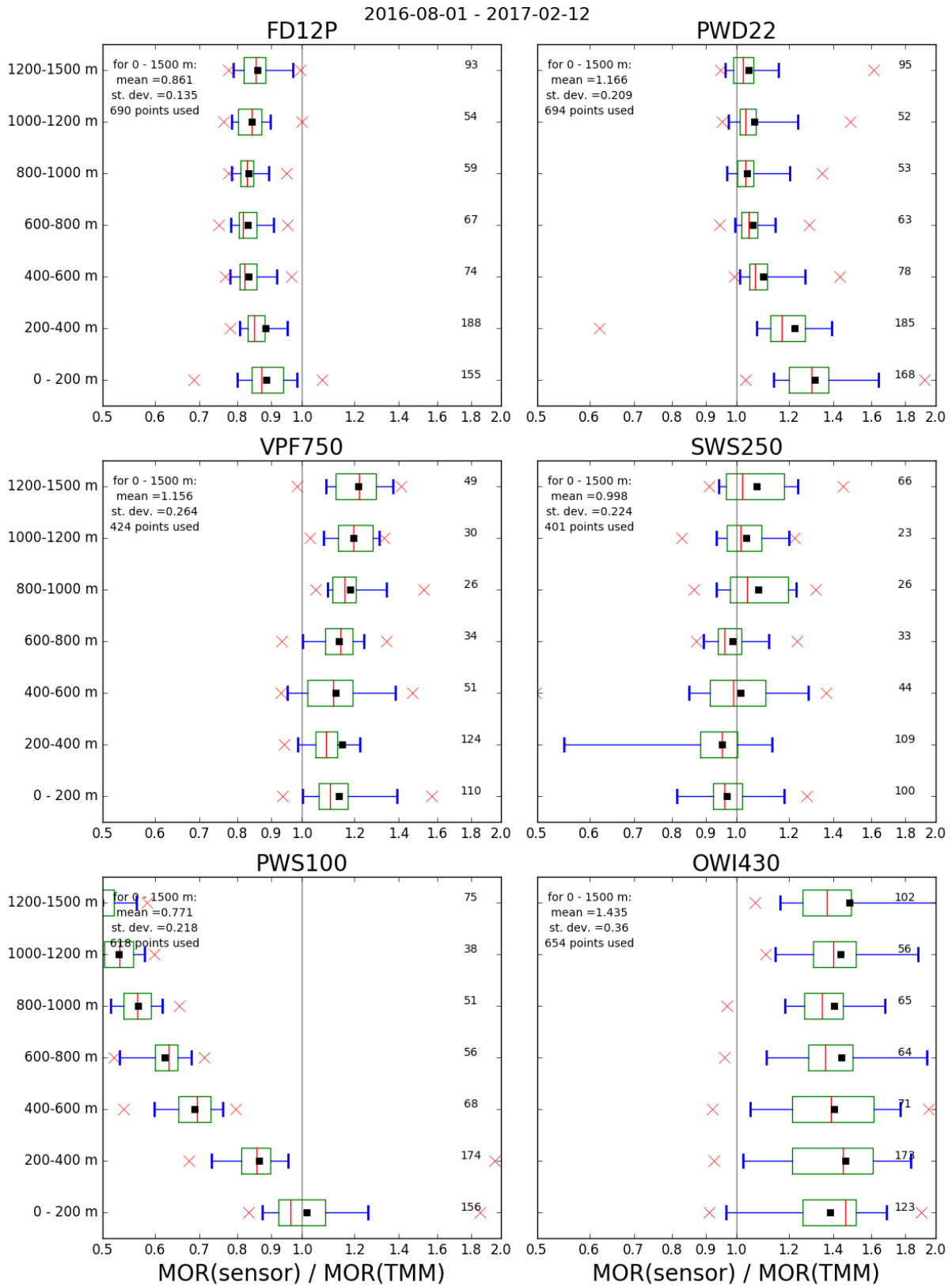


Figure 7 (a): Boxplots of the ratio between the reported MOR of the PWSs and the TMM for the evaluation period (a). Here the data is compiled to 10-minute averages, filtering out precipitation events, inhomogeneous conditions (standard deviation of the MOR in 10 minutes interval more than 10%), and requiring the availability of at each 8 1-minute valid data points with the 10-minute interval. The number of 10-minute data for each MOR interval is indicated on the right. Black square are the mean, the red stripe the median, the green box give the 25-75% and the blue caps give the 5-95% of the data, and the red crosses give the minimum and maximum.

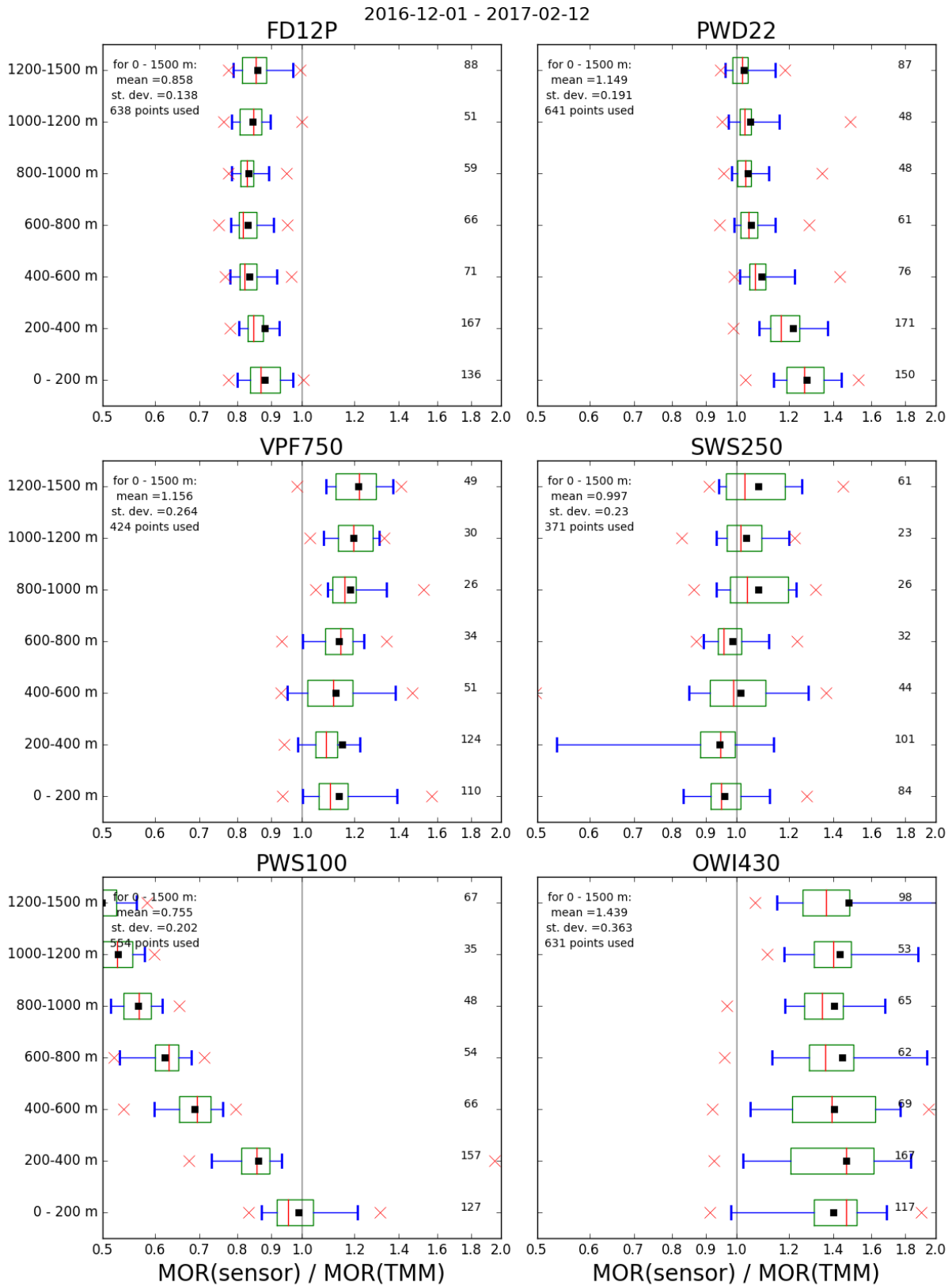


Figure 7 (b): Boxplots of the ratio between the reported MOR of the PWSs and the TMM for the evaluation period (b). Here the data is compiled to 10-minute averages, filtering out precipitation events, inhomogeneous conditions (standard deviation of the MOR in 10 minutes interval more than 10%), and requiring the availability of at each 8 1-minute valid data points with the 10-minute interval. The number of 10-minute data for each MOR interval is indicated on the right. Black square are the mean, the red stripe the median, the green box give the 25-75% and the blue caps give the 5-95% of the data, and the red crosses give the minimum and maximum.

6. TEMPERATURE

In this section an overview of the results for the 1-minute temperature reported by the PWSs under evaluation is given. The temperature obtained with the operational temperature sensor of the AWS (at 1.5 m and in a radiation screen) is used as the reference. The frequency distribution of the temperatures obtained by the PWSs and AWS is shown in **Figure 8** using a bin width of 1 °C, while the relative occurrence of the differences is given in **Figure 9**, also using a bin width of 1 °C. **Table 9** gives some key numbers of these differences, including the percentage of cases in which the agreement is according to the WMO requirement of ± 1 °C. Finally, in **Table 10** the POD, FAR and BIAS scores for temperatures above and temperatures below zero are given.

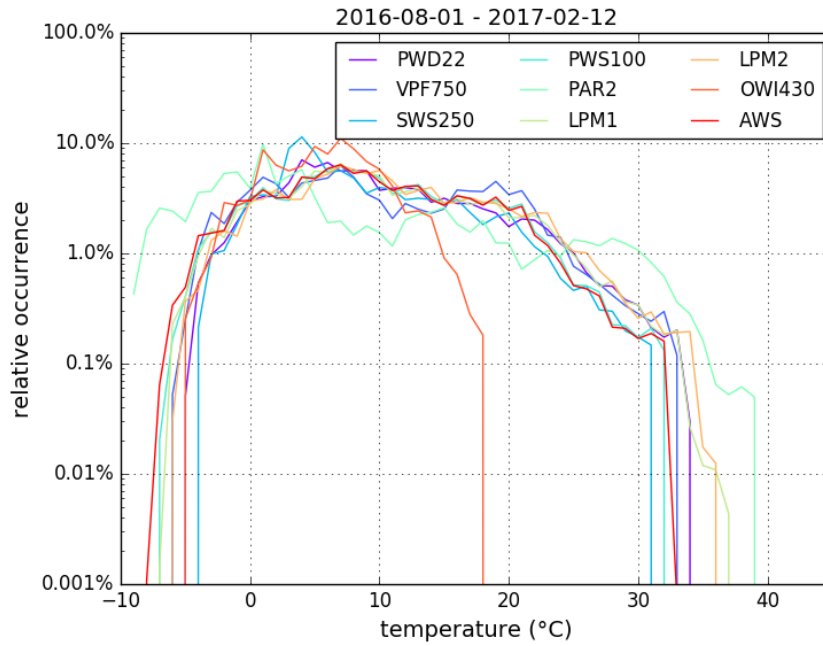


Figure 8 (a): The frequency distribution of the 1-minute averaged temperature reported by the PWSs and AWS using a using a bin width of 1 °C for the evaluation period (a).

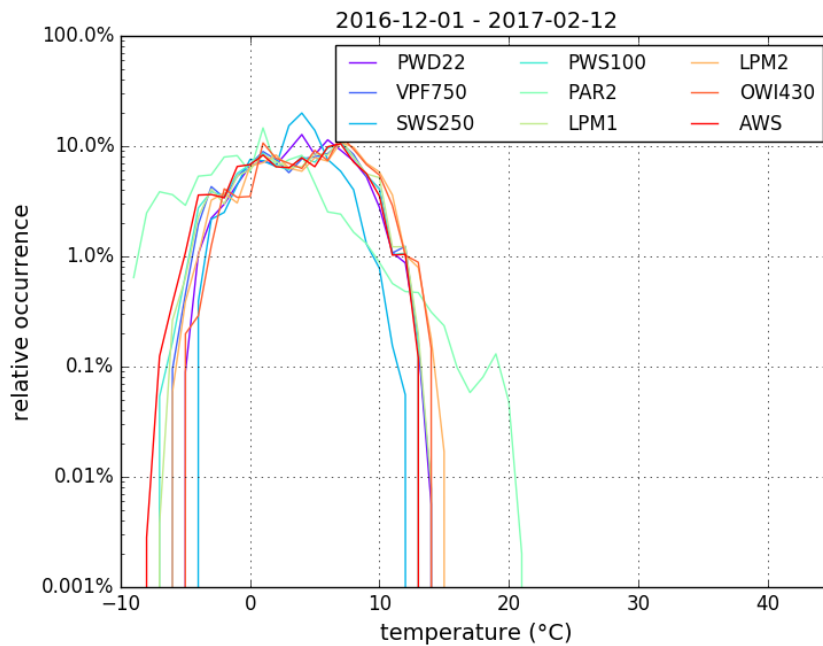


Figure 8 (b): The frequency distribution of the 1-minute averaged temperature reported by the PWSs and AWS using a using a bin width of 1 °C for the evaluation period (b).

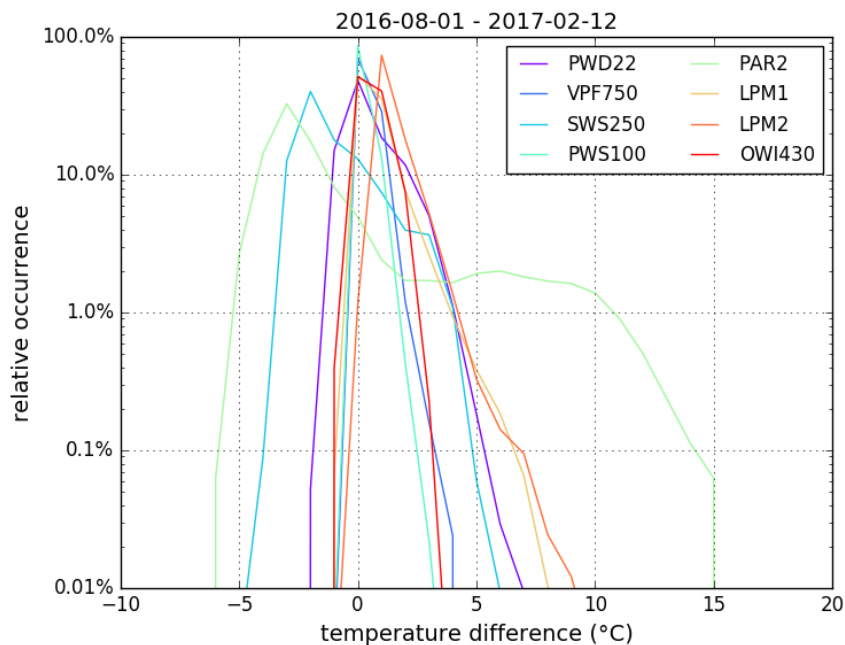


Figure 9 (a): The relative occurrence of the differences between the 1-minute averaged temperature of a PWS and the AWS using a bin width of 1 °C for evaluation period (a).

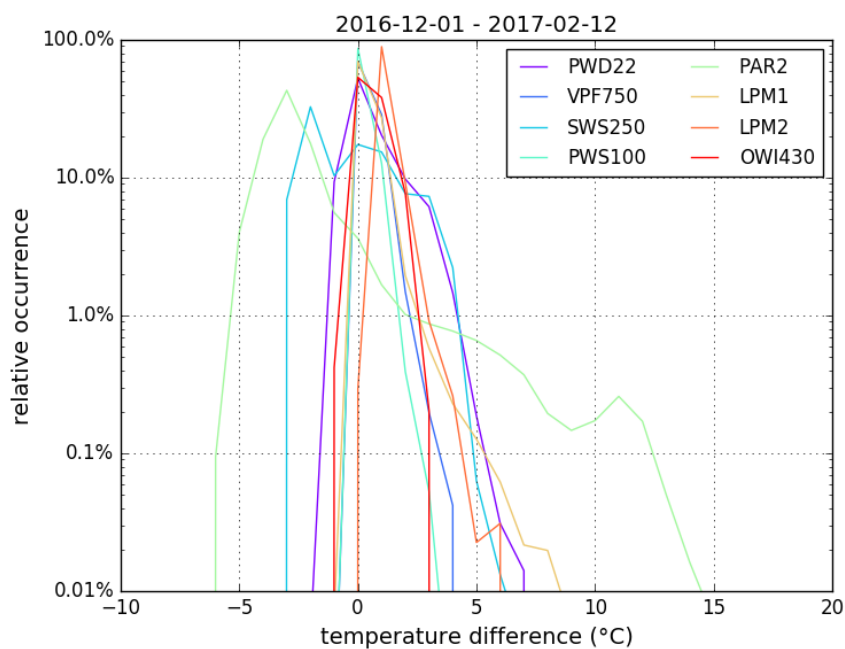


Figure 9 (b): The relative occurrence of the differences between the 1-minute averaged temperature of a PWS and the AWS using a bin width of 1 °C for evaluation period (b).

Table 9 (a): Statistics on the differences between the 1-minute averaged temperature of a PWS and the AWS (in °C) for the evaluation period (a).

	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
#	278231	187820	278194	279835	74642	276544	280729	147905
average	0.429	0.404	-1.106	0.244	-1.014	0.683	1.280	0.501
std. dev.	1.092	0.354	1.582	0.269	3.833	0.806	0.736	0.577
skew	1.114	-2.446	1.172	2.220	1.796	2.760	2.649	0.687
WMO $\pm 1^\circ\text{C}$	73.6%	94.9%	25.4%	97.8%	9.9%	81.1%	47.8%	82.8%
slope	0.988	0.992	0.889	0.991	1.295	1.039	1.038	0.962
correlation	0.979	0.998	0.960	0.999	0.917	0.991	0.992	0.983

Table 9 (b): Statistics on the differences between the 1-minute averaged temperature of a PWS and the AWS (in °C) for the evaluation period (b).

	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
#	106498	102851	106471	106286	49806	106494	106494	97833
average	0.515	0.442	-0.395	0.259	-2.434	0.431	1.042	0.481
std. dev.	1.075	0.343	1.824	0.251	2.206	0.510	0.403	0.582
skew	1.269	2.551	0.530	2.954	3.186	4.943	2.994	0.725
WMO $\pm 1^\circ\text{C}$	75.5%	93.7%	32.6%	98.1%	7.4%	92.9%	61.3%	83.1%
slope	0.827	0.963	0.625	0.975	1.088	0.978	0.984	0.928
correlation	0.946	0.994	0.870	0.997	0.783	0.985	0.990	0.982

Table 10 (a): Overview of several quantities indicating the agreement between the 1-minute temperature reported by PWS and AWS, and the POD, FAR and BIAS scores for temperature above and below zero °C for evaluation period (a).

	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
POD 0-98	100.0%	100.0%	99.8%	100.0%	86.3%	100.0%	100.0%	100.0%
FAR	4.3%	2.5%	4.7%	1.1%	1.8%	2.0%	3.6%	7.8%
BIAS	1.044	1.026	1.048	1.011	0.879	1.021	1.038	1.084
POD -98+0	66.2%	84.7%	62.3%	91.4%	94.3%	84.5%	71.0%	59.8%
FAR	0.5%	0.0%	1.9%	0.0%	33.9%	0.0%	0.0%	0.0%
BIAS	0.665	0.847	0.635	0.914	1.427	0.845	0.710	0.598

Table 10 (b): Overview of several quantities indicating the agreement between the 1-minute temperature reported by PWS and AWS, and the POD, FAR and BIAS scores for temperature above and below zero °C for evaluation period (b).

	PWD22	VPF750	SWS250	PWS100	PAR2	LPM1	LPM2	OWI430
POD 0-98	99.9%	100.0%	99.5%	100.0%	76.0%	100.0%	100.0%	100.0%
FAR	9.9%	5.2%	10.6%	2.7%	3.6%	4.9%	9.1%	9.6%
BIAS	1.109	1.054	1.114	1.028	0.789	1.051	1.100	1.106
POD -98+0	68.1%	84.8%	65.5%	92.0%	94.3%	85.0%	70.9%	60.4%
FAR	0.4%	0.0%	2.1%	0.0%	33.9%	0.0%	0.0%	0.0%
BIAS	0.684	0.848	0.669	0.920	1.427	0.850	0.709	0.604

7. SUMMARY

In this document an update on the present weather sensor field evaluation at the KNMI is given, reporting results for August 1, 2016 to February 12, 2017, complementing our earlier report (Wauben et al, 2016) for the period February 18, 2016 to July 31, 2016. All data regarding precipitation type, precipitation intensity, visibility and temperature are presented in tables and figures, following the same structure of the previous report, but without any in depth discussion or analysis.

REFERENCES

Wauben, Mathijssen, and Oudshoorn: Field evaluation of sensors for precipitation type discrimination, Paper 3(11), TECO, 2016

APPENDIX A: CONTINGENCY MATRICES

Below the contingency matrices of the 1-minute precipitation types (in $w_a w_a$ code) reported by each PWS versus the FD12P, and LPM1 versus LPM2, are given for both evaluation periods (a) and (b). The corresponding NWS and METAR codes can be found in Table 1. The colour coding indicates the different precipitation classes: no precipitation (white), unidentified (grey), liquid (blue), freezing (orange) and solid (green). The darker colours indicate cases where both sensors report the same precipitation.

Table 11 (a): Contingency matrices for the 1-minute precipitation types during evaluation period (a).

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		PWD22													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	228906	2	564	0	0	515	0	0	254	28	0	0	0	0
	40	755	0	226	24	0	385	19	0	33	13	0	0	0	0
	50	803	0	2515	0	0	2603	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	673	0	1428	0	0	7676	0	0	0	6	0	0	0	0
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	33	0	130	52	0	852	46	0	62	81	0	0	0	0
	70	225	0	16	0	0	135	7	0	1645	100	0	0	0	0
	75	0	0	3	0	0	25	0	0	15	34	0	0	0	0
	77	578	4	219	0	0	155	5	0	733	42	0	0	0	0
	78	5	0	0	0	0	0	0	0	11	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		VPF750													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	163476	0	100	4	0	70	0	4	2	0	4	0	0	0
	40	810	0	188	58	0	152	0	10	4	0	9	0	0	0
	50	2219	0	1432	38	0	1092	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	1716	0	1406	77	0	4378	0	28	0	0	13	0	9	3
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	185	0	124	36	0	463	0	9	0	0	4	0	0	0
	70	537	0	137	14	0	355	0	502	101	0	464	0	0	17
	75	9	0	0	0	0	35	0	25	0	0	7	0	0	0
	77	1375	0	188	62	0	60	0	7	44	0	0	0	0	0
	78	14	0	0	0	0	0	0	0	2	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		SWS250													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	214875	0	54	0	0	2799	0	6915	4868	0	4	0	0	0
	40	1191	0	126	0	0	91	0	28	11	0	8	0	0	0
	50	3340	0	1967	0	0	575	0	7	2	0	4	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	2636	0	2635	0	0	4248	0	142	41	0	62	0	0	4
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	212	0	206	0	0	767	0	50	2	0	19	0	0	0
	70	605	0	97	0	0	217	0	500	399	0	298	0	0	10
	75	10	0	0	0	0	23	0	20	8	0	16	0	0	0
	77	1513	0	153	0	0	38	0	5	5	0	6	0	0	0
	78	16	0	0	0	0	0	0	0	0	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		PWS100													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	226921	1756	2054	14	0	1820	2	0	6	1	9	0	0	0
	40	158	82	412	57	0	732	15	0	4	0	0	0	0	0
	50	166	113	2213	0	0	3248	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	128	67	1526	0	0	7879	0	0	0	0	0	0	0	0
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	18	15	131	143	0	813	26	0	1	0	0	0	0	0
	70	345	428	53	47	0	153	16	0	1030	0	56	0	0	0
	75	0	4	9	0	0	62	0	0	2	0	0	0	0	0
	77	787	534	287	52	0	28	1	0	26	0	21	0	0	0
	78	13	3	0	0	0	0	0	0	0	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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		PAR2													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	62734	0	592	0	157	122	0	0	4	0	0	0	12	3
	40	372	0	45	0	70	67	0	1	2	0	0	0	25	2
	50	616	0	936	0	1039	586	0	0	1	0	0	0	2	2
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	622	0	509	0	975	2424	0	0	2	0	0	0	30	13
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	41	0	9	0	33	252	0	5	3	0	0	0	32	11
	70	402	0	16	0	40	23	0	0	854	0	0	0	96	32
	75	9	0	1	0	3	16	0	2	2	0	0	0	28	4
	77	526	0	106	0	78	1	0	0	43	0	0	0	2	0
	78	16	0	0	0	0	0	0	0	0	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		LPM1													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	221233	165	5537	0	46	887	0	3	49	23	556	0	0	0
	40	129	0	768	0	121	403	0	13	21	4	8	0	0	0
	50	150	1	2526	0	1731	1592	0	0	0	0	6	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	194	2	1818	0	1887	5808	0	22	5	11	0	0	0	2
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	10	0	234	0	238	741	0	27	3	1	2	0	0	0
	70	354	0	136	0	43	37	0	68	1336	21	133	0	0	0
	75	0	0	10	0	9	19	0	24	7	8	0	0	0	0
	77	742	0	484	0	6	6	0	0	142	0	356	0	0	0
	78	14	0	0	0	0	0	0	0	1	0	1	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		LPM2													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	225785	170	5202	0	41	834	0	1	57	19	470	0	0	0
	40	134	0	763	0	113	406	0	15	21	5	9	0	0	1
	50	174	4	2629	0	1677	1544	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	192	1	1827	0	1902	5871	0	16	4	13	0	0	0	2
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	16	0	239	0	242	730	0	20	5	2	2	0	0	0
	70	390	0	121	0	39	40	0	66	1315	27	130	0	0	0
	75	1	0	9	0	9	18	0	25	5	10	0	0	0	0
	77	806	0	468	0	3	3	0	0	142	0	314	0	0	0
	78	13	0	0	0	0	0	0	0	1	0	2	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		LPM2													
LPM1	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	240997	139	685	0	1	303	0	0	23	20	49	0	0	0
	40	161	3	7	0	1	0	0	0	0	2	0	0	0	0
	50	1425	6	12124	0	232	343	0	0	15	0	38	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	1	0	401	0	4059	521	0	5	1	0	0	0	0	0
	60	325	0	412	0	628	10762	0	15	6	5	1	0	0	3
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	0	0	0	0	7	26	0	101	13	10	0	0	0	0
	70	15	0	15	0	0	4	0	16	1420	16	78	0	0	0
	75	20	1	0	0	0	7	0	6	8	27	0	0	0	0
	77	78	0	153	0	1	3	0	0	65	0	762	0	0	0
	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	1	0	0	0	1	0	0	0	1

Table 11 (b): Contingency matrices for the 1-minute precipitation types during evaluation period (b).

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PWD22																
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89	
	0	92502	2	431	0	0	235	0	0	254	28	0	0	0	0	
	40	559	0	186	24	0	330	19	0	33	13	0	0	0	0	
	50	192	0	911	0	0	1213	0	0	0	0	0	0	0	0	
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	60	241	0	1049	0	0	3506	0	0	0	6	0	0	0	0	
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	67	33	0	125	52	0	422	46	0	62	81	0	0	0	0	0
	70	225	0	16	0	0	135	7	0	1645	100	0	0	0	0	0
	75	0	0	3	0	0	24	0	0	15	34	0	0	0	0	0
	77	578	4	219	0	0	155	5	0	733	42	0	0	0	0	0
	78	5	0	0	0	0	0	0	0	11	0	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

VPF750															
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	89663	0	93	4	0	51	0	4	0	0	4	0	0	0
	40	744	0	184	58	0	150	0	10	1	0	9	0	0	0
	50	780	0	1054	38	0	435	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	904	0	1231	77	0	2543	0	28	0	0	13	0	0	0
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	185	0	124	36	0	463	0	9	0	0	4	0	0	0
	70	537	0	137	14	0	355	0	502	101	0	464	0	0	17
	75	9	0	0	0	0	35	0	25	0	0	7	0	0	0
	77	1375	0	188	62	0	60	0	7	44	0	0	0	0	0
	78	14	0	0	0	0	0	0	0	2	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SWS250															
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	91829	0	30	0	0	694	0	600	206	0	0	0	0	0
	40	948	0	114	0	0	79	0	11	6	0	6	0	0	0
	50	1033	0	996	0	0	282	0	1	0	0	4	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	1276	0	1382	0	0	1976	0	106	9	0	53	0	0	0
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	208	0	137	0	0	428	0	27	2	0	19	0	0	0
	70	605	0	97	0	0	217	0	500	399	0	298	0	0	10
	75	10	0	0	0	0	22	0	20	8	0	16	0	0	0
	77	1513	0	153	0	0	38	0	5	5	0	6	0	0	0
	78	16	0	0	0	0	0	0	0	0	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PWS100															
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	91022	893	897	14	0	606	2	0	6	1	8	0	0	0
	40	125	68	359	57	0	529	15	0	4	0	0	0	0	0
	50	69	38	731	0	0	1411	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	82	34	1091	0	0	3520	0	0	0	0	0	0	0	0
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	18	15	128	143	0	430	26	0	1	0	0	0	0	0
	70	345	428	53	47	0	153	16	0	1030	0	56	0	0	0
	75	0	4	9	0	0	61	0	0	2	0	0	0	0	0
	77	787	534	287	52	0	28	1	0	26	0	21	0	0	0
	78	13	3	0	0	0	0	0	0	0	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	89	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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		PAR2													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	42168	0	134	0	83	37	0	0	4	0	0	0	12	2
	40	341	0	40	0	70	67	0	1	2	0	0	0	25	2
	50	300	0	166	0	510	330	0	0	1	0	0	0	1	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	326	0	380	0	629	1463	0	0	2	0	0	0	28	9
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	41	0	9	0	33	252	0	5	3	0	0	0	32	11
	70	402	0	16	0	40	23	0	0	854	0	0	0	96	32
	75	9	0	1	0	3	16	0	2	2	0	0	0	28	4
	77	526	0	106	0	78	1	0	0	43	0	0	0	2	0
	78	16	0	0	0	0	0	0	0	0	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		LPM1													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	89687	0	2848	0	13	306	0	3	48	1	542	0	0	0
	40	97	0	646	0	116	260	0	13	21	4	7	0	0	0
	50	67	0	925	0	676	648	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	52	0	1200	0	1097	2422	0	22	5	4	0	0	0	0
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	8	0	232	0	216	332	0	27	3	1	2	0	0	0
	70	354	0	136	0	43	37	0	68	1336	21	133	0	0	0
	75	0	0	10	0	9	18	0	24	7	8	0	0	0	0
	77	742	0	484	0	6	6	0	0	142	0	356	0	0	0
	78	14	0	0	0	0	0	0	0	1	0	1	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		LPM2													
FD12P	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	89949	0	2696	0	13	262	0	1	57	0	470	0	0	0
	40	98	0	644	0	105	267	0	15	21	5	9	0	0	0
	50	88	0	921	0	677	630	0	0	0	0	0	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	60	60	0	1188	0	1116	2412	0	16	4	6	0	0	0	0
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	14	0	236	0	217	325	0	20	5	2	2	0	0	0
	70	390	0	121	0	39	40	0	66	1315	27	130	0	0	0
	75	1	0	9	0	9	17	0	25	5	10	0	0	0	0
	77	806	0	468	0	3	3	0	0	142	0	314	0	0	0
	78	13	0	0	0	0	0	0	0	1	0	2	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
		LPM2													
LPM1	wawa	0	40	50	55	57	60	65	67	70	75	77	78	87	89
	0	90600	0	298	0	0	88	0	0	22	0	48	0	0	0
	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	50	659	0	5535	0	131	103	0	0	15	0	38	0	0	0
	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	57	1	0	151	0	1781	237	0	5	1	0	0	0	0	0
	60	107	0	143	0	260	3497	0	15	6	0	1	0	0	0
	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	67	0	0	0	0	7	26	0	101	13	10	0	0	0	0
	70	14	0	15	0	0	4	0	16	1420	16	78	0	0	0
	75	0	0	0	0	0	1	0	6	8	24	0	0	0	0
	77	73	0	141	0	0	0	0	0	65	0	762	0	0	0
	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	