

INVESTIGATIONS INTO THE IMPROVEMENT OF AUTOMATED PRECIPITATION TYPE OBSERVATIONS AT KNMI

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ABSTRACT

The Royal Netherlands Meteorological Institute (KNMI) employs the Vaisala FD12P present weather sensor for automated observations of visibility, precipitation type and duration in the national meteorological observation network. The precipitation type output of this sensor is used fully automated in all synoptical and aeronautical reports, except for two international airports where an observer is still present. Several weaknesses of the FD12P precipitation type have been recognized since its introduction in November 2002, particularly concerning detection of mixed precipitation around 0 °C, hail detection, false alarms in dense fog and the detection of very light precipitation events. Therefore an investigation into the performance of other sensors for the observation of precipitation type was initiated.

A field test with the Thies LPM, Ott Parsivel, Lufft R2S and Vaisala WXT520 sensors started in De Bilt in September 2008. Data was analysed on 1-minute basis for special cases and hourly weather codes from all instruments were evaluated by meteorologists. Based on the results gathered during the two winters of the test, it was concluded that the Thies LPM optical disdrometer has added value and is partially able to solve the shortcomings of the FD12P. The evaluation of the combination of FD12P and LPM will be continued at the two airports with observers. In this paper the operational experiences of the automated precipitation type observations by the FD12P present weather sensor will be presented. Furthermore, the results of the field trial in De Bilt and a brief analysis of the wind effect on LPM measurements will be reported.

1. Introduction

Since the introduction of the new meteorological measurement network of KNMI in 2002, all synoptic and climatological reports are generated fully automatically. Currently a full set of automated observations including visibility, weather and clouds are made centrally available every 10 minutes for around 40 locations on the mainland of the Netherlands and on the North Sea. KNMI only still employs observers at the airports of Schiphol and Rotterdam, where they make visual observations for aeronautical reports.

The observation of the type of precipitation is an important source in generating the so-called present weather, which is usually expressed in the $w_a w_a$ weather code in case of automated synoptic observations. At KNMI the FD12P is used for this purpose in combination with a correction algorithm that is mainly based on temperature information. However, the transition from human observers to automated systems has led to inevitable differences in the present weather observation that require improvement, especially in wintry conditions. The main shortcomings experienced at KNMI (e.g. Wauben, 2002; De Haij, 2007) are:

- The sensor reports too few events of solid precipitation and the mixture rain/snow.
- The sensor is not able to classify light precipitation events correctly.
- The sensor does not detect hail and reports too many events with ice pellets.
- The sensor reports (solid) precipitation at low visibilities (MOR < 400 m).

These findings are largely in agreement with results from the WMO intercomparison PREWIC (Leroy and Bellevaux, 1998) and an exploratory study on the future of present weather observations which was executed within the framework of EUMETNET (Van der Meulen, 2003). Promising results of new technology optical disdrometers were reported in Bloemink and Lanzinger (2005) and Lyth (2008). In the autumn of 2008 KNMI started a test with four commercially available sensors for improvement of the precipitation type observation, in order to see whether the problems encountered by the FD12P listed above can be solved. The findings from this field test and the preceding evaluation of FD12P performance are discussed in this paper.

2. Automated observations of precipitation type at KNMI

2.1 The FD12P sensor

KNMI operates the Vaisala FD12P sensor, which uses the forward scatter principle, for measurements of visibility and precipitation amount and type. The sensor consists of an optical transmitter (875 nm) and receiver and a separate capacitive detector which are mounted on a two meter high pole mast. The sample volume, formed by the intersection of transmitter and receiver beams, has a size of approximately 0.1 dm³ and is located at a height of 1.75 m. Hydrometeors falling through the measurement volume are recognized by peaks in the receiver signal. The ratio of this optical signal (~particle size) and the DRD12 detector signal (~liquid content) is used to determine the precipitation type, together with temperature and the particle size distribution. The actual precipitation type is derived by the internal software from the measurements of the last 15 seconds to 5 minutes at maximum. The FD12P sensor is able to distinguish between 13 different liquid, freezing and solid precipitation types, listed in Table 1.

Table 1. Precipitation types reported by the FD12P PWS.

Precipitation type	w _a w _a code	NWS code	METAR code
No precipitation	00	C	-
Unknown precipitation	40	P	UP
Drizzle	50	L	DZ
Freezing drizzle	55	ZL	FZDZ
Drizzle and rain	57	LR	DZRA
Rain	60	R	RA
Freezing rain	65	ZR	FZRA
Drizzle/rain and snow	67	LRS	RASN
Snow	70	S	SN
Ice pellets	75	IP	PL
Snow grains	77	SG	SG
Ice crystals	78	IC	IC
Snow pellets	87	SP	GS
Hail	89	A	GR

2.2 Processing to weather codes

The 1-minute NWS codes from the FD12P are acquired on site by a sensor interface module and transmitted to the central server in De Bilt every 10 minutes. A set of six modification rules (PWc) are carried out on the data, using meteorological parameters measured by the FD12P itself (precipitation intensity PI) or other collocated sensors (air temperature TA, wet bulb temperature TW). The corrections are presented in Table 2. Most trivial correction is PWc1, which uses the 1.5 m wet bulb temperature measured at the AWS as a discriminator between liquid and freezing precipitation. Correction criteria were empirically derived from some years of experience with the FD12P sensor by KNMI and the Swedish Meteorological and Hydrological Institute (SMHI).

Successively, the 10-minute 'averaged' PWc code is determined from ten 1-minute values of the corrected PWc with a minimum required availability of 7 values. Generally, this is the most important (maximum) value of PWc which has occurred during the 10-minute interval. An exception is made for the occurrence of mixed precipitation. In case snow (70) is the most

important precipitation type and both snow and a combination of the PWc codes 50, 57, 60 and 67 occur at least 30% of time then a mixture (67) is reported. Similarly a mixture of rain and drizzle (57) is reported when rain (60) is the most important type and both rain and a combination of the PWc codes 50 and 57 are observed at least 30% of the time interval.

Table 2. Overview of conditions and corrections for the PWc modification currently in use at KNMI.

Name and description	Condition(s)	Correction(s)
PWc1 Use wet bulb temperature for freezing ppn	TW≤0.0 TW>0.0	L→ZL; LR,R→ZR ZL→L; ZR→R
PWc2 Correct for ice crystals above TIPX	TA>-10.0	IC→P
PWc3 Correct for snow above TSNX	TA>7.0	S→P
PWc4 Correct solid ppn to mixture rain/snow	1.0≤TW≤TWB*	S,SG,IC→LRS
PWc5 Correct solid ppn to mixture rain/snow	0.0≤TW≤TWB*	IP→LRS
PWc6 Correct for solid ppn above TWB	TW>TWB*	LRS,S,IP,SG,IC→P

* TWB=2.7+0.4*ln(PI+0.0012)

KNMI operates a weather code generator to generate $w_a w_a$ -weather codes, in conformity with WMO Table 4680, from the observations in the 10-minute databases. The generator is executed at the end of each 10-minute interval and reports the most significant weather of the past hour, in which the last 10 minutes are considered first. Note that not only precipitation type, but also other measurements like precipitation intensity, visibility and lightning information, is used in the generation of $w_a w_a$ (KNMI, 2005).

3. Evaluation of FD12P observations

3.1 Comparison with human observations

For most locations the introduction of automated observations at KNMI (November 2002) occurred without an overlap of the automated and manual observations. However, at the airports Schiphol, Rotterdam, Maastricht-Aachen, Groningen-Eelde and De Kooy and at De Bilt FD12P present weather sensors were operated almost 3 years in parallel with manual present weather observations for synoptic purposes (Wauben, 2002). As an example of the differences that occur, a comparison of the 157,824 hourly manual and automated observations for these six locations in the period 2000-2002 is presented in Table 3. The manual observation (cf. WMO Table 4677) and the (corrected) automated observation (cf. WMO Table 4680) are translated to the actual precipitation type code of which the number of occurrences is presented along the vertical and horizontal axis in the contingency matrix, respectively. Thereby it is assumed that the human observer can be used as reference 'truth', although differences between observers certainly exist and they are not faultless. The dark green cells indicate the number of cases for which the methods are fully in agreement (agreement Band0 = 90%), whereas the light green cells indicate the fraction of cases where the methods agree on the precipitation class (agreement Band1 = 94%). The Band0* and Band1* scores are more suitable since they do not take the large number of events without precipitation (C) into account.

The skill scores of the automated observation with respect to the human reference are given in the lower panel for detection ('Precipitation'), and liquid, freezing and solid precipitation. The POD (Probability Of Detection), FAR (False Alarm Rate) and CSI (Critical Success Index) scores for the overall detection of precipitation are 82%, 20% and 68%. Note that especially the performance for discrimination of freezing and solid precipitation is poor, with CSI scores of 31% and 56% respectively. The scores for freezing precipitation should however be treated carefully since the number of events is limited. A bias can be seen with the sensor reporting on average less solid precipitation (BIAS=0.78) than the human observer. Some types like snow pellets and hail (SP/A)

are not detected at all by the automated system. Moreover, the number of inconsistencies for especially the human observation of the mixture rain/snow (LRS) is significant.

Table 3. Contingency matrix of human and automated observations of the precipitation type at six stations in the Netherlands for the period 2000-2002. In the lower panel the skill scores for the precipitation classes, derived from this matrix, are presented.

Observer	FD12P PwC															Sum
	N/A	C	P	L	LR	R	ZL	ZR	LRS	S	IP	SG	IC	SP	A	
N/A	719	7494	42	282	154	663	17	9	2	10		4				9396
C	5230	117657	353	1234	248	2233	13	3	17	47	11	65				127111
P	2	25	3		1	7	253			2	3					296
L	310	1535	46	987	121	465		1	1	5	3					3474
LR	98	182	20	760	365	940		2	2	3	2					2374
R	545	1722	106	2014	1694	7709		1	1	13	4					13810
ZL		12	6		1			6	3		1		2			31
ZR		2						2	17				1			25
LRS	11	20	14	32	19	107		2	2	65	35	4	7			316
S	5	64	22	10	4	22		1	1	81	442	26	59			737
IP				1		3				1			1			8
SG	7	20	2	3	2	1		4		5	30	4	19			97
IC																0
SP	8	16	15	6	6	54				16	9	2	2			134
A	2	2			1	10										15
Sum	6937	128751	629	5331	2621	12463	46	41	209	587	47	160	0	0	2	157824
N/A	9.9%	Band0	89.5%	Band0*	47.3%	Band1	93.9%	Band1*	78.2%							

Precipitation			Liquid			Freezing			Solid		
FD12P			FD12P			FD12P			FD12P		
Obs	yes	no	Obs	yes	no	Obs	yes	no	Obs	yes	no
yes	16729	3600	yes	15055	3650	yes	28	28	yes	808	466
no	4224	117657	no	4261	119244	no	33	142121	no	181	140755
POD	82%		POD	80%		POD	50%		POD	63%	
FAR	20%		FAR	22%		FAR	54%		FAR	18%	
CSI	68%		CSI	66%		CSI	31%		CSI	56%	
HSS	78%		HSS	76%		HSS	48%		HSS	71%	
BIAS	1.03		BIAS	1.03		BIAS	1.09		BIAS	0.78	
N	24553		N	22966		N	89		N	1455	

3.2 Evaluation of additional corrections

Most of the issues indicated above were already recognized in earlier work. To see whether increased synergetic use of measurements on site would lead to improvement, an analysis of further modifications for the precipitation type was made, based on cross correlations with collocated parameters like visibility and temperature (De Haij, 2007). Some of these were adopted from ICAO Document 9837 (ICAO, 2006). The positively contributing corrections are listed in Table 4. Apart from the scores for the uncorrected ('pw') and corrected ('pwc') precipitation type for 2000-2002, Table 5 also lists the (CSI) scores after using these ten PwC+ corrections ('pwc+pos') and after using the PwC and a selection of PwC+ corrections together ('pwc+allpos').

Table 4. Overview of additional PwC+ corrections, based on cross correlations with other meteorological quantities measured on site. Corrections with positive impact are presented.

Name and description	Condition(s)	Correction(s)
PwC+1 No ppn if TA-TG>3°C over 20 min. period	TA-TG>3	ppn→C
PwC+5 No ppn if vis>40km for 5 min. period	MOR>40000	ppn→C
PwC+10 Snow with TA>4 °C is very rare	TA>4	S,SG→P
PwC+13 Snow is not observed when TW>1.5°C	TW>1.5	S,SG→R
PwC+15 Drizzle occurs only if RH>90%	RH<90	L→R
PwC+17 Drizzle occurs only if cloud base<1000m	C1>1000	L→R
PwC+19 Drizzle occurs only if MOR<10km	MOR>10000	L→R

PWc+21 Correct for false detection in dense fog	MOR<400	P,LRS,S,IP,SG→C
PWc+24 Modify detections of ice pellets	TW≤3 TW>3	IP→S IP→R
PWc+26 Use 10% rule for the mixture LRS	S and at least 1x L,L,R,R	S→LRS

The latter is indicated in the last row of Table 5 and shows that applying the (operational) PWc and the selected PWc+ corrections ('pwc+pos') leads to an overall increase in CSI of 44% for all precipitation types together, caused by 4089 adjustments. Correction PWc+17 was omitted because it creates a large imbalance in the occurrence of drizzle and rain. The performance has increased most for the mixture of drizzle/rain and snow (+14%), freezing rain (+9%), rain (+8%) and snow (+6%). Compared to the existing KNMI PWc corrections, the PWc+ corrections improve the scores only marginally and especially for liquid precipitation (which is not the main problem). However, they also quite effectively reduce the number of false alarms of solid precipitation during periods with low visibility and limit the number ice pellets events.

Table 5. CSI scores for the precipitation types reported by the FD12P, after application of the operational PWc correction ('pwc') and the additional corrections listed in Table 4 ('pwc+pos'). Nadj is the number of adjustments with respect to the uncorrected situation ('pw').

Case	C	P	L	LR	R	ZL	ZR	LRS	S	IP	SG	IC	SP	A	ACSI	Nadj
Sum_pw	93.8%	0.4%	13.6%	8.3%	44.3%	10.9%	33.3%	1.8%	47.0%	0.0%	7.8%	--	0.0%	0.0%	0.0%	0
Sum_pwc	93.8%	0.3%	13.7%	8.3%	44.4%	11.1%	42.5%	14.5%	51.0%	0.0%	8.4%	--	0.0%	0.0%	+26.8%	380
Sum_pwc+pos	93.9%	0.4%	14.4%	11.4%	54.7%	11.1%	33.3%	12.0%	55.7%	0.0%	10.1%	--	0.0%	0.0%	+35.7%	6242
Sum_pwc+pos	93.9%	0.4%	16.9%	10.8%	52.0%	11.1%	42.5%	15.7%	52.5%	0.0%	9.6%	--	0.0%	0.0%	+44.1%	4089

As further improvement of the FD12P precipitation type based on raw data did not seem likely (Bloemink, 2004), and the sensor will be taken out of production in 2010/2011, an investigation into new, affordable sensors for this purpose started in 2008 and still continues. The goal is to see whether one of these sensors is capable of improving the performance of the automated precipitation type observation, specifically for the issues encountered with the FD12P mentioned in Section 3.1.

4. Testing new sensors

4.1 Field test De Bilt

Four commercially available sensors were selected and purchased for this test in the summer of 2008. First of all, the optical disdrometers Thies Laser Precipitation Monitor (LPM) and Ott Parsivel measure the extinction in a thin sheet of light (approximately 50cm²) to estimate the diameter and fall velocity of each individual particle. The precipitation type is determined every minute from the particle property statistics compared to empirical relationships, and temperature (for the LPM). Beside the intensity, accumulation and type of precipitation the LPM and Parsivel also provide the size-fall speed distribution of the recorded particles.

The Lufft R2S sensor, a small 24 GHz Doppler radar system, was also included in the test. This sensor is mainly used in road weather applications and measures the fall speed of hydrometeors (≥ 0.3 mm drop size) above the sensor for the derivation of precipitation quantity and type. The advantage of the R2S is that it requires only little maintenance. Finally, the Vaisala WXT520 was selected, a compact weather station with a piezoelectric sensor on top that is able to characterize whether the precipitation is rain or hail (Salmi and Ikonen, 2005). Note that whereas the LPM and Parsivel sensors are able to report nearly all precipitation types that are available in the output of the FD12P, the R2S (R-LRS-S-A) en WXT (R-A) sensors report only a limited number of types. However, the sensors under test are not expected to replace the FD12P, but a combination is considered in order to overcome FD12P problems.

The sensors are installed on the test field in De Bilt since 12 September 2008 (see Figure 1). They are collocated within 30 m of the FD12P and other standard meteorological equipment, which offers the opportunity to analyse the relation with other parameters (e.g. precipitation amount,

wind) as well. All sensors under test are installed at 1.5 m above the surface, except for the Lufft R2S (2 m). The orientation of the transmitter-receiver axes of the LPM and Parsivel sensors is NW-SE, such that the measurement volume is perpendicular to the prevailing southwesterly wind direction with precipitation, minimizing the effect of the housing on the measurement. Except for the removal of spider webs on some occasions, no maintenance was carried out on the sensors. All sensors operated continuously without any technical problems for the full period of the trial (September 2008-March 2010).

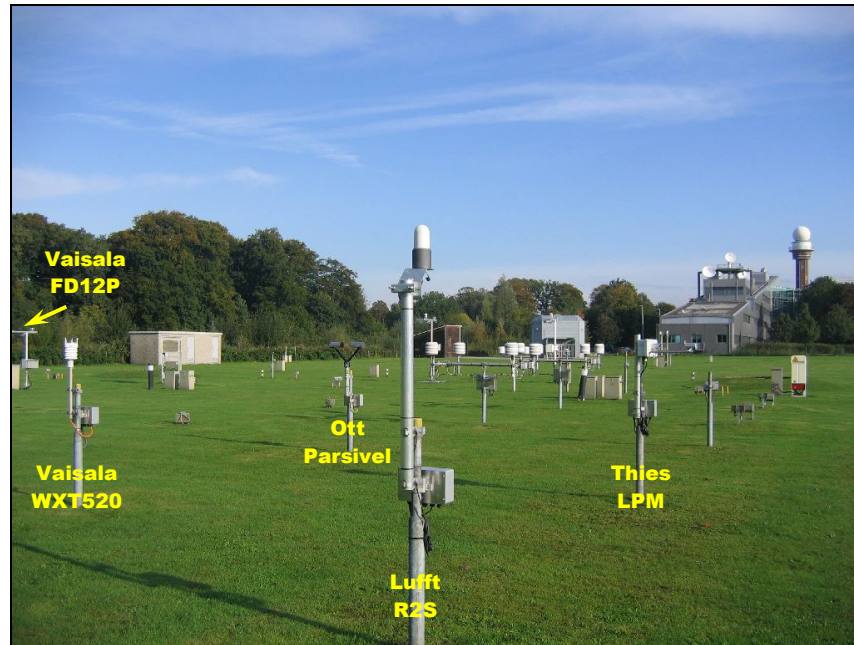


Figure 1. The test field in De Bilt, with the four sensors indicated in the foreground.

Every minute, the observations were acquired from all sensors and averaged to 10-minute and hourly weather codes (without intensity indication), which were evaluated on a routine basis by data validation specialists and meteorologists, respectively. They entered their level of agreement with the sensors in a web tool. Unfortunately, since these are not observers, they had to do this task on a best effort basis besides their normal operational duties, which limited the number of wintry cases with a useful evaluation.

4.2 Case studies

The left panel of Figure 2 reflects the situation in De Bilt on 3 February 2009, where the Thies LPM and Ott Parsivel significantly deviate from the FD12P in the type discrimination. Both optical disdrometers start to report mixed and solid precipitation from 16 UT, which is in better agreement with the evaluation of the meteorologist than the rain reported by the FD12P. The high number of hail reports by the Parsivel, which was seen for this sensor on more occasions, has not been confirmed and seems incorrect. Note that the LPM is more sensitive for very light precipitation, reporting a significant number of drizzle events between 13 and 14 UT. The detection and precipitation type capabilities of the Lufft R2S and Vaisala WXT520 seem inadequate. Given the large contribution of drizzle in the morning and afternoon and of solid precipitation in the evening, it is not surprising that WXT only detects 0.03 mm of accumulation on this day, as it was not designed to detect light drizzle or wintry precipitation. Note that the second FD12P sensor ('oper') included in the graphs is the sensor at the operational site De Bilt (06260), located approximately 200 m east of the test field.

In the evening of 16 January 2010 a marked transition from liquid to solid precipitation occurred in De Bilt, as seen in Figure 2 (right panel). Where the LPM, Parsivel and FD12P at the test site capture this transition very well, the second FD12P at the operational site is inconsistent and already reported snow during large parts of the afternoon, which seems incorrect. Note also the

occurrence of many events of unclassified precipitation (UP) by the FD12Ps in the evening and the capability of the LPM to detect the drizzle events in the periods 00-02 UT and 22-24 UT, which was confirmed by the meteorologist. The size-fall speed density distributions derived from the LPM data on this day are presented in Figure 3 for the time intervals 16-18 UT (left; N=34,931) and 19-21 UT (right; N=50,976). The recorded particles show a strong correlation with the Gunn-Kinzer relationship (Gunn and Kinzer, 1949) during the first period and hence serious doubt is thrown on the observations of solid precipitation made by the operational FD12P sensor.

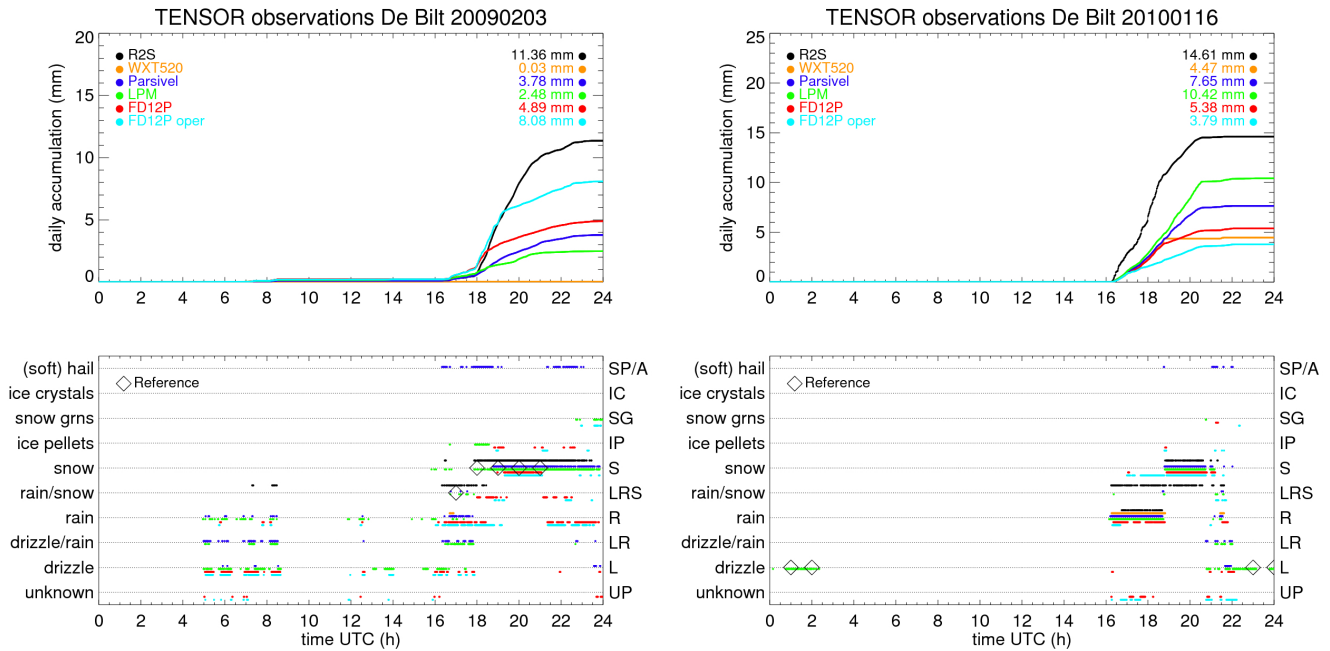


Figure 2. Accumulation and precipitation type reported by the sensors under test in De Bilt on 3 February 2009 (left) and 16 January 2010 (right). The (human) reference observations are presented by black diamonds. The total daily accumulation is given in the upper right corner.

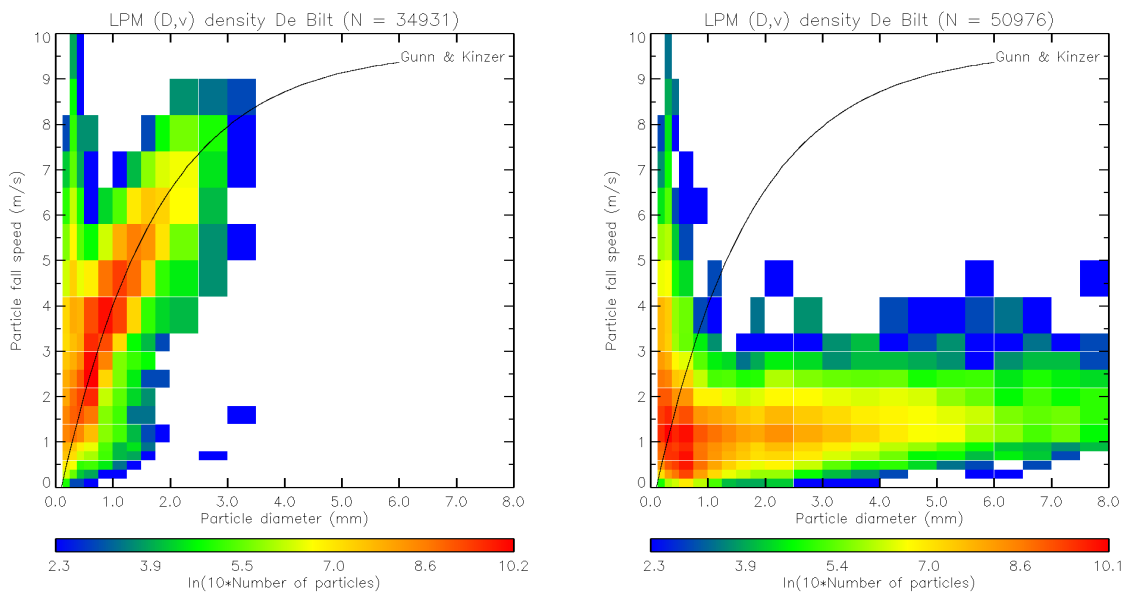


Figure 3. Accumulated density distribution of particle diameter (D) versus fall velocity (v) reported by the Thies LPM in De Bilt on 16 January 2010. The transition from rain (16-18 UT, left) to snow (19-21 UT, right) is evident. The Gunn-Kinzer line indicates the terminal fall velocity of rain drops as a function of drop size.

A very different pattern can be observed for the period 19-21 UT (right panel), where fall velocities are significantly lower (≤ 3 m/s) at similar and larger particle sizes, such that the high density of points around the Gunn-Kinzer curve has completely disappeared. The graph now clearly indicates that snowfall occurs, in accordance with all sensors at the test field, with an exception of the R2S. The latter sensor alternately detects snow (S) and the mixture drizzle/rain and snow (LRS).

Another case, where the FD12P falsely detects precipitation during dense fog, is illustrated in Figure 4. The Meteorological Optical Range (MOR) measured by the two FD12Ps drop consistently below 200 m shortly after 21 UT, leading to successive precipitation reports in the form of snow and snow grains with intensities up to 0.03 mm/h at temperatures just above freezing level. At 22 and 23 UT this erroneous behaviour is confirmed by the meteorologist (not shown here). Improvement can be achieved on this point, as the disdrometers on the test field clearly suffer less from this phenomenon.

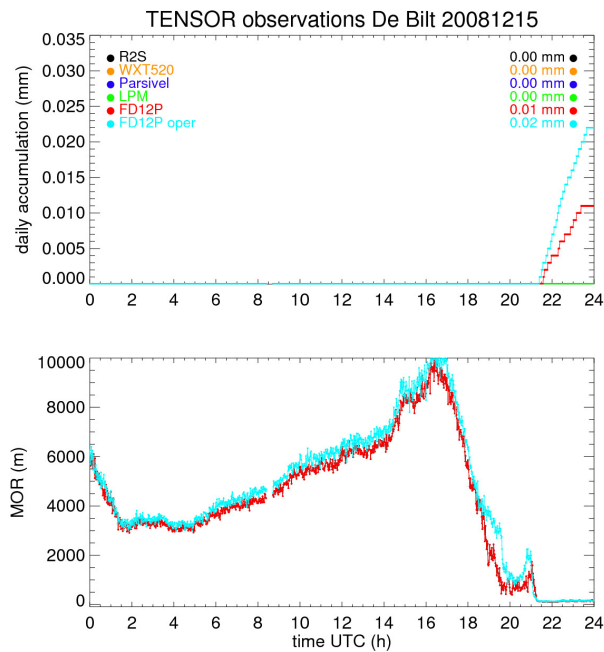


Figure 4. Precipitation accumulation and Meteorological Optical Range (MOR) measured by the sensors under test (lower panel: FD12Ps only) in De Bilt on 15 December 2008.

4.3 Results and outlook

Based on the results gathered during the two winters of the test, the Thies LPM disdrometer is the most promising sensor to improve the precipitation type observation in the observation network of KNMI. More specifically, it seems to give added value during transitions between liquid and solid precipitation, detection in dense fog and classification of very light precipitation. Some improvement for hail detection may be expected as well, although this remains a problematic type of precipitation for all sensors. Moreover the number of confirmed hail events in the test was limited, such that it is difficult to draw conclusions. However, it should be mentioned that the LPM also has some weak points, i.e. it sometimes reports false detections due to insects and spider webs and shows a significant wind direction dependency of the measured precipitation amount. Whereas the Ott Parsivel uses the same measuring principle as the LPM, this sensor gave slightly worse results. An overestimation of hail types and limited sensitivity in case of drizzle and snow grains was observed. Furthermore the Parsivel does not use additional temperature information.

The shortcomings experienced with the Lufft R2S are a limited sensitivity and many false reports of precipitation due to flying insects in the volume above the sensor, especially in summer. Moreover, the fixed temperature threshold used in the sensor for sleet (4°C) did not show good agreement with the other sensors and the reference. Finally, the Vaisala WXT520, which was included primarily for hail detection, did not report a single hail event during the 18 months of

measurements in De Bilt. Nevertheless at least two confirmed events of hail at the test field occurred in this period.

Summarized, the results of the hourly evaluation by the meteorologist in De Bilt (Table 5) support the added value of the LPM sensor on the test field. A selection has been made on the cases where the occurrence of precipitation was confirmed. It is evident that the Thies sensor shows the lowest number of disagreements, although still significant. Because of the limited set of types reported by the R2S and WXT sensors, they are not included here. Note that a full set of skill scores based on contingency tables was not calculated for this data set, because that would not make sense for the limited number of reference observations.

Table 5. Results of the hourly weather code evaluation in De Bilt, September 2008-March 2010.

	Hourly observations	
	# obs.	# OK/NOK
LPM	393	268/122
Parsivel	393	229/161
FD12P	393	247/142

A second field test where the LPM and FD12P will be compared with a human observer at the airports of Schiphol and Rotterdam is being prepared for the winter 2010-2011. In contrast to the trial in De Bilt the aim will be to obtain a fully covered reference data set from the observer with a high (1-minute) time resolution. Sensor output will not be presented to the observer. Interestingly, the LPM not only gives the dominating precipitation type in a 1-minute interval, but also an estimate of the number of particles associated with other types. This could give information on the quality of the discrimination and offers the possibility to optimize the output.

5. Analysis of the wind effect on LPM precipitation amount

Recent studies on the quality of optical disdrometers (e.g. Upton and Brawn (2008)) showed that the sensor housing of the LPM seriously masks the measurement volume in case the wind direction is unfavorable. The effect of the orientation of the LPM is explored briefly in this section. For this purpose, data from three differently orientated LPM sensors at the coastal test site Westermarkelsdorf was kindly made available by the German Weather Service (DWD). The transmitter-receiver axes of the sensors are shifted 60° with respect to each other, starting at an orientation of 100°. The analysed dataset from Westermarkelsdorf extends from 20 December 2006 to 24 February 2008.

In Figure 5 the average relative differences of the precipitation intensity measured by LPMs 77, 78 and 79 with respect to the intensity of the most suitable LPM for that wind direction is plotted for all wind directions. Observations are only included if the three intensities are available and positive. The upper panel shows all data points (N=48,505), the lower panel only includes observations for which the 2 m wind speed is higher than 5 m/s. The figure clearly shows that the precipitation measurement is disturbed for certain wind directions, where generally the measurement volume is positioned at the lee side of the sensor housing. According to the orientations of the sensors (see inset of Figure 6), these directions should be 280° for LPM77, 40° for LPM78 and 340° for LPM79. Especially the underestimation of LPM77 for wind directions around 270° is evident, showing that on average the reported precipitation intensity by that sensor is roughly 35% lower than the intensity of LPM79. For wind directions between 340 and 30° an evident positive anomaly in the average intensity is seen for LPM78 with respect to the other two LPM sensors. The reason for this feature is unknown. The lower panel shows similar results, but for some directions the number of cases is extremely reduced such that the value becomes doubtful.

Another way to obtain information on the masking effect is by a mutual comparison of the intensities reported by Thies disdrometers LPM77, LPM78 and LPM79 as a fraction of time (Upton and Brawn, 2008). Figure 6 gives the fraction of time for which one disdrometer reports a higher 1-minute intensity than the other. Normally, this fraction should be around 50% (magenta line) in case the instruments are well comparable. A significant deviation from this value can be

interpreted as an indication of the undercatch by one of the sensors due to masking. For the three combinations (i.e. LPM77>LPM78, LPM78>LPM79 and LPM79>LPM77), it becomes clear that for wind directions where the measurement volume is blocked by the sensor housing, the fraction is generally much lower than 50%. On the other hand, it also seems that (a lesser extent of) masking occurs in case the wind blows precipitation directly to the housing of the instrument along the receiver-transmitter axis, because all curves have more or less a symmetric pattern.

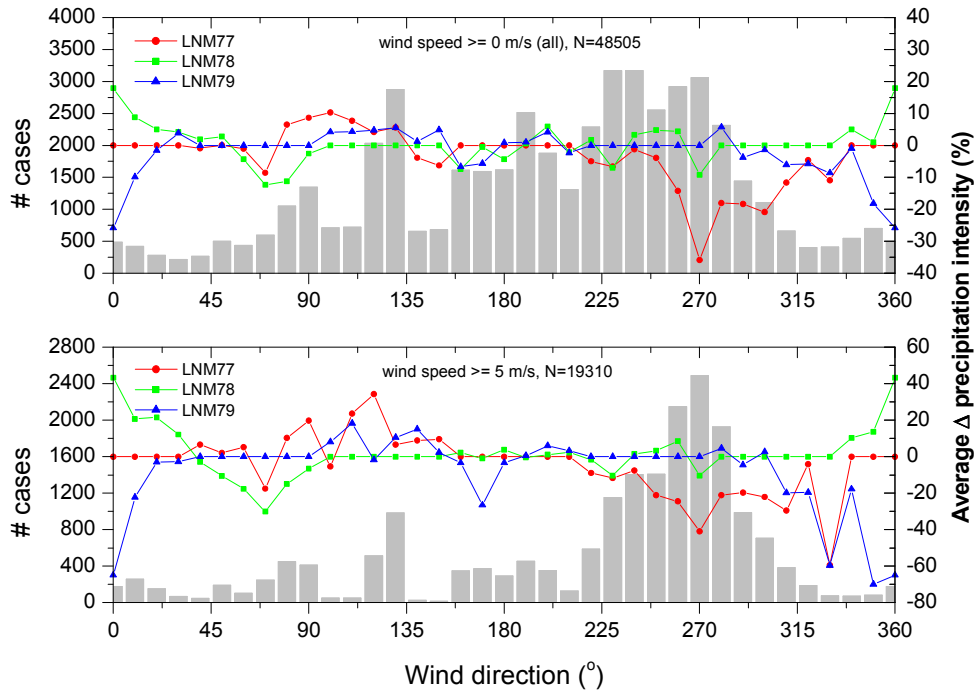


Figure 5. Relative average difference in precipitation intensity between sensors LPM77, LPM78 and LPM79 and the most suitable LPM for that wind direction, for all events (upper panel) and wind speeds ≥ 5 m/s (lower panel) at Westermarkelsdorf. Bin size is 10° .

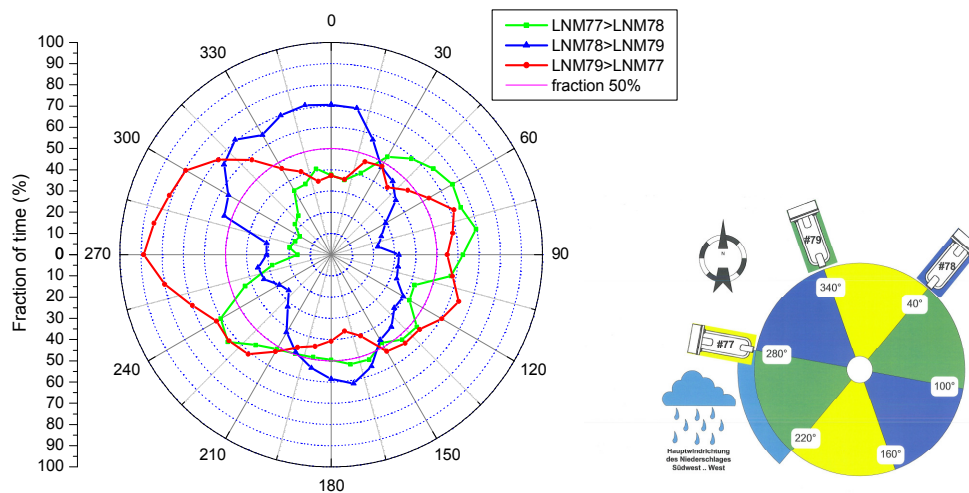


Figure 6. Polar plot of the fraction of time for which a certain LPM sensor reports a higher 1-minute intensity than another. The graph contains lines for the mutual comparison LPM77>LPM78 (green), LPM78>LPM79 (blue) and LPM79>LPM77 (red), together with an iso-line for the value 50%. The inset shows the orientation of the three instruments at DWD test site Westermarkelsdorf.

The general impression of Figure 6 is that the capture efficiency is higher for wind directions perpendicular to the transmitter-receiver axis of the instrument. The observed patterns show good agreement with the orientations of the three Thies LPMs at the test site. Note however that this result does not provide information on the capabilities of the sensor to report the precipitation type correctly under different wind influence. It is expected that the wind particularly affects particles with a low vertical velocity.

6. Conclusions and outlook

This paper describes the efforts undertaken at KNMI in recent years to improve the automated observation of the precipitation type, carried out with the Vaisala FD12P. Since the transition of human to fully automated observations several weak points of the sensor have been recognized, which require improvement. The discrimination of solid and mixed precipitation around 0°C, hail detection and false reports of precipitation in dense fog are most relevant issues. In order to improve the quality of automated present weather observations issued in the meteorological reports by KNMI, the sensor observations already undergo corrections (using temperature information) and 10-minute averaging.

A comparison of automated and human observations was carried out for the period 2000-2002 in which overlapping measurements were conducted at six Dutch stations. Poor skills are found especially for solid and mixed precipitation types, and hail detection. Additional corrections based on cross correlation with MOR and temperature did not give satisfactory improvement. Therefore an investigation into the performance of new sensors for the observation of precipitation type was initiated, resulting in a test of the Thies LPM, Ott Parsivel, Lufft R2S and Vaisala WXT520 under Dutch conditions.

From the field test in De Bilt (September 2008-March 2010) it can be concluded that the Thies LPM has added value and is partially able to solve the shortcomings of the FD12P. The hourly evaluation by the meteorologist was only sparsely available, but showed slightly better agreement for the LPM than for the Parsivel and FD12P. The R2S and WXT520 do not seem suitable for improvement of the automated present weather observation. A new field test is being prepared, where the FD12P and LPM will be compared with a human observer at two airports starting in winter 2010-2011. Eventually, the expected improvement in performance derived from this test should lead to a decision whether or not to implement the sensor for operational use. A combination of the FD12P and the disdrometer output in order to obtain an optimal precipitation detection and type discrimination will be investigated in more detail.

Analysis of data from three differently oriented Thies LPMs at DWD test site Westermarkelsdorf indicates that a significant blocking effect due to the sensor housing may be expected. For the least ideal wind directions average differences of up to 35% in the measured precipitation intensity were observed.

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