Automated discrimination of precipitation type using the FD12P present weather sensor: evaluation and opportunities

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1 Introduction

1.1 Automation of visual observations

The Royal Netherlands Meteorological Institute (KNMI) operates the Vaisala FD12P present weather sensor for observations of visibility, precipitation type, intensity and duration in the national meteorological observation network of the Netherlands. Currently, 36 Vaisala FD12Ps are operated at 23 different locations in the network[1]. Multiple sensors of this type are often operated on aeronautical sites for measurements of Runway Visual Range (RVR) on several locations along runways.

Efforts were made at KNMI in the past decade to automate visual observations of visibility, clouds and present weather and to guarantee its quality with respect to the previous situation with human observations. As a result of the automation, human observers were removed from weather stations in November 2002 and recently also from regional airports. Observers are presently only active at the largest civil airports Schiphol (Amsterdam) and Zestienhoven (Rotterdam), but only for aeronautical observations. As a result, all synoptical (SYNOP) and climatological (KLIM) and nearly all aeronautical (METAR) reports issued by KNMI are now completely based on automated observations. In addition to the resulting cost reduction, advantages of the introduction of automated observations are the objectivity of the observations and the higher update frequency of the central system in De Bilt, i.e. every 10 minutes the 1-minute observations from all stations in the network are acquired and processed.

The observation of precipitation type is one of the so-called present weather observations. Since the introduction of the Vaisala FD12P weather sensor, it is known that the discrimination of precipitation type is not always correct. Precipitation occurs mostly in a liquid form in the Netherlands. Wintry precipitation (freezing or solid) has a significant impact on the society, particularly for the safety of traffic and aeronautical operations. Hence meteorologists benefit largely from correct observations of wintry precipitation for nowcasting and forecasting practices. Unfortunately, problems with respect to the automated precipitation type observations are just experienced frequently during wintry precipitation events. Besides errors which are introduced by the sensor characteristics, the calculated performance of the system is also poor because of the temperate climate in the Netherlands. It is generally characterized by a lack of persistent wintry precipitation. When wintry precipitation (freezing or solid) occurs, the intensity or duration is low most of the time, or the precipitation is preceded or followed by mixed or liquid precipitation. This regularly introduces an ambiguous or faulty determination of precipitation type by the automated system, with respect to human observations. The problems concerning the discrimination of freezing and solid precipitation are recognized at KNMI, but it is not trivial to solve them. In this report, the focus will be on the most stringent problems concerning precipitation type discrimination with the FD12P experienced in the Netherlands and on possible modifications that can be made in the automated system to improve these observations.

Determination of the performance of automated observations is complex. Firstly, it requires overlapping observations from a reliable reference. The human observer, which is often used in comparison studies, is however a subjective reference and not always faultless (Van der Meulen, 2003). Differences between manned and automated observations with respect to timing and measurement volume introduce inconsistencies. Furthermore, the validation is difficult because some of the measured phenomena are very rare, depending on the local climate. Hence, it takes some time to collect enough data to produce reliable results on the performance of the detection of these phenomena by the automated system. Wauben (2002)

[1] Reference date: July 1, 2007.

investigated the quality of automated cloud, visibility and weather observations at KNMI, based on one year of data from stations De Bilt and Schiphol. Since more data has been collected now and more experience with the FD12P has been gathered, one of the main goals of this study is to analyze the agreement of the manned and automated data in the extended data set.

There is an increasing trend in the automation of meteorological observations to apply correction algorithms to enhance the performance (Van der Meulen, 2006). Most of these corrections modify measured data, based on empirically derived conditions. However this practice is not always desirable for all parties concerned, meteorological institutes are often forced to make these efforts because no detailed information on the internal software of the sensors is released by the manufacturer. KNMI currently employs six corrections in the processing of automated precipitation type observations. An inventory of other interesting automated corrections for precipitation type will also be made in this study.

1.2 Earlier work

The World Meteorological Organization (WMO) arranged an intercomparison (PREWIC, 1993-1995) of present weather sensors in Canada and France (Leroy and Bellevaux, 1998). Several sensors, using different technologies, were tested on their abilities in the field of precipitation detection and precipitation type discrimination. The Vaisala FD12P performed the best of all optical sensors in PREWIC, but some drawbacks were found as well. The main findings regarding the FD12P are:

- It has a high level of detection for rain and snow and the detection of drizzle is good relative to other sensors.
- An undetermined type of precipitation is rarely indicated. Generally, it is only indicated at the beginning and end of a precipitation event and during very light snow.
- The FD12P gives the best identification for drizzle, but it does barely exceed 50%. Drizzle events are also identified as rain or mixed precipitation, snow grains or ice pellets.
- Rain is well identified. Very light rain is sometimes seen as drizzle, and rarely as snow or mixed precipitation.
- Snow is well identified. Light and intermittent snow events are sometimes seen as drizzle.
- Significant differences are found between two identical sensors in the detection of low intensity precipitation.
- Hail is not reported, although the manufacturer claims this capability.

KNMI started an instrument comparison of the HSS PW402B and Vaisala FD12P present weather sensors in March 1993 (Van der Meulen, 1994). The output of these sensors was compared to human observations at the same location. Since a limited number of snow events were recorded, the study only dealt with the detection and discrimination of liquid precipitation. Good correspondence was found between the human observer and the automated systems for the detection of precipitation, but the agreement was significantly worse for cases with drizzle and slight rain. However, the FD12P reported these types better than the HSS sensor. The extensive range of possibilities for reporting solid precipitation types and the ability to transmit w_aw_a codes were mentioned as additional advantages of the FD12P sensor.

Wauben (2002) compared the precipitation type reported by the FD12P and a human observer at two KNMI stations in the year 2000. The Critical Success Index (CSI, see Section 2.3) found for liquid precipitation in the analysis is about 60%, while the CSI for solid precipitation is 39% for Schiphol and 57% for De Bilt. The sensor reported 30 to 50% less solid precipitation than the human observer and primarily missed events in this precipitation class within the temperature range of 0 to 4°C. The CSI for freezing precipitation in De Bilt is 25%, but only 4 events with freezing precipitation were reported by the sensor and one by the human observer, which makes this score unreliable.

An exploratory study on the future of present weather observations was executed within the framework of EUMETNET (Van der Meulen, 2003). An overview of all kinds of existing present weather observing techniques is given, as well as R&D opportunities to improve them and aim for more sensor synergy. Concerning precipitation detection and precipitation type observations by automated present weather systems, the following problems are listed:

- Only a few sensors are able to identify drizzle, and with insufficient performance.
- No PW systems identify hail (although specified); only one specific sensor can detect hail (acoustically).
- Mixed precipitation (drizzle/rain or rain/snow) is reported seldom; mostly as rain only, or as snow only.
- Type of precipitation is not well reported during very light precipitation.
- Rate of snowfall is not reported accurately enough or with delay.
- Systems using optics are very sensitive to pollution and require frequent maintenance, especially at coastal stations (deposition of salt by sea spray).

Possible improvements on the precipitation type discrimination by using the particle size information from the FD12P were studied by Bloemink (2004). Especially the detection of the mixture of rain and snow was focused on, since three winters with data from the FD12P and a human observer resulted in very poor agreement for this type. The measured particle size distributions under wintry conditions were analyzed to possibly join this information with the existing PWc correction at KNMI. Although the use of this information resulted in a clearer distinction between rain and snow, it was concluded that an improvement for the mixture of rain and snow is not likely. However, an improvement for the distinction between drizzle and a mixture of rain and drizzle seemed possible.

1.3 Goals and outline

As noted in Section 1.2, some typical problems regarding the detection of precipitation and the discrimination of precipitation type arise from earlier work. This study has the main objective to investigate possible improvements regarding the automated observation of precipitation type originating from the Vaisala FD12P weather sensor. This involves making suggestions for additional precipitation type corrections in the processing system of KNMI, as well as of assessing possible adjustments in the parameters of the sensor's internal software. The latter practice will be dependent on the degree of cooperation with the manufacturer, because detailed information on the internal algorithm of the sensor is not available. Firstly, the main problems concerning the discrimination of precipitation type should be identified. This task is executed by means of overlapping data from the FD12P and a human observer, observations from collocated FD12P sensors and an analysis of the hourly issued automated weather codes, which are validated by KNMI for climatological use and monitoring purposes.

More specifically, the following actions are a part of this study:

- Give an overview of the frequency distribution of precipitation types from manned and automated observations in the Netherlands.
- Define the main problems concerning observations of precipitation type at KNMI.
- Compare coinciding automated and manned observations for the period 2000-2002 as an extension of the analysis carried out by Wauben (2002).

- Define regimes in other meteorological parameters (e.g. wet bulb temperature, precipitation intensity and visibility) during which problems in the discrimination occur.
- Test additional corrections in the processing of precipitation type to improve the overall performance of the automated system. Specifications of these corrections were obtained from experience and ongoing work or from e.g. cross correlations which are discussed in ICAO Document 9837 (ICAO, 2006).
- Analyze the corrections introduced in the hourly climatological data by the validation carried out by the I-ID department of KNMI.
- Examine the performance of collocated FD12P sensors, indicating roughly the decrease in agreement which can be attributed to the sensor characteristics and the distance between the sensors.
- Send interesting cases for the identified problems to Vaisala for analysis and reprocessing, to investigate the possibility of optimizing the internal algorithm of the FD12P.
- Explore the added value of precipitation type discrimination using temperature profile information (Ivens, 1987). This method is used at KNMI for forecasting wintry precipitation using modeled temperature profiles and radar observations.

Firstly, in Chapter 2 background information will be given on the precipitation type discrimination by the FD12P sensor, as well as the processing of measurements in the KNMI central database. Since verification scores are used as performance indicators in large parts of this report, some commonly used verification scores are also described briefly.

Chapter 3 gives an overview of the occurrence of precipitation types reported by the human observer and the automated system at eight stations in the period 1990-2006.

In Chapter 4 a comparison of coinciding manned and automated observations for six stations in the Netherlands is discussed. Representative events for the most striking differences are gathered and analyzed with respect to the regimes of occurrence.

Chapter 5 lists the six existing KNMI PWc corrections and 25 other opportunities (PWc+) to improve the precipitation type from the FD12P. The PWc corrections and 18 PWc+ corrections are tested and their added value is investigated.

Collocated observations of precipitation type from identical FD12P sensors are studied in Chapter 6. Firstly, data from two closely collocated sites in De Bilt are compared. Furthermore observations from seven FD12P sensors at Schiphol airport are compared and the spatial dependency of the observations is analyzed. Finally, an exploration of the occurrence of freezing precipitation at Schiphol is carried out, including the location of the temperature and humidity sensors which are used to correct freezing precipitation.

Chapter 7 compares hourly based unvalidated observations of precipitation type with observations validated by the I-ID department of KNMI, for 14 stations in the Netherlands in the period 2003-2006. An analysis of the cumulative differences in precipitation duration and intensity with respect to the rain gauge on the same site is performed.

In Chapter 8 a preliminary exploration of the so-called NeSo method (Ivens, 1987) is presented. Temperature profiles from radiosonde and HIRLAM are used to compare the output of this method with precipitation type reports from the automated system for a period of 18 months.

Chapter 9 gives the conclusions of this study and also lists some recommendations for possible improvements and further research.

2 Precipitation type determination

2.1 The Vaisala FD12P

The Vaisala FD12P weather sensor (Vaisala, 1998) uses the principle of forward scattering for measurements of visibility and precipitation amount and type. The sensor consists of an optical transmitter and receiver and a capacitive detector which are mounted on a two meter high pole mast. It is also equipped with an internal temperature sensor and optionally a background luminance sensor is placed on top. The transmitter emits pulses with a wavelength of 875 nm at a frequency of 2.3 kHz. The receiver unit measures the intensity of the light which is scattered in the sample volume. The sample volume has a size of approximately 0.1 dm^3 and is formed by the intersection of the transmitter and receiver beams, which meet each other at an angle of 33° on a height of about 1.75 m above the surface. Figure 2.1 shows a picture of the FD12P sensor in De Bilt.

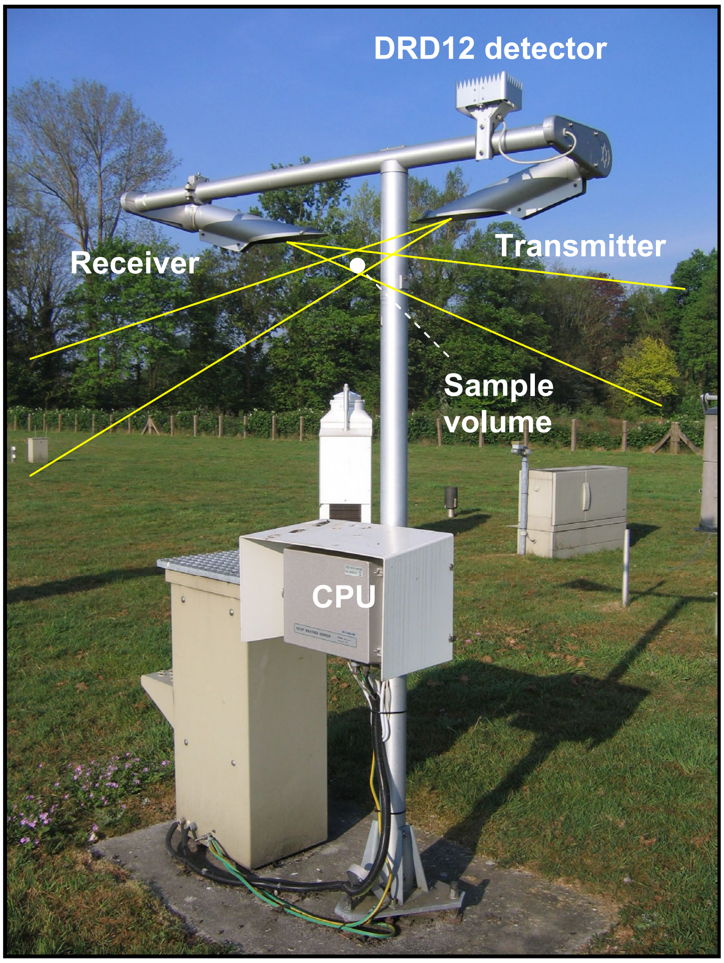

Figure 2.1. The Vaisala FD12P weather sensor in De Bilt (station 260).

When no substantial particles are present in the sample volume, the receiver will record a continuous signal, from which the extinction and Meteorological Optical Range (MOR) are determined. In those cases, the light is only scattered on aerosols. However, when precipitation falls through the sample volume, peaks are visible in the recorded signal. The amplitude of a peak is proportional to the size of the scattering particle. A noise limit is calculated to distinguish between signal peaks caused by noise and signal peaks caused by precipitation particles. The capacitive precipitation detector delivers a second important signal, which is dependent on the thickness of the water film on the detector. This signal is a measure of the liquid water content of the precipitation. The fallen precipitation is removed quickly from the sensor because it consists of two slanted detectors, which are heated. The DRD12 detector is surrounded by a shield to minimize the effects of wind and birds.

The precipitation type discrimination of the FD12P is primarily based on the typical differences in signals which are measured during events with liquid and solid precipitation (Vaisala, 2000). A schematic illustration of the basic precipitation type determination in the internal software is shown in Figure 2.2. Solid precipitation causes a lower signal on the capacitive detector than liquid precipitation, for particles of the same size. Hence the ratio of the optical signal and the DRD12 detector signal is used to determine the basic precipitation type. The temperature of the sensor is also included, for example for the discrimination between liquid and freezing precipitation. Furthermore, the maximum size within the particle size distribution is used to determine the precipitation type in more detail, e.g. to distinguish into rain and drizzle or snow and snow grains.

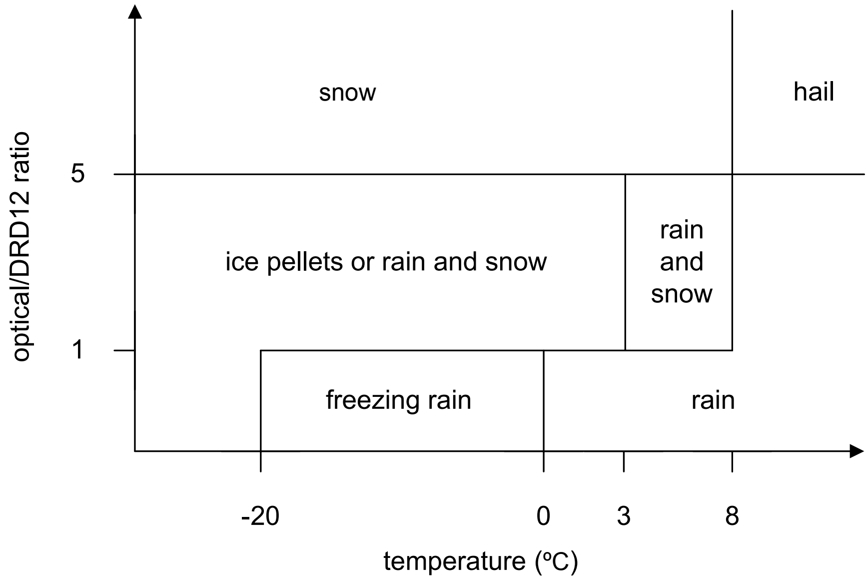

Figure 2.2. Illustration of the basic precipitation type determination by the FD12P.

The actual precipitation type is determined in the internal software from the analysis of the measurements of the last 15 seconds to 5 minutes at maximum. Some time delay is taken into account to deliver smooth transitions of the precipitation type. The internal software enables the user to adapt several parameters dependent on e.g. local climate conditions. The actual precipitation type is reported by the FD12P every 15 seconds in NWS and PW code (see Table 2.1), together with the MOR, precipitation intensity and background luminance (optional). The accuracy of the measured precipitation intensity is about 30 %, the sensitivity of detection is better than 0.05 mm/h. The sensor also reports a code for present and past weather and the cumulative precipitation amount, but these are not in use at KNMI. The precipitation duration is not directly measured by the sensor, but calculated in the SIAM (Sensor Intelligent Adaptation Module) from all 12-second intervals for which the 1-minute precipitation intensity is above 0.05 mm/h.

Table 2.1. Precipitation types reported by the FD12P.

Precipitation type	Dutch translation	PW code	NWS code	METAR code
No precipitation	Geen neerslag	00	C	-
Unknown precipitation	Neerslag (onbekend type)	40	P	UP
Drizzle	Motregen	50	L	DZ
Freezing drizzle	Onderkoelde motregen	55	ZL	FZDZ
Drizzle and rain	Motregen en regen	57	LR	DZRA
Rain	Regen	60	R	RA
Freezing rain	Onderkoelde regen	65	ZR	FZRA
Drizzle/rain and snow	Motregen/regen en sneeuw	67	LRS	RASN
Snow	Sneeuw	70	S	SN
Ice pellets	IJsregen	75	IP	PL
Snow grains	Motsneeuw	77	SG	SG
Ice crystals	IJsplaatjes/ijsnaaldjes	78	IC	IC
Snow pellets	Korrelhagel/korrelsneeuw	87	SP	GS
Hail	Hagel	89	A	GR

2.2 Data acquisition and processing

The KNMI SIAM DZ4 sensor interface (Bijma, 2006) polls the FD12P every 12 seconds, which is the default sample interval in the KNMI observation network. The SIAM generates the 12-second sample, 1-minute and 10-minute maximum, minimum and average values of the precipitation type. It translates the actual NWS codes from the FD12P to PW codes. At automated weather stations, the data is collected locally and forwarded every 10 minutes to the central database (CIBIL) of KNMI in De Bilt. For airports, the data is also stored and processed locally. For more details on the KNMI network architecture at automated stations and airports, the reader is referred to Wauben et al. (2002).

A precipitation type correction is executed in the CIBIL database computer every 10 minutes. This correction adapts the 1-minute value of a PW code to the PWc code, if it was reported under suspicious conditions. By default, the PWc code equals the PW code. Correction criteria were empirically derived from some years of experience with the FD12P sensor by KNMI and the Swedish Meteorological and Hydrological Institute (SMHI). The PW correction uses several meteorological parameters which are measured by the FD12P or other collocated sensors. It is discussed in more detail in Section 5.1.

The central database computer determines the 10-minute 'averaged' PWc code from ten 1-minute values of PWc. Generally, this is the most important (maximum) value of PWc which has occurred during the 10-minute interval (Wauben, 2001). An exception is made for the occurrence of mixed precipitation. If 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 the time then a mixture of drizzle/rain and snow (67) is reported. Similarly a mixture of rain and drizzle (57) is determined if rain (60) is the most important type and both rain and a combination of the PWc codes 50 and 57 occur at least 30% of the time. If less than 7 out of 10 1-minute values in the 10-minute interval are available, the PWc code is not reported.

KNMI operates a weather code generator to generate w_aw_a-weather codes from the observations in the CIBIL database, in conformity with WMO Table 4680 (WMO, 1995; Appendix B.2). The generator is executed at the end of each 10-minute interval. The w_aw_a-code reports the most significant weather of the past hour, in which the last 10 minutes are considered first. It is reported for automated weather stations only and is the alternative for the hourly ww-code reported for manned weather stations (in conformity with WMO Table 4677, see Appendix B.1). Significant differences exist in the descriptions and timing of the ww- and w_aw_a-codes. Hence they can not easily be compared. Therefore all comparisons in this report are based on the actual precipitation type, expressed in PW or PWc code. A classification of possible manned and automated actual weather codes for each PW code is listed in Table 2.2. This table is used throughout this report for the translation to the PW code in case that the used data consists of a weather code only. Note that although a human observer does not report unknown precipitation (40), the non-unique description of ww-codes 95 en 97 in Table 4677 oblige us to translate them as such.

Table 2.2. Translation table for manned (ww) and automated (w_aw_a) weather codes to actual PW code for precipitation at the time of observation.

Precipitation class	PW	NWS	ww-codes	w_aw_a -codes
Solid	89	A	89+90+96+99	89+93+96
	87	SP	87+88	
	78	IC	76+78	78
	77	SG	77	77
	75	IP	79	74-76
	70	S	70-75+85+86	70-73+85-87
	67	LRS	68+69+83+84+93+94	67+68
Freezing	65	ZR	66+67	64-66
	55	ZL	56+57	54-56
Liquid	60	R	60-65+80-82+91+92	60-63+81-84
	57	LR	58+59	57+58
	50	L	50-55	50-53
Unknown	40	P	95+97	40-49+80+92+95
No precipitation	00	C	0-49	0-39+90+91+94+99

The meteorological parameters relevant to the precipitation type and which will be used to discuss the analyses, are listed in Table 2.3. Generally, these parameters are 10-minute average values, unless mentioned otherwise. The PWc corrections discussed in this report are however applied on a 1-minute time basis. The name conventions in this table will be used throughout the report. Translations from WW to PW_WW and WaWa to PW_WaWa are carried out in accordance with Table 2.2.

Table 2.3. Parameters used in the analyses discussed in this report.

Parameter	Description	Unit
WW	Weather code (human observer) past hour	-
PW_WW	PW code from weather code (human observer)	-
WaWa	Weather code (automatic) past hour	-
PW_WaWa	PW code from weather code (automatic)	-
PWc	Corrected PW code	-
PW	PW code	-
PW(c)-1	(Corrected) PW code previous time interval	-
PW(c)+1	(Corrected) PW code next time interval	-
PI	Precipitation intensity FD12P	mm/h
PD	Precipitation intensity FD12P	s
NI	Precipitation intensity rain gauge	mm/h
ND	Precipitation duration rain gauge	s
ZM	Meteorological Optical Range (MOR) FD12P	m
PS	Surface pressure	hPa
TA	Air temperature (1.5 m)	°C
TW	Wet bulb temperature	°C
TG	Grass temperature (10 cm)	°C
RH	Relative humidity	%
C1	Lowest cloud base	m
NC	Total cloud cover	octa

2.3 Verification scores

The performance of categorical measurements and forecasts is commonly expressed in a number of verification scores. A 2x2 contingency matrix can be made for the results of each combination of “yes/no” events, see Table 2.4. Each event can be classified in one of the four cells in the matrix, corresponding to the situations below:

a: both the human observer and the sensor report the event (correct hit)
b: the human observer reports the event, but the sensor does not (missed event)
c: the sensor reports the event, but the human observer does not (false alarm)
d: both the human observer and the sensor do not report the event (correct rejection)

The total number of events is **n = a + b + c + d**
The total number of relevant events is **N = a + b + c**

Table 2.4. Illustration of a 2x2 contingency matrix for comparing observations from a sensor and a human observer.

		Sensor	
		Yes	**No**
Human observer	**Yes**	**a** : correct hits	**b** : missed events
	No	**c** : false alarms	**d** : correct rejections

The verification scores are subsequently expressed as a function of the values in the matrix. The numbers of entries in the 2x2 contingency matrix are used to determine the following verification scores (Kok, 2000):

Probability of Detection (POD) = 100% * a/(a+b)
The POD indicates the fraction of the total number of human observations of an event that is correctly reported by the sensor.
False Alarm Ratio (FAR) = 100% * c/(c+d)
The FAR indicates the fraction of the number of sensor observations that is not reported by the human observer.
Critical Success Index (CSI) = 100% * a/(a+b+c)
The CSI indicates the number of correct hits with respect to the sum of the number of correct hits, missed events and false alarms. The number of correct rejections (**d**) is not incorporated in the score and therefore it is commonly used for phenomena with a low frequency of occurrence.
Heidke Skill Score (HSS) = 100% * (ad-bc)/((ad-bc) + ½n(b+c))
The HSS is another popular verification score that indicates how well a sensor performs with respect to a human observer. This score is corrected for the chance one would have by employing random guess. A negative outcome implies a worse result and a positive outcome a better result than random guess.
BIAS = (a+c)/(a+b)
The BIAS is also given for each contingency matrix in the report. The bias is equal to the ratio of the number of sensor observations and the number of human observations.

3 Precipitation types in the Netherlands 1990-2006

3.1 Introduction

This section gives an overview of the occurrence of different precipitation types in the Netherlands for the period 1990-2006. This information indicates the relative contribution of each precipitation type in the total number of observations and should be consulted when the main problems in precipitation typing are identified. Generally, the analysis period can be divided in a period with manned observations (1990-2002) and a period with automated observations (2002-2006). More precisely, the automated observations at KNMI started on November 20, 2002 for synoptical and climatological reports. A change in the frequency distribution of the different precipitation types during the transition from the first to the second period can be interpreted as a first indication of a change in the characteristics due to the automated system, although year-to-year variations occur. It must be remarked that the automated observations may be influenced to some extent by the corrections applied during the hourly validation at KNMI (see Section 7).

A data set with observations from hourly SYNOP reports for eight stations in the Netherlands is used for this purpose. The stations used are Valkenburg (WMO code 210), De Kooy (235), Schiphol (240), De Bilt (260), Eelde (280), Vlissingen (310), Rotterdam (344) and Beek (380). A map of the Netherlands indicating the locations of these stations is found in Appendix A. Hourly ww-codes and w_aw_a-codes are acquired for the manned and automated observations, respectively. The i_x parameter (WMO Table 1860) is included in the SYNOP report and indicates whether the measurement is performed by a human observer (1-3) or by an automated system (4-7). The actual PW codes for both types of observations are determined by translating the weather codes following Table 2.2. The total number of hourly observations included is about 150000 per station for the whole period. Note that the calculated occurrences indicate the fraction of 10-minute intervals for which a certain precipitation type was reported. This is different from the duration of precipitation as a fraction of total time, since it is assumed here that precipitation occurs for the whole interval. Moreover, the 10-minute precipitation type is generally equal to the highest PW code found in the interval (Section 2.2). Hence, one should keep in mind that lower PW codes are overruled and that their occurrence could be underestimated.

3.2 Manned and automated observations

Time series of the annual relative occurrence of actual precipitation type reports in the hourly manned and automated observations of the eight stations are shown in Figure 3.1. On average a precipitation type is reported in 12.4% of the total number of observations, which implies that in almost 9 out of 10 cases no precipitation is observed in the 10-minute interval. The lines for the different stations follow the average value fairly well, the most precipitation events occur in the years 1993, 1998 and 2000. The highest average frequency of occurrence over all years is seen for De Bilt (260), where a value of 13.9% is found. On the other hand, actual precipitation is reported at Valkenburg (210) only 10.9% of time on average. The same stations arise when the maximum and minimum occurrences of precipitation type reports are considered for manned observations only.

A distinction between the observed precipitation types in the manned and automated observation period is made in Table 3.1. The manned period (a) contains hourly observations from January 1, 1990 to November 20, 2002, the automated period (b) from November 20, 2002 to December 31, 2006. The frequency of occurrence of missing events (N/A) and precipitation events (Ppn) is given as a percentage of the total number of available observations, whereas the values for the individual precipitation types are expressed relative to the number of observations with precipitation.

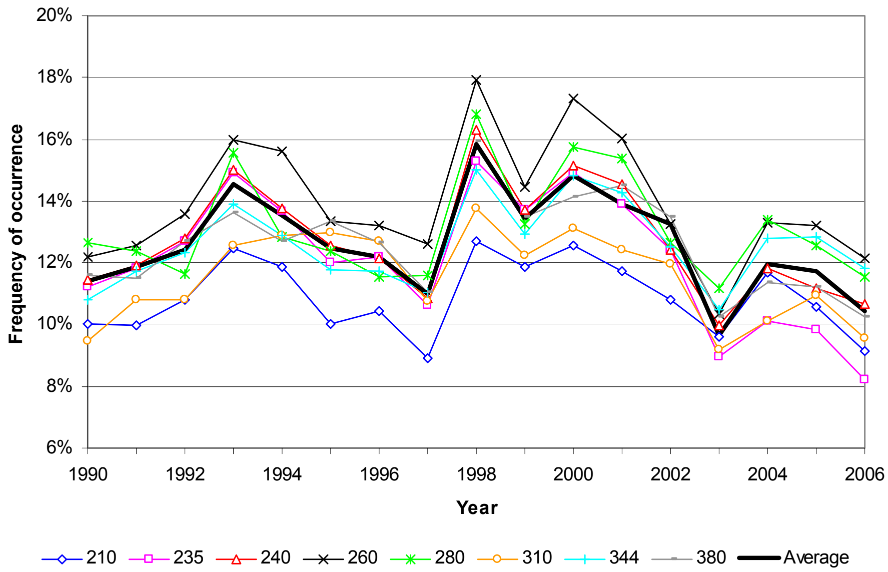

Figure 3.1. Time series of the annual relative occurrence of actual precipitation for the eight stations, over the period 1990-2006.

Table 3.1a. Frequency of occurrence of precipitation type reported by the human observer in the period January 1, 1990 - November 20, 2002. The value 0.0% indicates an occurrence lower than 0.05% and an empty cell indicates no events at all.

				Liquid			Freezing		Solid						
Station	**N/A**	**Ppn**	**P**	**L**	**LR**	**R**	**ZL**	**ZR**	**LRS**	**S**	**IP**	**SG**	**IC**	**SP**	**A**
210 Valkenburg	0.4%	11.1%	1.9%	12.1%	4.9%	76.6%	0.3%	0.1%	0.9%	1.9%	0.1%	0.3%		0.8%	0.1%
235 De Kooy	0.3%	13.0%	1.5%	13.3%	6.7%	72.9%	0.4%	0.1%	1.1%	2.3%	0.1%	0.4%		1.0%	0.1%
240 Schiphol	0.4%	13.3%	1.3%	14.8%	15.6%	62.5%	0.3%	0.2%	1.1%	2.6%	0.0%	0.6%		0.9%	0.1%
260 De Bilt	0.2%	14.6%	1.5%	20.2%	10.2%	61.8%	0.5%	0.1%	0.9%	2.7%	0.2%	1.0%		0.7%	0.2%
280 Eelde	0.6%	13.4%	1.3%	19.9%	14.2%	56.7%	0.4%	0.2%	2.2%	3.9%	0.1%	0.7%		0.4%	0.0%
310 Vlissingen	0.3%	12.0%	1.6%	14.7%	6.7%	72.6%	0.3%	0.2%	0.6%	1.6%	0.1%	0.8%	0.0%	0.6%	0.1%
344 Rotterdam	0.4%	12.7%	1.5%	15.0%	13.3%	65.2%	0.3%	0.1%	1.2%	2.3%	0.1%	0.4%		0.7%	0.1%
380 Beek	0.5%	13.1%	1.1%	17.7%	13.8%	58.5%	0.4%	0.1%	1.5%	5.2%	0.1%	1.3%	0.0%	0.1%	0.1%
Average	**0.4%**	**12.9%**	**1.4%**	**16.1%**	**10.8%**	**65.5%**	**0.4%**	**0.2%**	**1.2%**	**2.9%**	**0.1%**	**0.7%**	**0.0%**	**0.8%**	**0.1%**

Table 3.1b. Same as Table 3.1a, but for automated observations in the period November 20, 2002 - December 31, 2006.

				Liquid			Freezing		Solid						
Station	**N/A**	**Ppn**	**P**	**L**	**LR**	**R**	**ZL**	**ZR**	**LRS**	**S**	**IP**	**SG**	**IC**	**SP**	**A**
210 Valkenburg	1.7%	10.4%	1.8%	29.9%	10.3%	52.2%	0.0%	0.1%	0.5%	4.0%	0.0%	1.1%			
235 De Kooy	0.3%	9.4%	1.7%	26.9%	9.8%	55.4%	0.4%	0.2%	0.8%	4.0%	0.0%	0.9%			
240 Schiphol	0.1%	11.0%	2.0%	20.3%	12.7%	58.9%	0.0%	0.1%	1.0%	3.8%		1.1%			
260 De Bilt	0.0%	12.2%	1.7%	17.9%	12.8%	61.6%	0.1%	0.1%	1.0%	3.6%	0.1%	1.2%			
280 Eelde	0.0%	12.2%	1.1%	28.0%	9.0%	53.3%	0.3%	0.3%	0.7%	5.9%	0.0%	1.4%			
310 Vlissingen	0.1%	10.2%	1.4%	25.5%	15.2%	53.2%	0.1%	0.2%	0.7%	2.9%		0.9%			0.0%
344 Rotterdam	0.2%	12.1%	2.1%	22.9%	13.7%	55.9%	0.2%	0.1%	0.7%	3.4%	0.0%	1.0%			
380 Beek	0.0%	11.0%	1.9%	26.4%	9.2%	50.8%	0.1%	0.1%	1.1%	8.0%	0.0%	2.3%			
Average	**0.3%**	**11.1%**	**1.7%**	**24.5%**	**11.6%**	**55.3%**	**0.1%**	**0.2%**	**0.8%**	**4.5%**	**0.0%**	**1.2%**			**0.0%**

A precipitation type is reported in 12.9% of the total number of manned observations and in 11.1% of the total number of automated observations. For both types of observations, most precipitation events are found for De Bilt (260) and Eelde (280), while stations Valkenburg (210) and Vlissingen (310) report the least precipitation events. Generally the stations show a decrease of 1% to 2% in the number of events with a precipitation type reported after the transition to automated observations, but it is evident that the decrease at station De Kooy (235) is more pronounced (-3.6%). The results for the automated period show that precipitation is generally reported less frequent for the coastal stations Valkenburg, De Kooy and Vlissingen. It is obvious that the breakdown of the liquid precipitation class is very different for the manned and automated period. More drizzle (L) is reported in the automated observations, increasing from 16.1% to 24.5%, at the expense of rain events (R), for which the frequency of occurrence has decreased at the same time from 65.5% to 55.3%. The ratio of the annual relative occurrences of drizzle and rain for the eight stations is presented in Figure 3.2.

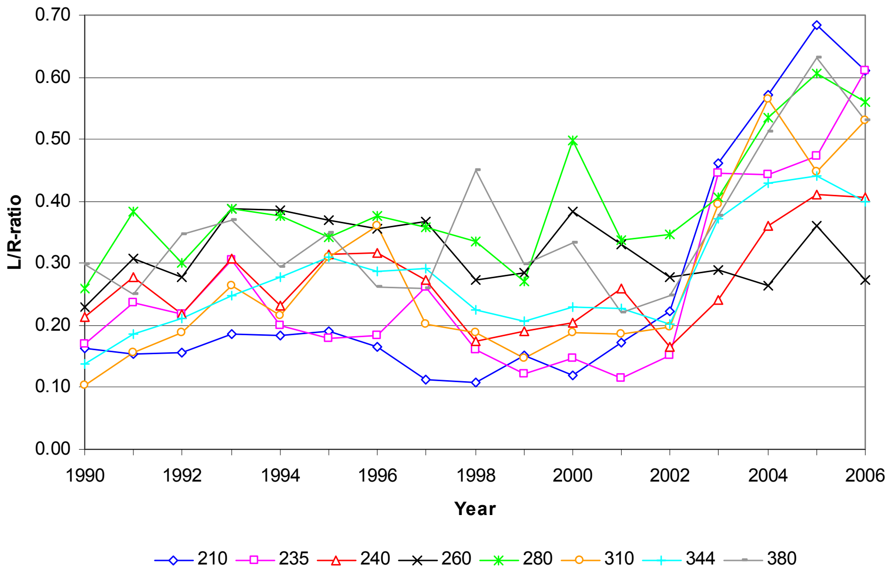

Figure 3.2. Time series of drizzle/rain-ratio (L/R) for the eight stations, 1990-2006.

The observed L/R-ratio varies between 0.1 and 0.5 in the manned period, whereas it strongly increases for most stations after the automation of visual observations. The strongest increase is seen for station Valkenburg (210), which reaches a value of 0.68 in 2005. Remarkably, this station shows on average the lowest value for L/R during the period with manned observations. The other stations generally show a higher L/R in the automated period as well, only station De Bilt (260) does not show significant higher values. The differences in L/R-ratio are very pronounced, but not very important to users of the precipitation type observations. It is more important that observations are correctly classified as liquid precipitation or not. Moreover, the indirect effect of a changing L/R-ratio on for example the reduction of visibility should be evident from the reported visibility itself.

Freezing precipitation is reported by the automated system (0.3%) less frequently than by the human observer (0.5%). As freezing drizzle (ZL) and freezing rain (ZR) are in general rare phenomena and two completely different periods are considered here, no conclusions can be deduced from this difference. However, the reduction is especially seen for freezing drizzle and thus might be related to a reduced detection by the automated system of precipitation at low intensities. Solid precipitation is reported for 5.9% of the number of precipitation events on average. The frequency of occurrence observed for solid precipitation is the highest for stations Beek (380) and Eelde (280), which can be expected based on their eastern location and agrees well with climatological information for the Netherlands in the period 1971-2000 (Sluijter and Nellestijn, 2002). On average 7.3% and 8.3% of the total number of precipitation events is classified as solid in Beek and Eelde for the manned period, for the automated period these numbers are 8.0% and 11.5%. Again no conclusions can be drawn from the observed differences, since the periods are not comparable due to the strong variability of the occurrence of solid precipitation from year to year. Years with solid precipitation occurrence above the average are 1996 (13.0%), 2001 (10.3%) and 2005 (11.3%), while in the years 1992, 1997 and 2002 solid precipitation was only reported in 2.3%, 2.3% and 1.0% of the number of precipitation events, respectively. It is evident that the automated system is not able to detect events with snow pellets (SP) and hail (A). The frequencies of occurrence for these types are 0.8% and 0.1% for the human observations, respectively, but diminish almost to zero for the automated period. Only one event of hail was reported by the automated system in Vlissingen (310).

This feature is also markedly present in the subdivision of the solid precipitation class in Figure 3.3, for the manned (a) and automated (b) observations. The frequency of occurrence for each solid precipitation type is relative to the total number of solid precipitation events. While snow pellets and hail contribute up to 23% to solid precipitation in the manned period, these types have completely disappeared in the figure for the automated observations. Furthermore, less events of the mixture drizzle/rain and snow (LRS) are reported for the automated observation period, while snow and snow grains are reported more frequently. The relative contribution of LRS in the solid precipitation class is on average 20.9% for the manned and only 12.4% for the automated observations. As a percentage of the total number of precipitation observations, this amounts to 1.2% and 0.8%, respectively.

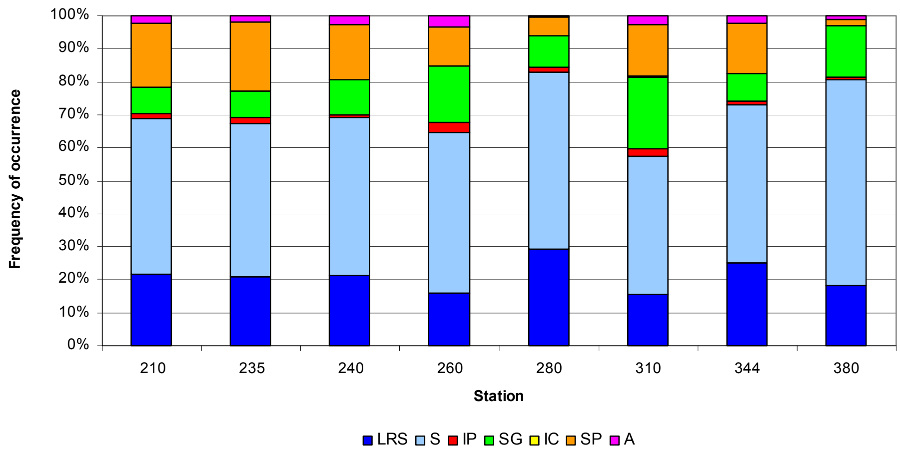

Figure 3.3a. Relative occurrence of solid precipitation types, expressed as percentage of the total number of solid precipitation events in the manned observations (1990-2002) for eight stations.

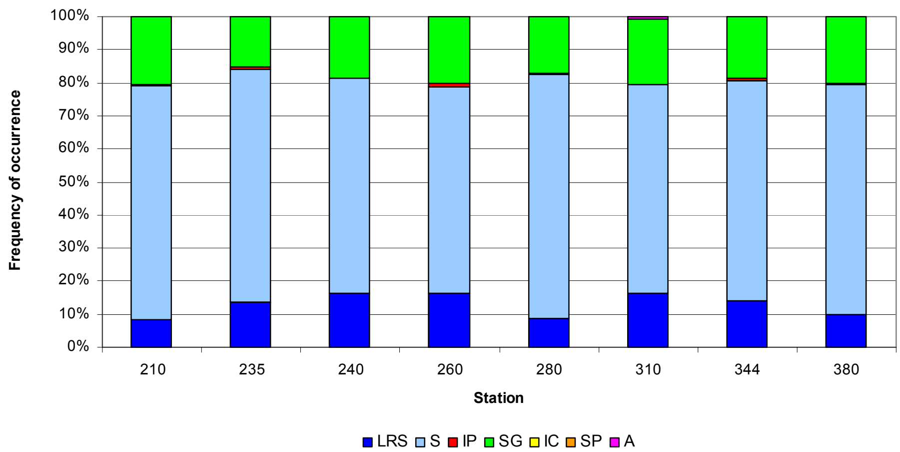

Figure 3.3b. Same as Figure 3.3a, but for automated observations (2002-2006).

4 Comparison with a human observer

4.1 An analysis for six Dutch stations (2000-2002)

The exploration of the performance of automated precipitation type observations by the FD12P is based on the analysis of data from different sources. Hourly observations reported by a human observer at six stations in the Netherlands for the period 2000-2002 are compared with coinciding automated observations at these stations, originating from the 1-minute observations of the FD12P. As the human observer generates a hourly synoptic report for hour hh+1 at hh:50, the ten 1-minute automated observations between hh:45 and hh:55 are included here in the calculation of representative 10-minute values. The uncorrected PW code is used to investigate the initial sensor performance, without any additional corrections. The stations considered in this comparison are De Kooy (235), Schiphol (240), De Bilt (260), Eelde (280), Rotterdam (344) and Beek (380).

A contingency matrix of the comparison is shown in Table 4.1a. A total number of 157824 hourly observations containing all six stations and three years is included. The grey “N/A” cells include events for which the human or automated observation (or both) is not available. These events however do not affect the scores. A large number of automated observations is missing because the 1-minute automated observations were not stored for all stations from January 1, 2000. The main cause of missing human observations is the switch to automated observations in November 2002.

As an example for the interpretation of the contingency matrix: the human observers have reported drizzle (L) in 3474 cases. During these events, the automated observation was not available in 310 cases, and it reported 1535 cases with no precipitation (C), 36 cases with unknown precipitation (P), 983 cases with drizzle, 120 cases drizzle and rain (LR), etcetera. The Band0 and Band1 scores below the matrix indicate the percentage of the total number of observations for which the precipitation type (green) or precipitation class (light green) are observed in conformity with the human observer, respectively. Band0* and Band1* are similarly calculated, but the human observations of events with no precipitation (C) are omitted in these scores.

Table 4.1a. Contingency matrix of observed and measured precipitation type at six stations in the Netherlands, 2000-2002.

	FD12P PW															
Observer	**N/A**	**C**	**P**	**L**	**LR**	**R**	**ZL**	**ZR**	**LRS**	**S**	**IP**	**SG**	**IC**	**SP**	**A**	**Sum**
N/A	719	7494	31	284	156	661	14	5		18	8	6				9396
C	5230	117657	286	1238	248	2233	9	2	2	90	28	88				127111
P	2	25	3	1	7	253				2	3					296
L	310	1535	36	983	120	461	1		3	17	6	2				3474
LR	98	182	17	759	365	938	1		4	2	6	2				2374
R	545	1722	101	2005	1693	7689		2	6	13	30	2			2	13810
ZL		12	6	2	1	1	5	1		1		2				31
ZR		2				9	2	11				1				25
LRS	11	20	13	31	19	106		2	6	38	63	7				316
S	5	64	21	11	4	22			5	440	106	59				737
IP				1		4		1		1		1				8
SG	7	20	2	5	2	1	2			30	8	20				97
IC																0
SP	8	16	14	6	6	54			1	9	18	2				134
A	2	2			1	9				1						15
Sum	6937	128751	530	5326	2622	12441	34	24	27	662	276	192	0	0	2	157824

N/A	9.9%	Band0	89.4%	Band0*	46.8%	Band1	93.9%	Band1*	78.0%

Table 4.1b lists an overview of the verification scores for the precipitation classes which were defined in Table 2.2: liquid (L, LR and R), freezing (ZL and ZR) and solid (LRS, S, IP, SG, IC, SP and A) precipitation. The POD, FAR and CSI scores for the overall detection of

precipitation are 82%, 20% and 68%. The scores for liquid precipitation resemble these very much, because most of the precipitation falls in a liquid form. The scores for the other precipitation classes are fairly lower, showing values for the POD, FAR and CSI of 34%, 51% and 25% for freezing and 64%, 28% and 51% for solid precipitation. Note that especially freezing precipitation is a rare phenomenon (N=76), which questions the reliability of the scores. A bias can be seen with the sensor reporting on average less freezing (BIAS=0.70) and solid precipitation (BIAS=0.88) than the human observer. The frequency of occurrence of the reported precipitation type by the human observer and the FD12P is given in Figure 4.1.

Table 4.1b. Scores for the precipitation classes, determined from the contingency matrix in Table 4.1a. The reports from the human observer are along the vertical.

Precipitation			*Liquid*			*Freezing*			*Solid*		
	yes	**no**		**yes**	**no**		**yes**	**no**		**yes**	**no**
yes	16729	3600	**yes**	15013	3692	**yes**	19	37	**yes**	815	459
no	4224	117657	**no**	4275	119230	**no**	20	142134	**no**	312	140624
POD		82%	**POD**		80%	**POD**		34%	**POD**		64%
FAR		20%	**FAR**		22%	**FAR**		51%	**FAR**		28%
CSI		68%	**CSI**		65%	**CSI**		25%	**CSI**		51%
HSS		78%	**HSS**		76%	**HSS**		40%	**HSS**		68%
BIAS		1.03	**BIAS**		1.03	**BIAS**		0.70	**BIAS**		0.88
N		24553	**N**		22980	**N**		76	**N**		1586

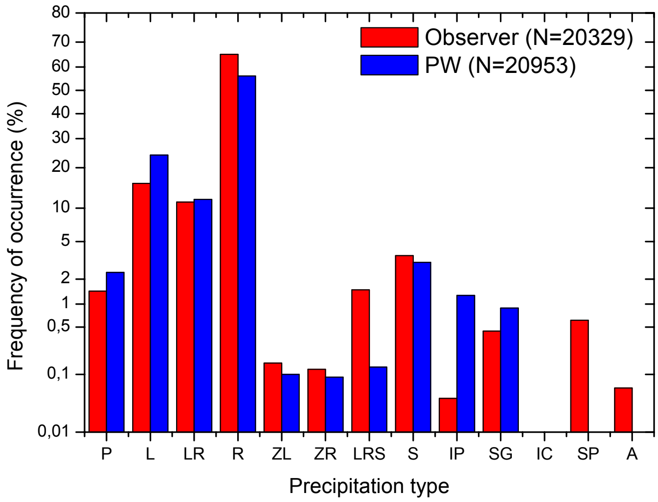

Figure 4.1. Frequency of occurrence of reported precipitation types by the human observer (red) and by the FD12P (blue) at six stations, period 2000-2002.

An overview of the annual scores for the precipitation classes at all six stations individually is listed in Table 4.2. The scores for precipitation detection and the identification of liquid precipitation are again very similar and also relatively constant for the different cases. Whereas the average CSI scores (Sum_pw) are 68% and 65% respectively, the CSI scores for the separate cases vary between 63% and 74% for precipitation detection and between 59% and 74% for liquid precipitation. The calculated biases are fairly close to 1.

The average CSI score for freezing precipitation is only 25%. This poor performance is marked by the variable scores which are seen for the 18 separate cases and is related to the very low frequency of occurrence of freezing precipitation. In some cases, the scores could not even be calculated because of a lack of events. The lower scores are also present more or less for solid precipitation, although it is seen that for example the wintry year 2001 shows reasonable scores for this precipitation class. The CSI scores for solid precipitation in this year range between 46% (Schiphol) and 64% (Eelde).

Table 4.2. Scores for the precipitation classes measured at six stations for the years 2000, 2001 and 2002 separately. The second row shows the overall scores, which were already shown in Table 4.1b.

		Precipitation						*Liquid*						*Freezing*						*Solid*					
Station	**Case**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**
	Sum_pw	**82%**	**20%**	**68%**	**78%**	**1.03**	**24553**	**80%**	**22%**	**65%**	**76%**	**1.03**	**22980**	**34%**	**51%**	**25%**	**40%**	**0.70**	**76**	**64%**	**28%**	**51%**	**68%**	**0.88**	**1586**
De Kooy	235_00	85%	20%	69%	79%	1.06	1047	83%	23%	66%	76%	1.08	1029						0	33%	42%	27%	42%	0.57	26
	235_01	79%	24%	63%	74%	1.04	1542	74%	26%	59%	70%	1.00	1355	100%	50%	50%	67%	2.00	4	72%	32%	54%	69%	1.05	203
	235_02	80%	19%	67%	77%	0.99	1115	79%	19%	66%	77%	0.97	1077		100%	0%	0%		1	0%	100%	0%	0%	2.29	23
Schiphol	240_00	82%	21%	67%	77%	1.04	1614	80%	23%	65%	75%	1.04	1550						0	46%	21%	41%	58%	0.58	64
	240_01	83%	21%	68%	78%	1.06	1559	81%	25%	64%	74%	1.08	1414	44%	43%	33%	50%	0.78	12	53%	23%	46%	62%	0.69	158
	240_02	84%	18%	71%	81%	1.02	1120	83%	19%	69%	79%	1.02	1110						0	0%	100%	0%	0%	1.86	20
De Bilt	260_00	78%	18%	66%	75%	0.95	1754	75%	20%	63%	73%	0.94	1659	0%	100%	0%	0%	1.00	2	66%	31%	51%	67%	0.96	91
	260_01	79%	19%	67%	76%	0.98	1650	75%	22%	62%	73%	0.96	1484	67%	56%	36%	53%	1.50	11	72%	25%	58%	73%	0.96	168
	260_02	82%	12%	74%	82%	0.93	696	80%	13%	71%	80%	0.92	672	0%		0%	0%	0.00	3	24%	78%	13%	23%	1.06	31
Eelde	280_00	81%	19%	68%	78%	1.00	1435	80%	20%	66%	76%	1.00	1346						0	79%	21%	65%	79%	1.00	86
	280_01	85%	20%	70%	79%	1.06	1630	82%	25%	64%	75%	1.10	1397	50%	56%	31%	47%	1.13	13	71%	12%	64%	78%	0.80	235
	280_02	82%	18%	70%	80%	1.00	1131	82%	20%	68%	78%	1.02	1101	33%	50%	25%	40%	0.67	4	50%	31%	41%	58%	0.72	22
Rotterdam	344_00	81%	22%	65%	75%	1.04	1492	78%	24%	63%	74%	1.02	1400						0	65%	23%	55%	70%	0.84	88
	344_01	79%	22%	65%	75%	1.02	1516	76%	27%	59%	71%	1.05	1425	0%		0%	0%	0.00	1	55%	15%	50%	66%	0.64	116
	344_02	81%	18%	69%	79%	0.99	1090	81%	19%	68%	79%	1.00	1081	0%		0%	0%	0.00	2	25%	67%	17%	29%	0.75	6
Beek	380_00	85%	24%	67%	77%	1.11	1387	84%	26%	65%	75%	1.13	1315	33%	20%	31%	47%	0.42	13	64%	28%	51%	67%	0.89	55
	380_01	89%	22%	71%	80%	1.14	1580	88%	22%	70%	80%	1.13	1393	0%	100%	0%	0%	0.14	8	74%	32%	55%	70%	1.09	181
	380_02	89%	18%	74%	83%	1.09	1195	89%	19%	74%	83%	1.10	1172	0%		0%	0%	0.00	2	50%	70%	23%	37%	1.67	13

The automated reports used in this section will undergo a selection here to investigate the impact of several (non-meteorological) parameters. These are primarily timing and threshold parameters to come from 1-minute to 10-minute observations. The verification scores for each precipitation class are used to detect the improvement or deterioration that can be ascribed to the corresponding modification in the used parameters.

The overall scores of the initial data set are given in the second row (Sum_pw) of Table 4.3. The scores in the five rows below the initial scores are representative for changes in the time frame of the automated observations. Hence, the 10-minute PW codes are not constructed from the 1-minute values in the default interval hh:45-hh:55, but in the intervals hh:30-hh:40, hh:35-hh:45, hh:40-hh:50, hh:50-hh+1:00 and hh:55-hh+1:05, respectively. Only the hh:50-hh+1:00 interval shows improvement for all precipitation classes with respect to the CSI scores, but the differences are only small.

Table 4.3. Scores for the precipitation classes measured at six stations, 2000-2002.

	Precipitation						*Liquid*						*Freezing*						*Solid*					
Case	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**
Sum_pw	**82%**	**20%**	**68%**	**78%**	**1.03**	**24553**	**80%**	**22%**	**65%**	**76%**	**1.03**	**22980**	**34%**	**51%**	**25%**	**40%**	**0.70**	**76**	**64%**	**28%**	**51%**	**68%**	**0.88**	**1586**
Sum_hh3040	71%	31%	54%	65%	1.03	26709	70%	32%	52%	64%	1.03	24904	34%	50%	25%	40%	0.68	75	56%	35%	43%	60%	0.86	1658
Sum_hh3545	74%	28%	58%	69%	1.03	26210	73%	30%	55%	67%	1.03	24449	32%	47%	25%	40%	0.61	72	59%	32%	46%	63%	0.86	1628
Sum_hh4050	78%	24%	62%	73%	1.03	25436	76%	26%	60%	71%	1.03	23801	32%	53%	24%	38%	0.68	76	61%	30%	49%	65%	0.87	1602
Sum_hh5000	84%	19%	70%	79%	1.03	24254	82%	21%	67%	78%	1.03	22679	38%	38%	30%	47%	0.61	69	64%	26%	53%	69%	0.86	1555
Sum_hh5505	81%	20%	67%	77%	1.02	24526	80%	22%	65%	76%	1.02	22908	41%	32%	34%	51%	0.61	67	63%	27%	51%	68%	0.87	1572
Sum_max4050	85%	28%	64%	74%	1.19	27188	83%	30%	61%	72%	1.19	25444	38%	51%	27%	42%	0.77	78	68%	35%	50%	66%	1.03	1729
Sum_max405000	89%	32%	63%	73%	1.31	28910	87%	34%	60%	71%	1.31	26985	46%	42%	35%	51%	0.80	75	72%	38%	50%	66%	1.15	1832
Sum_max5000	87%	26%	67%	76%	1.18	26633	86%	28%	64%	75%	1.18	24854	43%	43%	32%	49%	0.75	74	69%	33%	52%	68%	1.04	1710
Sum_1minpw	80%	18%	68%	78%	0.98	23874	78%	20%	65%	76%	0.98	22438	34%	47%	26%	41%	0.64	73	63%	26%	51%	68%	0.86	1562
Sum_itm8	82%	20%	68%	78%	1.03	24539	80%	22%	65%	76%	1.03	22966	34%	51%	25%	40%	0.70	76	64%	28%	51%	68%	0.88	1586
Sum_itm9	82%	20%	68%	78%	1.03	24517	80%	22%	65%	76%	1.03	22950	34%	51%	25%	40%	0.70	76	64%	28%	51%	68%	0.88	1581
Sum_itm10	82%	20%	68%	78%	1.03	24502	80%	22%	65%	76%	1.03	22936	34%	51%	25%	40%	0.70	76	64%	28%	51%	68%	0.88	1581
Sum_day	84%	21%	69%	78%	1.05	12723	81%	22%	66%	76%	1.05	11892	48%	58%	29%	44%	1.14	35	65%	30%	51%	67%	0.93	790
Sum_night	81%	20%	68%	78%	1.01	11830	79%	22%	65%	75%	1.01	11088	26%	40%	22%	36%	0.43	41	63%	25%	52%	68%	0.85	796
Sum_pilt01	59%	39%	42%	57%	0.97	12046	55%	40%	41%	55%	0.92	11100	13%	79%	9%	16%	0.61	46	49%	49%	33%	50%	0.97	735
Sum_pigt01	76%	7%	72%	82%	0.82	16107	75%	11%	69%	79%	0.84	15319	38%	25%	34%	51%	0.51	44	63%	12%	58%	74%	0.72	973

Next, the automated PW code is not chosen as a single value at hh:50, but as the maximum value of a combination of the 10-minute PW codes at hh:40, hh:50 and hh+1:00 in the 'Sum_max4050', 'Sum_max405000' and 'Sum_max5000' cases within the table. The changes are marginal and mostly negative with respect to the initial scores. Only freezing precipitation shows slightly better agreement by using a combination of subsequent PW codes, but only a small number of cases is included. The initial CSI of 25% increases to 27%, 35% and 32% for the maximum of the PW codes at (hh:40 and hh:50), (hh:40, hh:50 and hh+1:00) and (hh:50 and hh:00), respectively. In the case 'Sum_1minpw' the 10-minute precipitation type is set to no precipitation if only one out of ten minutes in the interval reports precipitation. The cases 'Sum_itmx' select the events for which the minimum available number of 1-minute observations in a 10-minute interval has a value 'x'. The default value for x is 7. Next, the distinction between daytime and nighttime observations is made, using the 06-18 UTC reports in the case 'Sum_day' and the 18-06 UTC reports in the case 'Sum_night'. The changes found for all these selections are very small.

The impact of precipitation intensity on the automated detection of precipitation is nicely illustrated in the last two rows. The case 'Sum_pilt01' includes all automated observations with a 10-minute FD12P precipitation equal to or lower than 0.1 mm/h, whereas the case 'Sum_pigt01' includes events with a 10-minute intensity above 0.1 mm/h. It is clear that the automated observations perform better for higher intensities. Both selections have a number of observations of the same order of magnitude for each precipitation class, but the scores diverge largely. The CSI scores for the identification of liquid, freezing and solid precipitation are 41%, 9% and 33% for the low intensities and 69%, 34% and 58% for the high intensities, respectively.

4.2 The main problems

The overall contingency matrix (Table 4.1a) gives insight in the main problems regarding precipitation type identification by the FD12P. Most of them were already cited in Section 1.2. The features that strike the most are:

1. The sensor reports precipitation when the human observer does not and vice versa.
The human observer reports precipitation in 3600 cases when the sensor does not, the opposite occurs in about 4200 cases. Hence there is a small imbalance in the detection of precipitation (BIAS=1.03), with the human observer being less sensitive. Note that differences in observing practices between the human observer and the automated system explain these inconsistencies to some extent. The sensor lacks any kind of spatial information, because its measurement is only representative for the measurement volume of 0.1 dm^3. Precipitation falling in the field of view of the human observer but not exactly on the instrument will not be detected by the sensor. Furthermore the occurrence of intermittently falling precipitation or ending or starting precipitation may cause a timing inconsistency for the human observer and the sensor.

Figure 4.2 shows the histogram and the cumulative probability graph of the precipitation intensity reported by the FD12P and the rain gauge for the 4224 events where the sensor reports precipitation and the human observer does not. It is evident from this figure that this inconsistency typically occurs for low precipitation intensities. The cumulative probability is about 70% for a precipitation intensity below 0.05 mm/h and about 93% for a precipitation intensity below 0.5 mm/h. In the opposite situation, where the human observer reports precipitation and the sensor does not, the reported precipitation intensity by the rain gauge is non-zero in 528 out of 3600 inconsistent events, with an average value of 0.07 mm/h. It should be noted here that the collocation of the human observer, rain gauge and FD12P is poor at some of the used stations. The collocation in De Bilt is quite good but for example at De Kooy the observer and the sensors are separated some hundreds of meters from each other. This effect also contributes to the inconsistencies related to the detection of precipitation.

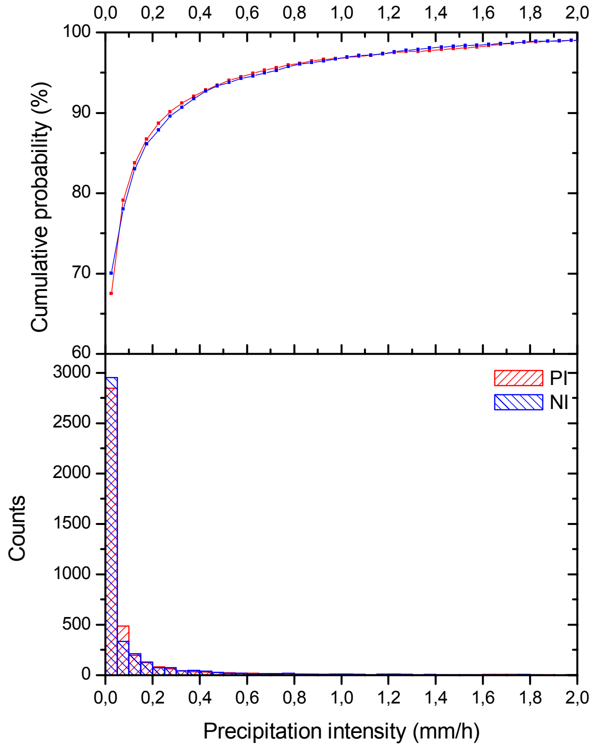

Figure 4.2. Histogram and cumulative probability of the precipitation intensity reported by the FD12P (PI) and rain gauge (NI) for events where the sensor reports precipitation and the human observer does not.

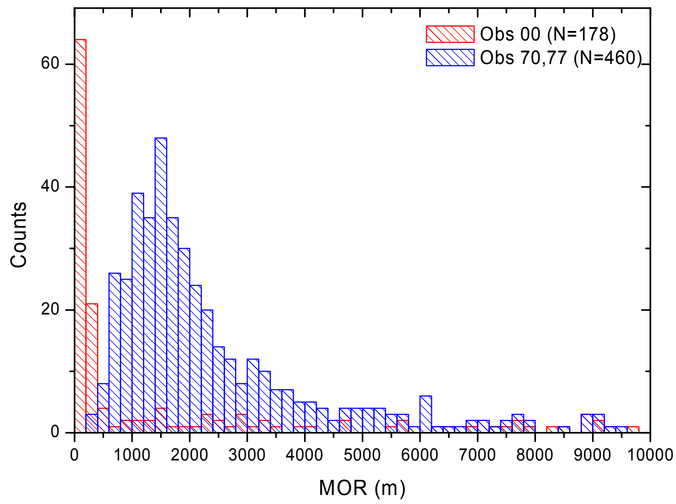

Figure 4.3. Histograms of Meteorological Optical Range (MOR) for sensor reports of snow (S) and snow grains (SG), where the human observer reported no precipitation (C, red) or the correct precipitation type (S or SG, blue).

A special cross correlation is found when the sensor reports solid precipitation, while the human observer reports no precipitation. These events occur when the MOR is very low, typically below 400 m. It seems that the threshold for precipitation detection in the sensor optical signal becomes very low during these events due the occurrence of fog or fog patches. This implies that small variations in the signal may already lead to the faulty detection of precipitation particles, mainly reported as snow or snow grains. This artifact is clearly seen in the histograms of the sensor reports of snow and snow grains in Figure 4.3. The red bars in the histogram (N=178) represents cases for which the human observer does not report precipitation (C), the blue bars (N=459) contains all cases for which the human observer reports the same type as the sensor (i.e. S or SG). It is obvious that all hits with a MOR below 200 m can be classified as false alarms of snow or snow grains.

Two examples of this undesired phenomenon are included in Appendix C. Figures C.1 and C.2 show the time series of 1-minute sensor reports for station De Bilt Test (261) on October 28, 2003 and November 25, 2004, respectively. These cases include 5 and 13 hourly events, respectively, for which the human observer does not report precipitation, while the corrected precipitation type from the FD12P reports snow or snow grains. The 10-minute MOR for these cases is between 130 and 660 m, but mostly below 400 m. It strikes that the automated observations for station 260 (not shown) report snow or snow grains for these events as well.

2. The sensor reports relatively many drizzle events at the expense of rain events.
This artifact was already discussed in Section 3.2. The relative contributions of all precipitation types in the automated and manned observations can be seen in Figure 4.1. It is clear that the sensor reports relatively more drizzle (24%) and less rain (56%) than the human observer does (16% drizzle and 65% rain).

Drizzle is a precipitation type consisting of liquid water drops smaller than 0.5 mm in diameter. It is commonly associated with low stratiform cloud types like stratus and stratocumulus. Classification of drizzle by the FD12P uses the measured particle size distribution, whereas the human observer also uses the information about the source of the precipitation. Nevertheless, this problem is not very important for most users, they appreciate the correct classification of these events within the liquid precipitation class more.

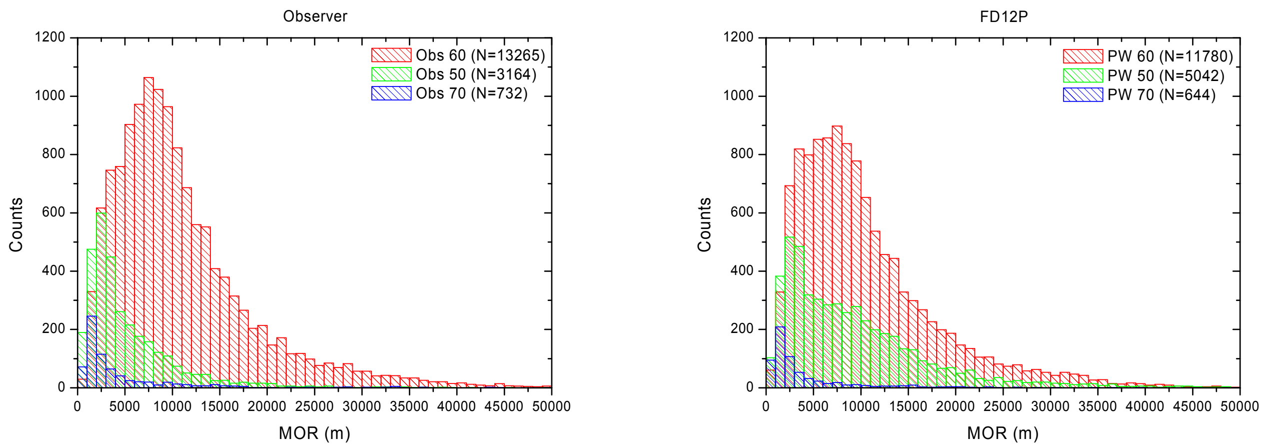

Figure 4.4. Histograms of Meteorological Optical Range (MOR) for rain (60), drizzle (50) and snow (70), according to the observer (left) and FD12P (right).

In Figure 4.4 the histograms of MOR for rain, drizzle and snow are plotted, according to the human observer and the FD12P. It is clear that these three precipitation types more or less have their own regime of occurrence, with observed maxima in the bin 7000-8000 m for rain, the bin 2000-3000 m for drizzle and the bin 1000-2000 m for snow. Of course the precipitation intensity also affects the MOR, but this is not taken into account here. It is evident that the distribution of the drizzle events is much broader for the FD12P than it is for the observer, indicated by a significant contribution for MOR values above 10000 m for the drizzle events reported by the sensor. Relative humidity (RH) and first cloud base (C1) could also be interesting variables for a better discrimination between rain and drizzle (McRobbie, 2002; McRobbie et al., 2002; ICAO, 2006).

3. The sensor has problems to identify freezing precipitation correctly.
The FD12P often reports liquid precipitation or no precipitation (C) when the human observer reports freezing precipitation (ZL or ZR). The same occurs in the opposite direction, but to a lesser extent.

In 20 cases the sensor reports freezing precipitation while the human observer does not. More specifically, the observer does not report precipitation (C) in 11 cases and in 5 cases there is an inconsistency observed with solid precipitation. The number of situations for which the observer reports liquid precipitation is limited to 4. This implies an opposite sign of the FD12P air temperature (or so-called "cross arm temperature") with respect to the wet bulb temperature measured by the temperature and humidity sensor on the site. An additional correction using this wet bulb temperature partially solves these cases.

Table 4.4. Hourly observations on a 10-minute basis at station Beek (380) on December 27, 2000. The parameters #PW and #PWc give the number of automated 10-minute PW and PWc codes reporting freezing precipitation in the past hour.

hhmm	PW_WW	PW	PWc	PI	NI	TW	PW-1	PW+1	#PW_FZ	PWc-1	PWc+1	#PWc_FZ
0050	0	0	0	0.00	0.00	-0.9	0	0	0	0	0	0
0150	0	0	0	0.00	0.00	-0.9	0	0	0	0	0	0
0250	0	0	0	0.00	0.00	-0.8	0	0	2	0	0	2
0350	55	55	55	0.10	0.00	-0.8	55	65	5	55	65	5
0450	55	0	0	0.00	0.00	-0.7	0	55	3	0	55	3
0550	55	0	0	0.00	0.00	-0.4	0	55	1	0	55	1
0650	55	40	40	0.00	0.00	-0.4	0	55	3	0	55	3
0750	55	0	0	0.00	0.00	-0.3	55	0	5	55	0	5
0850	65	55	55	0.12	0.06	-0.2	65	55	5	65	55	5
0950	50	55	55	0.07	0.00	0.0	55	55	6	55	55	6
1050	50	75	67	0.05	0.00	0.1	75	50	2	75	50	2
1150	0	0	0	0.00	0.00	0.3	0	0	0	0	0	0
1250	0	0	0	0.00	0.00	0.6	0	0	0	0	0	0
1350	50	0	0	0.00	0.00	0.6	0	0	0	0	0	0
1450	50	0	0	0.00	0.00	0.2	0	0	0	0	0	0
1550	0	0	0	0.00	0.00	0.2	0	0	0	0	0	0
1650	65	0	0	0.00	0.00	0.0	0	60	0	0	65	0
1750	65	60	65	3.11	2.10	-0.2	77	60	0	77	65	3
1850	65	65	65	1.16	0.68	-0.2	65	65	2	65	65	3
1950	65	55	55	0.21	0.10	-0.2	55	55	3	55	55	3
2050	55	77	77	0.01	0.00	-0.3	75	77	4	75	77	4
2150	0	0	0	0.00	0.00	-0.2	77	0	0	77	0	0
2250	65	77	77	0.02	0.00	-0.2	77	77	0	77	77	0
2350	70	75	75	0.10	0.21	-0.3	75	75	0	75	75	0

The opposite, where there is freezing precipitation according to the human observer which is not reported by the sensor, occurs 37 times. In 20 out of these 37 cases the sensor reports no precipitation at all (C) or unknown precipitation (P). Liquid precipitation is observed by the automated system 13 times, again indicating the opposite signs of the cross arm and wet bulb temperatures as mentioned above, but the other way around. Finally, the sensor reports solid precipitation for 4 10-minute intervals. An analysis of the 1-minute PW codes yields that no liquid or freezing precipitation types is reported during these intervals, hence the solid precipitation does not overrule existing observations of the types with a lower PW code.

Remarkably, 17 out of these 37 cases occur at station Beek (380), mainly on December 27, 2000 and December 17, 2001. A chronological overview of the relevant hourly 10-minute observations at Beek on December 27, 2000 is listed in Table 4.4. Furthermore the time series of 1-minute PW code, 10-minute PWc code and hourly derived PW code from the SYNOP for this day are presented in Figure 4.5. Especially in the morning the sensor reports several events with freezing precipitation, but these do not always coincide with the reports of freezing precipitation by the observer, issued at hh:50. This is seen in the observations at 04:50, 05:50 and 07:50, where there is no precipitation reported by the sensor but the PW codes in the preceding (PW-1) and following (PW+1) intervals indicate the presence of freezing precipitation. The number of PW codes indicating freezing precipitation in the past hour is 3, 1 and 5, respectively.

The corrected PW code (PWc), which will be discussed in detail in the next section, is also included in the table. One of the steps in the PWc correction algorithm adapts 1-minute observations of liquid precipitation to freezing precipitation if the wet bulb temperature TW is equal to or below 0°C, while the opposite happens if TW is greater than 0°C. The effect is visible in the 10-minute observations at 16:50 and 17:50, where the initial codes 60 (rain) for PW and PW+1 are adjusted to code 65 (freezing rain). The correction of PW at 17:50 is in agreement with the human observation. Later in the evening, snow grains (77) are reported by the sensor at 20:50 and 22:50, whereas the human observer still reports freezing precipitation. The corresponding 10-minute intervals do not contain any automated 1-minute detections of freezing drizzle or freezing rain. Hence the priority that is given to solid precipitation over freezing precipitation in the derivation of the 10-minute PW code does not affect the number of misses of freezing precipitation in this case.

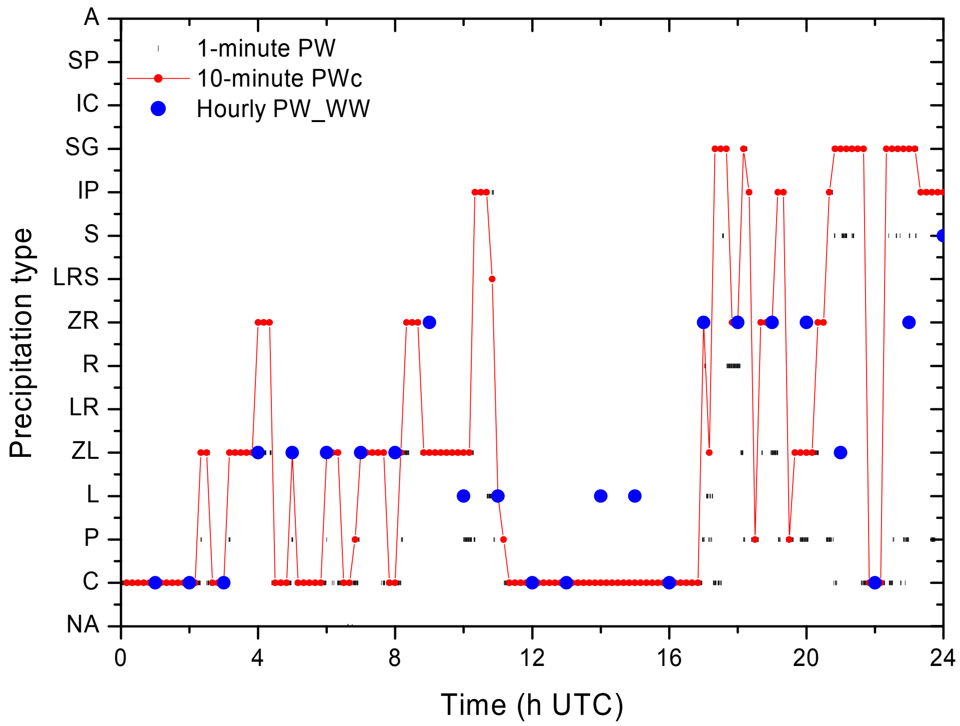

Figure 4.5. Measured 1-minute PW code (black), 10-minute PWc code (red) and hourly PW code reported by the human observer (blue) for Beek on December 27, 2000.

Inconsistencies between liquid and freezing precipitation are generally caused by the different temperatures which are used to classify the precipitation type; the FD12P software uses the cross arm temperature, while the human observer classifies freezing precipitation based on the wet bulb temperature derived from the temperature, humidity and pressure sensors on the site. Possibly the observer deviates from existing regulations for the reports of freezing precipitation because his visual observations do not agree with the findings of the automated system. An accurate timing of the manned observations is likely very important in the comparison, referring to the example mentioned above for station Beek. A detailed analysis of the occurrence of freezing precipitation on different locations at Schiphol airport is presented in Section 6.4.

4. The sensor reports too few events with solid precipitation and the mixture rain and snow. The BIAS for solid precipitation is 0.88, which implies that the FD12P reports 12% less solid precipitation than the observer. This is in agreement with Wauben (2002) where a BIAS lower than 1 (0.73) for solid precipitation was found in De Bilt for the year 2000. The sensor reports a mixture of drizzle/rain and snow (LRS) in only 27 cases, against 316 cases for the human observer. Also snow grains (SG), snow pellets (SP) and hail (A) are observed significantly less by the sensor. Ice pellets on the other hand are observed clearly too much (BIAS=33.5). In this part, the focus will be on the discrimination between the occurrence of snow and rain (or a mixture of them), whereas the problems concerning the identification of ice pellets and hail are discussed further onwards in this section.

Mixtures of drizzle/rain and snow are hard to detect, because they are often preceded or followed by events with solely liquid or solid precipitation. Hence the timing of the measurement is very important. Furthermore the observer may distinguish a few snow flakes during rainfall easily, but these few particles may be averaged out by the sensor. The CIBIL algorithm in use for the generation of 10-minute mixture events from 1-minute observations (see Section 2.2) might also play a role here, besides the sensor performance itself. An example of failing detection of the mixture of drizzle/rain and snow according to the observer is seen in the time series of sensor data at station 261 for February 26, 2001 (Appendix C, Figure C.3). Whereas the human observer in De Bilt reports LRS at 13:50, 16:50 and 23:50, the corrected precipitation type from the automated system indicates the occurrence of either rain or snow.

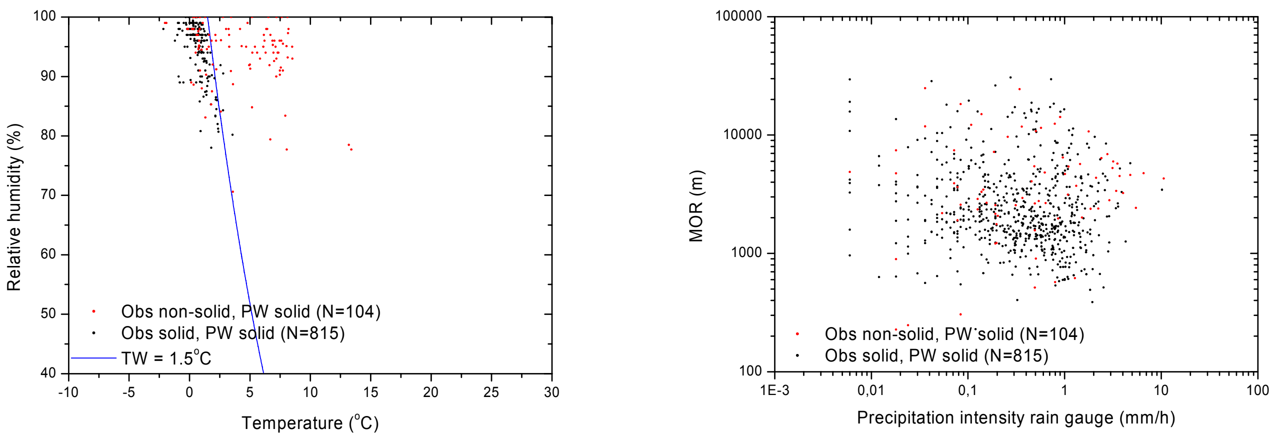

Figure 4.6. (TA,RH)-diagram (left) and (NI,MOR)-diagram (right) concerning false alarms of solid precipitation by the FD12P. Black dots represent events where both the sensor and the human observer report precipitation with a PW code of 67 or higher. Red dots correspond to events where the sensor reports a PW code of 67 or higher, but the human observer reports precipitation with a PW code lower than 67. The 1.5°C isotherm of wet bulb temperature is denoted by the blue line in the (TA,RH)-diagram.

Figure 4.6 shows diagrams for air temperature versus relative humidity and for rain gauge precipitation intensity versus MOR. The events for which both the sensor and the human observer report solid precipitation (PW≥67) are depicted by black dots, together with the events for which the sensor falsely reports solid precipitation (red dots). The human observer reports precipitation in those cases, but with a PW code smaller than 67. For convenience, these events are called ‘non-solid’, although strictly speaking this group contains the unknown, liquid and freezing precipitation events.

In Figure 4.4 it was already shown that snow and rain can be roughly discriminated between by considering the effect of both precipitation types on visibility. It is known that snow reduces visibility (or MOR) 4 to 10 times more efficiently than rain with equal intensity expressed in mm/h (ICAO, 2006). However, the boundaries are not very stringent, which makes the implementation of a suitable correction difficult. Moreover, the FD12P uses the precipitation type in its internal algorithm to determine the precipitation intensity, depending on the water content of the corresponding type. Intensities measured during snow events are thereby adjusted to lower values. Although the rain gauge also has problems in reporting the intensity of solid precipitation correctly, the precipitation intensity of the gauge is used here in the relation to MOR.

The (NI,MOR)-diagram does not look very promising for possible improvements, because both of the sets of points are scattered throughout the same large area in the plot. The (TA,RH)-diagram seems to offer more opportunities for corrections concerning false alarms of solid precipitation. The isotherm for TW=1.5°C is likely a good boundary to use in the correction of faulty solid into non-solid reports (ICAO, 2006), although there are also some ‘hits’ on the right side of this isotherm. The exact precipitation type is not directly determined by applying a correction as such, but the overall performance of the sensor for the detection of the solid precipitation class will probably get better. On the other hand, the bias for solid precipitation detection will decrease even further. It should be noted here that the wet bulb isotherm is calculated with a constant standard pressure of 1013.25 hPa.

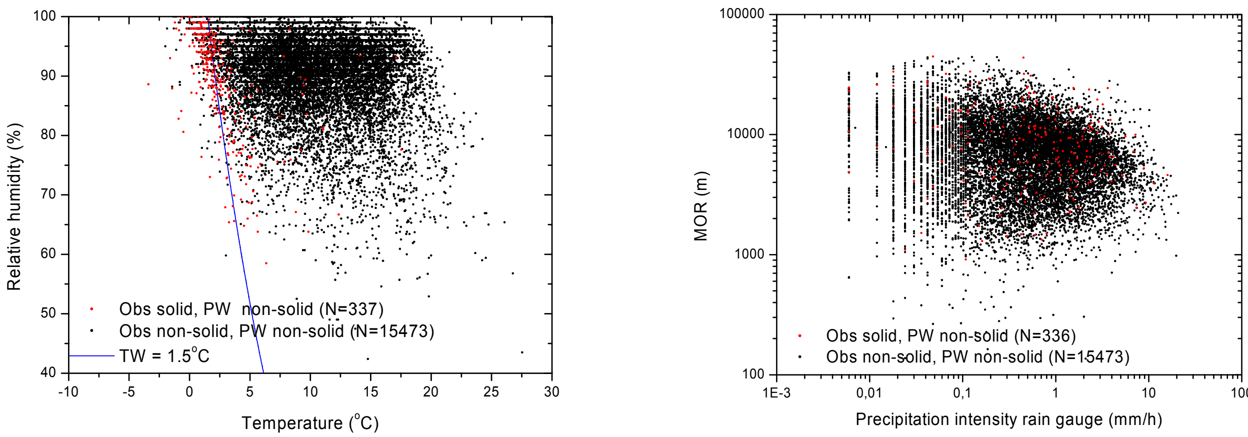

Figure 4.7. Same as Figure 4.6, but for the non-solid precipitation events reported by the sensor, with the missed solid events in red.

The diagrams to analyze the misses of solid precipitation by the FD12P are shown in Figure 4.7. The misses are largely concentrated near the TW=1.5°C isotherm, but finding suitable corrections for this case is much more difficult. For example, using TW=1.5°C as a lower limit for the occurrence of liquid precipitation gives 163 correct corrections from liquid to solid precipitation, but also introduces 235 faulty reports of solid precipitation.

A disdrometer measures the size and fall speed of hydrometeors and seems a promising device for e.g. the discrimination of solid precipitation particles. A field test of the Thies Laser Precipitation Monitor (LPM) disdrometer was undertaken the German Weather Service (DWD) to investigate the performance of this relatively new type of sensor (Bloemink and Lanzinger, 2002). It was concluded that the Thies disdrometer compares about equally well to an observer as the Vaisala FD12P sensor, with an agreement with the observer of about 91% for precipitation phase. However, mixed precipitation is also a weak point for this sensor.

5. The sensor reports too many events with ice pellets.

The actual occurrence of ice pellets (IP) is very rare, only 8 human observations of ice pellets are observed in Table 4.1a. The sensor however reports 276 cases with ice pellets.

The sensor reports of IP are mainly classified by the human observer as no precipitation (28 events), rain (30 events), a mixture of drizzle/rain and snow (63 events), snow (106 events) or snow pellets (18 events). Hence the major part of false IP detections coincides with a reference observation that indicates the occurrence of another solid precipitation type. An adjustment of an internal parameter (SNOW PELLETS LIMIT) in the particle size distribution analysis of the internal software of the FD12P could possibly decrease the false alarm rate of ice pellets.

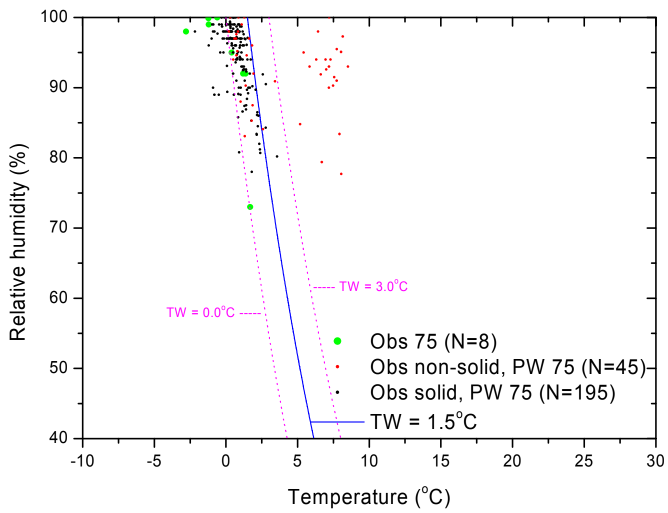

Figure 4.8. (TA,RH)-diagram for false alarms of ice pellets. Human observations of ice pellets are now denoted by green dots. The dotted lines in magenta represent the isotherms of TW=0.0°C and TW=3.0°C.

A (TA,RH)-diagram for the false detections of ice pellets is presented in Figure 4.8. The scatter points are subdivided in cases for which the human observer reports non-solid precipitation and solid precipitation. Additionally, the eight 'real' human observations of ice pellets are denoted by green dots. Note that 22 of the misses can be easily modified to liquid events by applying a threshold in TW of 3°C, although the exact liquid precipitation type is still not specified in that case. On the other side, points left of the TW=0°C isotherm seem to coincide mainly with human observations of solid precipitation. Unfortunately most events in this figure are observed in the transition area between the 0°C and 1.5°C isotherms.

A day with many false alarms of IP for station 261 is presented in Appendix C, Figure C.4. The 1-minute time series on March 2, 2005 indicate a significant number of ice pellets detections on this day, alternating with reports of mainly snow and snow grains. More specifically, the hourly corrected precipitation type reported by the automated system indicates ice pellets at the time of observation at 03, 12, 14, 16, 18, 19 and 23 UTC. The human observer however reports snow for all of these cases. The closely collocated sensor at station De Bilt (260) also reports ice pellets in two of these cases and reports snow for the others, in conformity with the observer (not shown).

6. The sensor does not detect hail.
The FD12P is not capable of detecting hail and snow pellets correctly. This is a commonly known problem for optical present weather systems (Van der Meulen, 2003). Human observations of hail and snow pellets are primarily classified as liquid precipitation (mainly rain) or other solid precipitation (mainly snow and ice pellets) by the FD12P. Only two reports of hail by the sensor are seen in the overall contingency matrix, but the human observer reported rain in those cases.

An example of a day with misses of snow pellets is seen in Appendix C, Figure C.5. This figure presents the 1-minute time series for station 261 on February 23, 2002. The human observer in De Bilt reports snow pellets (SP) at 07:50, 11:50, 12:50, 13:50 and 16:50, but both FD12P sensors in De Bilt (locations 260 and 261) miss these events and alternatively report no precipitation (C), unknown precipitation (P) and rain (R) in the 10-minute PWc codes for these periods.

No action is taken by KNMI to improve the detection of (winter) hail by the sensor types which are currently in operational use. Hail detection by an acoustic hail detector from Optical Scientific, Inc (OSI) might be considered (Bloemink, 2004). However this sensor did not improve the performance of hail detection over a LEDWI present weather sensor during a test carried out by the National Weather Service over 2 winters. Moreover the sensor can not be purchased separately from the LEDWI system.

5 Precipitation type corrections

5.1 Introduction to the PWc and PWc+ corrections

KNMI sent some cases with typical problems to Vaisala for analysis and reprocessing, to investigate the possibilities for adaptations in the internal software of the FD12P. For most cases, improvements were not possible, for others the manufacturer stated that there was a risk of reduced quality in other cases. Since the answers are not very encouraging, the focus in this section will be on the improvements that could be achieved by adapting the existing correction algorithm which is applied to 1-minute PW codes (see Section 2.2). The criteria for these so-called PWc corrections are based on empirically determined relationships of correlations. They use meteorological parameters which are also measured by the FD12P or other collocated sensors on the same site.

PWc corrections 1 to 6, which are currently in use at KNMI, are listed in Table 5.1. Furthermore, the ICAO 9837 document (ICAO, 2006) lists some corrections and principles on possible cross correlations, of which the feasibility will be tested in this section. These corrections are given in Table 5.2 and are called correction PWc+1 to PWc+20. Finally, PWc+21 to PWc+26 were identified during this study and are also listed in this table. Note that corrections PWc+ 25 and 26 are not applied to 1-minute PW codes but to a set of ten separate PW codes, to possibly reclassify rain events as a mixture of drizzle and rain (LR) or snow events as a mixture of drizzle/rain and snow (LRS), respectively. Whereas in the current processing a threshold of 30% is used (see Section 2.2), a threshold of 10% for both components of the mixture (R and LR+R or S and LRS+R+LR+L, respectively) is tested here.

Table 5.1. Overview of conditions and adaptations concerning the PWc corrections 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 operationally measures the grass temperature at 10 cm (TG) and air temperature at 1.5 m (TA) above the surface. PWc+ corrections 2, 3 and 8 include the temperature at 50 cm above the surface and are therefore not tested as correction steps here. Furthermore, PWc+4 and 18 need more information on cloud amount and are omitted as well. PWc+ corrections 7 and 9 include trends in several meteorological variables and therefore require time information. Since it was chosen to test all possible corrections in the same way, they are not assessed here. Finally, PWc+20 does not directly present a definition of the correction and is therefore not considered here. An example of the effect of the precipitation type on the MOR was already shown in Figure 4.4. Although the PWc+ 1 and 2 are based on 20 minute intervals, the default time basis of 1 minute will be used here for all selected PWc+ corrections.

Table 5.2. Overview of conditions and adaptations concerning the additional PWc+ corrections to be tested. The abbreviation 'ppn' must be read as 'any type of precipitation'.

Name and description	Condition(s)	Correction(s)
PWc+1 No ppn if TA-TG>3 over 20 min. period	TA-TG>3	ppn→C
PWc+2 No ppn if T50-TG>1.5 over 20 min. period	-	-
PWc+3 No ppn if T50>TA+2 and TG>T50+2 (day)	-	-
PWc+4 No ppn if no clouds detected above 4500 m	-	-
PWc+5 No ppn if vis>40000 for 5 min. period	ZM>40000	ppn→C
PWc+6 No ppn if relative humidity is below 50%	RH<50	ppn→C
PWc+7 No ppn if RH ↓ or TA-TD ↓ or visibility ↑	-	-
PWc+8 Start of ppn or fog if T50-TG suddenly drops	-	-
PWc+9 Isotherm T50/TG at 0:melting snow possible	-	-
PWC+10 Snow with TA>4 is very rare	TA>4	S,SG→P
PWc+11 No liquid ppn if TA<-5	TA<-5	L,LR,R→P
PWc+12 Mixtures rain and snow occur for TA in [-1,5]	TA<-1 or TA>5	LRS→P
PWc+13 Snow is not observed when TW>1.5	TW>1.5	S,SG→R
PWc+14 Snow is observed if TA<0 and RH<80	TA<0 and RH<80	ppn→S
PWc+15 Drizzle occurs only if RH>90	RH<90	L→R
PWc+16 Snow is observed if vis<1000 and C1>1500	ZM<1000 and C1>1500	ppn→S
PWc+17 Drizzle occurs only if C1<1000[2]	C1>1000	L→R
PWC+18 Rain is observed if no clouds above 3000 m	-	-
PWc+19 Drizzle occurs only if ZM<10000	ZM>10000	L→R
PWc+20 Snow decreases MOR 4-10x more than rain	-	-
PWc+21 Correct for precipitation at low ZM	ZM<400	P,LRS,S,IP,SG→C
PWc+22 No ppn if cloud cover is zero	NC=0	ppn→C
PWc+23 Unknown ppn above TA=6 is liquid	TA>6	P→R
PWc+24 Change detections of ice pellets	TW≤3 TW>3	IP→S IP→R
PWc+25 10% rule for the mixture LR	R + at least 1x L,LR	R→LR
PWc+26 10% rule for the mixture LRS	S + at least 1x L,LR,R	S→LRS

[2] ICAO Doc. 9837 uses a threshold in the first cloud base of 500 m (ICAO, 2006).

5.2 Added value of the corrections

Firstly, the added value of the current KNMI PWc correction algorithm is considered. The contingency matrix for the comparison of the PW codes as derived from the hourly reports of the human observer and the FD12P PWc code is shown in Table 5.3a. The situation is strictly identical as in the comparison presented in Table 4.1a in Section 4.1, only now the corrections PWc1 to PWc6 have been applied to the 1-minute PW codes from the sensor.

Table 5.3a. Contingency matrix of observed and measured precipitation type at six stations in the Netherlands, 2000-2002. PWc correction steps 1 to 6 are applied to the measured precipitation type.

	FD12P PWc															
Observer	**N/A**	**C**	**P**	**L**	**LR**	**R**	**ZL**	**ZR**	**LRS**	**S**	**IP**	**SG**	**IC**	**SP**	**A**	**Sum**
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	13	4					2	13810
ZL		12	6	1			6	3		1		2				31
ZR		2				3	2	17				1				25
LRS	11	20	14	32	19	107		2	65	35	4	7				316
S	5	64	22	10	4	22	1	1	81	442	26	59				737
IP				1		3		2		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%

Table 5.3b. Scores for the precipitation classes, determined from the contingency matrix in Table 5.3a. The reports from the human observer are along the vertical.

Precipitation			***Liquid***			***Freezing***			***Solid***		
	yes	**no**		**yes**	**no**		**yes**	**no**		**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

The PWc correction generally improves the scores with respect to the initial situation in the previous section. This does not apply to the detection of precipitation or the discrimination of liquid precipitation, but for freezing and solid precipitation the scores are clearly better. The POD for freezing precipitation improves from 34% to 50% at the cost of an increased FAR (51% to 54%), but nevertheless the CSI score increases from 25% to 31%. The POD for solid precipitation decreases slightly from 64% to 63%, but at the same time the FAR decreases from 28% to 18%, which finally results in an improvement of the CSI score from 51% to 56%. It is evident that the performance for mixtures of drizzle/rain and snow (LRS) is much better, leading to 209 reports by the automated system, of which 65 events are hits. Also many false alarms of ice pellets are adapted by the PWc correction. Generally speaking, the automated system now reports less faulty solid precipitation cases but demonstrates an increased contribution of unknown precipitation (P). Furthermore, there are more automated than human reports of freezing precipitation (BIAS=1.09). Note that the figures for Band0, Band0* and Band1* have also slightly increased with respect to Table 4.1a.

The impact of each PWc correction individually is investigated and reported in Table 5.4. The overall CSI scores for the precipitation types without PWc correction are given in the second row (Sum_pw). The precipitation types initially scoring the best are snow (S), rain (R) and freezing rain (ZR), with 47.0%, 44.3% and 33.3%, respectively. These are in general also the types occurring at higher intensities, hence the detection is likely easier for the FD12P. The small-particle size versions of these types, snow grains (SG), drizzle (L) and freezing drizzle (ZL), score much lower on average. The CSI scores for these precipitation types are only 7.8%, 13.6% and 10.9%. Using all the PWc corrections together (Sum_pwc) particularly improves the performance of the automated system with respect to the mixture drizzle/rain and snow (increase from 1.8% to 14.5%), but also the discrimination of freezing rain (33.3% to 42.5%), snow (47.0% to 51.0%) and snow grains (7.8% to 8.4%) is somewhat better.

Table 5.4. CSI scores for the 14 precipitation types reported by the FD12P, after application of each PWc correction individually. The row 'Sum_pw' represents the original situation without PWc correction, the row 'Sum_pwc' reports the scores after application of all PWc corrections. Individual CSI scores which have increased or decreased at least 0.1% with respect to the initial situation, are colored green and red, respectively.

Case	C	P	L	LR	R	ZL	ZR	LRS	S	IP	SG	IC	SP	A	ΔCSI	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_pwc1	93.8%	0.4%	13.6%	8.3%	44.3%	11.1%	42.5%	1.8%	47.0%	0.0%	7.8%	--	0.0%	0.0%	+9.4%	31
Sum_pwc2	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_pwc3	93.8%	0.4%	13.6%	8.3%	44.3%	10.9%	33.3%	1.9%	47.5%	0.0%	7.8%	--	0.0%	0.0%	+0.6%	14
Sum_pwc4	93.8%	0.4%	13.6%	8.3%	44.3%	10.9%	33.3%	2.7%	47.0%	0.0%	7.8%	--	0.0%	0.0%	+0.8%	12
Sum_pwc5	93.8%	0.4%	13.6%	8.3%	44.3%	10.9%	33.3%	14.4%	47.5%	0.0%	7.8%	--	0.0%	0.0%	+13.0%	185
Sum_pwc6	93.8%	0.3%	13.6%	8.3%	44.4%	10.9%	33.3%	1.3%	50.5%	0.0%	8.8%	--	0.0%	0.0%	+4.0%	139

The ΔCSI parameter in Table 5.4 sums all increases and decreases of the CSI scores with respect to the initial scores. Although it is not an exact measurement of the total change in performance, it is a convenient parameter to indicate the overall improvement or deterioration which results from the correction that is considered. In the last column, Nadj gives the total number of adjustments with respect to 'Sum_pw'. Obviously, it is especially corrections PWc 1, 5 and 6 contributing to the overall improvement. The PWc 3 and 4 corrections contribute only marginally, while PWc2 changes nothing at all in this case. The latter is not surprising, since the occurrence of ice crystals (IC) is a very rare phenomenon in the Netherlands and this type does not occur in the analysis at all. When taking the number of corrections representative for the average situation, it is estimated that the current KNMI PWc correction is employed in about 0.3% of time, or in 1.7% of the time when a precipitation type is reported by the FD12P.

The effect of the PWc+ corrections, which were listed in Table 5.2, is presented in Table 5.5. Corrections PWc+ 6, 14, 16, 17 and 22 have an overall negative effect and corrections PWc+ 11 and 12 do not cause any changes for the current data set. Correction PWc+14 causes an overall ΔCSI of -42.4%, diminishing the chance on a hit of freezing precipitation (ZL/ZR) and snow grains. It is clear that this correction should not be implemented in its current form. Most adjustments are made in the drizzle/rain discrimination, primarily introduced by corrections PWc+ 15, 17 and 19. For example, correction PWc+17 is employed in 5598 cases because the first cloud base (C1) is observed above 1000 m during drizzle events. The original value of 500 m (ICAO, 2006) is likely too low for our purpose. This value would lead here to 6941 corrections, with an increased CSI for rain (54.0%), but at the expense of a significantly lower CSI for drizzle (5.0%) and drizzle or rain (6.5%). The overall ΔCSI for this correction would be -0.8% instead of the 13.0% that is achieved with the threshold in C1 of 1000 m.

Table 5.5. Same as Table 5.4, but for the PWc+ corrections.

Case	C	P	L	LR	R	ZL	ZR	LRS	S	IP	SG	IC	SP	A	ΔCSI	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+1	93.8%	0.4%	13.6%	8.3%	44.3%	11.1%	33.3%	1.8%	47.0%	0.0%	7.8%	--	0.0%	0.0%	+0.2%	9
Sum_pwc+5	93.8%	0.4%	13.6%	8.4%	44.3%	10.9%	33.3%	1.8%	47.0%	0.0%	7.8%	--	0.0%	0.0%	+0.1%	74
Sum_pwc+6	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%	8
Sum_pwc+10	93.8%	0.4%	13.6%	8.3%	44.3%	10.9%	33.3%	1.9%	49.5%	0.0%	7.8%	--	0.0%	0.0%	+2.6%	58
Sum_pwc+11	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+12	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+13	93.8%	0.4%	13.6%	8.4%	44.2%	10.9%	33.3%	1.6%	50.5%	0.0%	8.6%	--	0.0%	0.0%	+3.9%	100
Sum_pwc+14	93.8%	0.4%	13.6%	8.3%	44.3%	2.8%	3.7%	1.8%	47.3%	0.0%	2.8%		0.0%	0.0%	-42.4%	200
Sum_pwc+15	93.8%	0.4%	15.7%	9.7%	49.5%	10.9%	33.3%	1.8%	47.0%	0.0%	7.8%	--	0.0%	0.0%	+8.6%	2227
Sum_pwc+16	93.8%	0.4%	13.6%	8.3%	44.2%	10.9%	33.3%	2.1%	45.6%	0.0%	7.9%	--	0.0%	0.0%	-1.2%	48
Sum_pwc+17	93.8%	0.4%	14.4%	10.9%	53.9%	10.9%	33.3%	1.8%	47.0%	0.0%	7.8%	--	0.0%	0.0%	+13.0%	5598
Sum_pwc+19	93.8%	0.4%	16.6%	10.3%	50.2%	10.9%	33.3%	1.8%	47.0%	0.0%	7.8%	--	0.0%	0.0%	+10.7%	3046
Sum_pwc+21	93.9%	0.4%	13.6%	8.3%	44.3%	10.9%	33.3%	1.8%	48.4%	0.0%	9.8%	--	0.0%	0.0%	+3.5%	134
Sum_pwc+22	93.8%	0.4%	13.6%	8.4%	44.9%	10.9%	33.3%	1.2%	45.6%	0.0%	7.9%	--	0.0%	0.0%	-1.3%	573
Sum_pwc+23	93.8%	0.2%	13.5%	8.5%	44.5%	10.9%	33.3%	1.8%	47.1%	0.0%	7.8%	--	0.0%	0.0%	+0.0%	543
Sum_pwc+24	93.8%	0.4%	13.6%	8.3%	44.4%	10.9%	33.3%	6.5%	50.8%	0.0%	7.8%	--	0.0%	0.0%	+8.5%	268
Sum_pwc+25	93.8%	0.4%	13.6%	8.7%	40.9%	10.9%	33.3%	1.8%	47.0%	0.0%	7.8%		0.0%	0.0%	-3.1%	1199
Sum_pwc+26	93.8%	0.4%	13.6%	8.3%	44.3%	10.9%	33.3%	2.9%	48.1%	0.0%	7.8%		0.0%	0.0%	+2.1%	25

Corrections PWc+ 10, 13 and 21 cause some improvement in the detection of solid precipitation. This results from the removal of false alarms. For example, PWc+21 introduces 126 removals of false alarms of solid precipitation and only 8 misses. The application of PWc+24 changes 268 automated reports of ice pellets into liquid (22 events) and solid (246 events) precipitation. The overall improvement in CSI is significant (8.5%) and individually occurs for rain, snow and the mixture drizzle/rain and snow. The CSI score for ice pellets itself remains zero because there are no hits, but the FAR reduces from 100% to 0% by this correction. Of course the user must be warned that the implementation of such a correction completely restrains the automated system from the detection of ice pellets. The corrections that include an adapted averaging method for the 10-minute precipitation type are PWc+25 and 26. The 10% rule that is applied for the construction of the 10-minute drizzle/rain mixture (PWc+25) has a negative effect (-3.1%), changing almost 1200 rain events into this mixture. However, the 25 corrections corresponding to the 10% rule for the averaging of the drizzle/rain and snow (LRS) mixture lead to a small improvement in the CSI scores for both snow (+1.1%) and the mixture itself (+1.1%).

Table 5.6 eventually lists the CSI scores for each precipitation type as a result of combinations of PWc and PWc+ corrections and Table 5.7 lists the POD, FAR, CSI, HSS, BIAS and N for the precipitation classes. In these tables, the case 'Sum_pw' represents the original situation with uncorrected PW-codes. The case 'Sum_pwc' and 'Sum_pwc+' list the results after application of all the PWc and PWc+ corrections, respectively. In the case 'Sum_pwc+pos', only the positively contributing PWc+ corrections are considered, hence this reflects the situation when PWc+ corrections 1, 5, 10, 13, 15, 17, 19, 21, 24 and 26 are employed. Finally, the case 'Sum_pwcallpos' gives the results of the comparison where the PWc corrections are complemented with eight of the nine selected PWc+ corrections. Correction PWc+17 is omitted because it introduces a large imbalance in the detection of drizzle and rain, together with the other tested corrections with this specific target, i.e. PWc+ 15 and 19. Hence this case contains PWc corrections 1 to 6 and PWc+ corrections 1, 5, 10, 13, 15, 19, 21, 24 and 26, in that order of execution.

The increased CSI scores in the case 'Sum_pwcallpos' result in an overall ΔCSI of 44.1%, due to a total number of 4089 adjustments. The performance has increased most for the mixture of drizzle/rain and snow (+13.9%), freezing rain (+9.2%), rain (+7.7%) and snow (+5.5%). The PWc corrections primarily contribute to the improvement of the detection of the mixture drizzle/rain and snow and freezing rain, whereas the PWc+ corrections are the main contributors to the improved discrimination of rain. Both the PWc and PWc+ corrections contribute with respect to the improved discrimination of snow. Note that the end result of the comparison with a combination of PWc and PWc+ corrections might be subject to conflicting correction steps and also depends on the order of the used corrections.

The separate verification scores in Table 5.7 show that the discrimination of the precipitation classes by the automated system has improved with respect to the original situation, when a set of corrections is used which consists of the PWc corrections, the positively contributing PWc+ corrections or a combination these two types. The improvement is most clearly seen for solid precipitation. A slightly decreased POD is largely compensated by a decreased FAR for all cases, which leads to a CSI which increases from 51% to 56% for 'Sum_pwc' and to 57% for 'Sum_pwcallpos'. Note that the application of all PWc+ correction steps ('Sum_pwc+') leads to a poor performance for freezing precipitation, where the POD, FAR, CSI and HSS have values of 4%, 75%, 3% and 6%, respectively. This results from correction PWc+14.

Table 5.6. Same as Table 5.4, but for combinations of PWc and PWc+ corrections (see text).

Case	C	P	L	LR	R	ZL	ZR	LRS	S	IP	SG	IC	SP	A	ΔCSI	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+	93.8%	0.2%	13.7%	11.1%	54.6%	2.9%	3.7%	10.3%	54.0%	0.0%	3.8%	--	0.0%	0.0%	-13.2%	6879
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_pwcallpos	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

Table 5.7. Scores for the precipitation classes measured by the FD12P, after application of combinations of PWc and PWc+ corrections.

	Precipitation						*Liquid*						*Freezing*						*Solid*					
Case	POD	FAR	CSI	HSS	BIAS	N	POD	FAR	CSI	HSS	BIAS	N	POD	FAR	CSI	HSS	BIAS	N	POD	FAR	CSI	HSS	BIAS	N
Sum_pw	**82%**	**20%**	**68%**	**78%**	**1.03**	**24553**	**80%**	**22%**	**65%**	**76%**	**1.03**	**22980**	**34%**	**51%**	**25%**	**40%**	**0.70**	**76**	**64%**	**28%**	**51%**	**68%**	**0.88**	**1586**
Sum_pwc	82%	20%	68%	78%	1.03	24553	80%	22%	66%	76%	1.03	22966	50%	54%	31%	48%	1.09	89	63%	18%	56%	71%	0.78	1455
Sum_pwc+	82%	19%	68%	78%	1.01	24322	80%	22%	65%	76%	1.03	22969	4%	75%	3%	6%	0.14	62	62%	21%	53%	69%	0.79	1489
Sum_pwc+pos	82%	20%	68%	78%	1.02	24422	81%	22%	66%	76%	1.03	22983	34%	50%	25%	40%	0.68	75	64%	15%	57%	73%	0.75	1415
Sum_pwcallpos	82%	20%	68%	78%	1.02	24393	80%	22%	66%	76%	1.03	22932	50%	54%	31%	48%	1.09	89	63%	14%	57%	73%	0.74	1408

Table 5.8. Contingency matrix of observed and measured precipitation type at six stations in the Netherlands, 2000-2002. The PWc corrections and PWc+ corrections 1, 5, 10, 13, 15, 19, 21, 24 and 26 are applied to the measured precipitation type.

	FD12P PWcallpos															
Observer	**N/A**	**C**	**P**	**L**	**LR**	**R**	**ZL**	**ZR**	**LRS**	**S**	**IP**	**SG**	**IC**	**SP**	**A**	**Sum**
N/A	719	7511	27	213	124	761	17	9	2	10		3				9396
C	5230	117817	270	416	96	3170	13	3	16	54		26				127111
P	2	25	3	1		260			3	2						296
L	310	1539	43	850	128	595	1	1	4	3						3474
LR	98	182	20	613	372	1081	2	2	3	1						2374
R	545	1733	106	816	911	9679		1	13	4					2	13810
ZL		13	6	1			6	3				2				31
ZR		2				3	2	17				1				25
LRS	11	20	14	19	14	125		2	72	32		7				316
S	5	67	22	5	3	27	1	1	90	457		59				737
IP						4		2		1		1				8
SG	7	21	2	2	1	3	4		5	34		18				97
IC																0
SP	8	16	15			66			19	8		2				134
A	2	2				11										15
Sum	6937	128948	528	2936	1649	15785	46	41	227	606	0	119	0	0	2	157824

N/A	9.9%	Band0	90.9%	Band0*	56.4%	Band1	94.0%	Band1*	78.1%

The contingency matrix for the renewed comparison with the automated observations corrected by the PWc and positively contributing PWc+ corrections is shown in Table 5.8. Note that the column with ice pellets (IP) on the sensor side is completely empty as a result of PWc+ correction 24. The Band0, Band0*, Band1 and Band1* have increased with respect to the contingency matrices for the FD12P PW and PWc sets, indicating the increased agreement of the automated observations with the precipitation type observations (Band0) and precipitation classes (Band1) as reported by the human observer. Figure 5.1 gives the frequency of occurrence histograms of the 14 precipitation types for the Observer and the uncorrected (PW) and corrected precipitation type (PWcall) by the automated system.

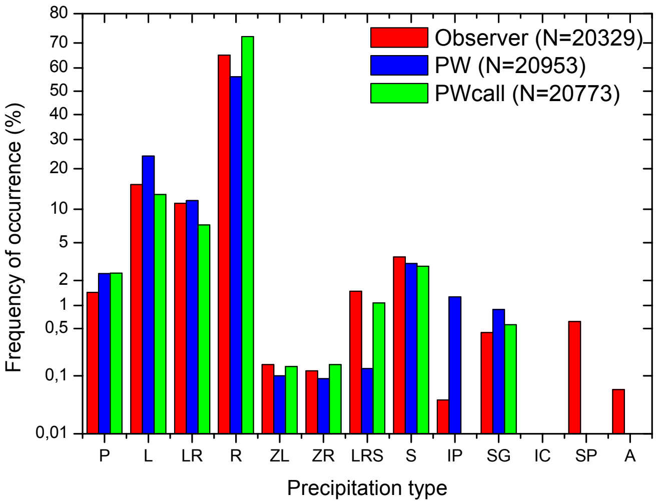

Figure 5.1. Frequency of occurrence of reported precipitation types by a human observer (red) and by the FD12P uncorrected PW code (blue) and PW code corrected by the PWc corrections and PWc+ corrections 1, 5, 10, 13, 15, 19, 21, 24 and 26 (green).

In Section 4.2 it was stated that the FD12P reports too many drizzle events at the expense of rain events, compared to the observer. The frequency of occurrence of drizzle, the mixture drizzle/rain and rain is clearly overcorrected after the application of the PWc and selected PWc+ correction steps. The contribution decreases from 24.1% to 13.1% for drizzle and increases from 56.2% to 72.3% for rain, whereas the frequency of occurrence of these precipitation types according to the human observer is 15.6% and 65.3%, respectively. Note that also the frequency of occurrence of freezing drizzle, freezing rain and the mixture drizzle/rain and snow has increased, which seems more plausible compared to the observer. The occurrence of snow grains has somewhat decreased (0.9% to 0.6%), mainly as a result of the removal of false alarms of SG by corrections PWc6 and PWc+ 13 and 21.

Table 5.9. Same as Table 5.6, but for corrections applied on a 10-minute base.

Case	C	P	L	LR	R	ZL	ZR	LRS	S	IP	SG	IC	SP	A	ΔCSI	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**
Sum10_pwc	93.8%	0.3%	13.6%	8.3%	44.3%	9.6%	45.9%	14.7%	50.4%	0.0%	8.6%	--	0.0%	0.0%	+28.4%	414
Sum10_pwc+	93.8%	0.2%	16.1%	8.3%	48.9%	11.1%	33.3%	1.9%	52.2%	0.0%	9.6%	--	0.0%	0.0%	+14.1%	4460
Sum10_pwc+pos	93.9%	0.3%	16.2%	8.3%	49.1%	11.1%	33.3%	1.8%	53.9%	0.0%	9.9%	--	0.0%	0.0%	+16.6%	4136
Sum10_pwcallpos	93.9%	0.2%	16.8%	8.4%	47.8%	9.6%	45.9%	14.9%	52.2%	0.0%	9.7%	--	0.0%	0.0%	+38.3%	2876

In the analyses in this section the precipitation type corrections are all applied to 1-minute PW codes, but the processing system also allows the correction of 10-minute PW codes in a similar way. The CSI scores for the reported precipitation types with 10-minute corrections applied are shown in Table 5.9. Except for the existing PWc corrections, the number of adjustments and the degree of improvement is generally lower than for the corrections on a 1-minute base. Since corrections PWc+ 25 and 26 concern the averaging of 10 PW codes, they are logically not incorporated in these 10-minute corrections. Separate corrections which result in a higher value of ΔCSI on a 10-minute than on a 1-minute basis are PWc 1 and 6 and PWc+ 12, 13, 14, 16, 21 and 22.

6 Analysis of collocated observations

6.1 Introduction

An analysis of multiple collocated FD12P sensors can provide information on the extent of spatial representativeness of precipitation type observations. Additionally, it points out the most stringent problems when inconsistencies between different sensors are considered. Observations of two collocated FD12P sensors in De Bilt will be analyzed in this section, together with an investigation of the spatial dependency of precipitation type skills for seven FD12P sensors at Schiphol.

The contingency matrices and skill scores presented in these analyses should be interpreted different from the ones in the comparison with the human observer (Section 4.1). Since there is no reference and all sensors are liable to errors in some way, observations are purely compared here to analyze the inconsistencies caused by the distance between two seemingly identical sensors and by other influences that are not directly specified. These influences may be related to differences in sensor characteristics, contamination on the sensor, local circumstances, etc. However, the calculation of the verification scores occurs in the same way as in the previous section, using the observations along the vertical as 'reference' observations as if they are from a human observer.

6.2 De Bilt 260 versus 261

Observations on a 1-minute time basis for the locations 260 (operational site) and 261 (test field) in De Bilt are acquired from the KMDS (KNMI Meteorological Data distribution System) database and translated to 10-minute PWc codes. The FD12P sensors at these locations are positioned within approximately 30 m of each other. Hence information on the effect of sensor-to-sensor variation in the discrimination of precipitation type can be obtained from the results. The considered period here is February 20, 2003 to December 31, 2006. No manned observations are available for this period, hence the comparison will be focused on automated observations only. Only the days for which the daily data files for both locations are available are included in the analysis. A possible exchange of one or both sensors is not accounted for. An extensive consistency trial for eight FD12P sensors was conducted by the UK Met Office to ascertain the range of differences between seemingly identical units (Shearn, 2002).

Table 6.1a. Contingency matrix of the 10-minute PWc observations for the collocated sensors at locations 260 (operational site) and 261 (test field) in De Bilt, 2003-2006.

	260 PWc															
261 PWc	**N/A**	**C**	**P**	**L**	**LR**	**R**	**ZL**	**ZR**	**LRS**	**S**	**IP**	**SG**	**IC**	**SP**	**A**	**Sum**
N/A	7	853	4	19	15	52			5	27		5				987
C	274	171500	216	285	28	524	8	4	4	19	1	32	3			172898
P		157	217	48	3	63	1	4	1	18		9				521
L	1	308	68	2933	721	947										4978
LR	2	61	3	288	1260	1472		1	2							3089
R	4	519	65	474	958	11465		2	48	4		2			7	13548
ZL		2	2				6	2			1					13
ZR		1				2		14			3	3				23
LRS				2		10			153	39		2				206
S		17	19			2		1	22	623	23	66				773
IP		2					2	4		37	33	5				83
SG		22	18	1		7		4	2	56	15	322				447
IC		2														2
SP																0
A																0
Sum	288	173444	612	4050	2985	14544	17	36	237	823	76	446	3	0	7	197568

N/A	0.6%	Band0	96.0%	Band0*	71.9%	Band1	98.7%	Band1*	93.6%

A contingency matrix for the comparison between the 10-minute corrected PWc codes at locations 260 and 261 is shown in Table 6.1a. The corresponding verification scores for the precipitation classes are found in Table 6.1b. The agreement between the two automated systems is very good for the overall detection, liquid and solid precipitation, where POD has values of 95%, 95% and 93% and FAR is 5%, 5% and 10%, respectively. The corresponding values of the BIAS are around 1. Freezing precipitation shows the worst scores, with a POD, FAR and CSI of 61%, 58% and 33%, respectively. Note again that this is the least occurring precipitation class (N=67), with the sensor at 260 reporting more freezing precipitation (BIAS=1.47). The different wet bulb temperatures used at both locations are likely not very important here, because most of the inconsistencies for freezing events occur where the other location reports no precipitation at all, or unknown or solid precipitation.

Table 6.1b. Scores for the precipitation classes, determined from the contingency matrix in Table 6.1a. The events at station 261 are along the vertical.

Precipitation			***Liquid***			***Freezing***			***Solid***		
	yes	**no**		**yes**	**no**		**yes**	**no**		**yes**	**no**
yes	22585	1091	**yes**	20518	1090	**yes**	22	14	**yes**	1398	113
no	1124	171500	**no**	975	173717	**no**	31	196233	**no**	157	194632
POD		95%	**POD**		95%	**POD**		61%	**POD**		93%
FAR		5%	**FAR**		5%	**FAR**		58%	**FAR**		10%
CSI		91%	**CSI**		91%	**CSI**		33%	**CSI**		84%
HSS		95%	**HSS**		95%	**HSS**		49%	**HSS**		91%
BIAS		1.00	**BIAS**		0.99	**BIAS**		1.47	**BIAS**		1.03
N		24800	**N**		22583	**N**		67	**N**		1668

Many inconsistencies are observed where one of the sensors reports precipitation and the other does not. The precipitation detection however seems to be fairly in balance, the sensor at 260 reports 1124 cases when the sensor at 261 does not, the opposite occurs in 1091 cases. Furthermore there is also a considerable number of inconsistencies for the discrimination of the mixture drizzle/rain and snow (LRS). This was already cited as one of the problems of the FD12P precipitation type discrimination in Section 4.2.

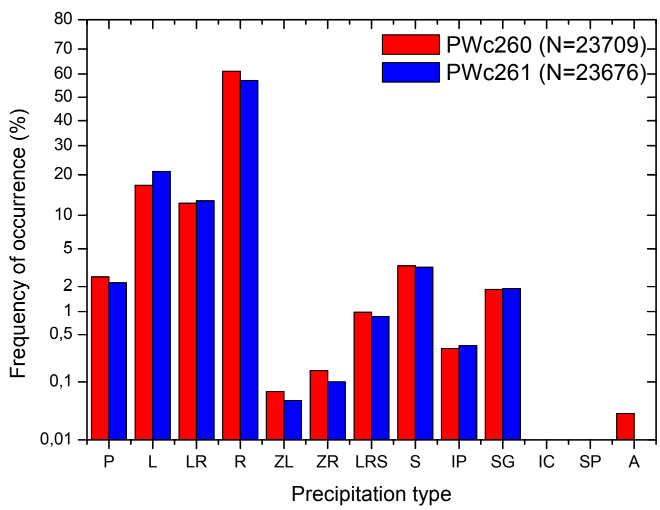

Figure 6.1. Frequency of occurrence of the 10-minute corrected precipitation type PWc for the collocated sensors at locations 260 (red) and 261 (blue) in De Bilt, 2003-2006.

Figure 6.1 gives the frequency of occurrence histograms for the corrected precipitation type at the two locations. The histograms resemble each other well, but there is a significant difference in the contributions of rain and drizzle. The PWc code for 260 reports drizzle in 17.0% and rain in 61.1% of the cases, while for location 261 the PWc code reports drizzle in 21.0% and rain in 57.2% of the cases. Hence, the average L/R-ratios are 0.29 and 0.37 for stations 260 and 261, respectively. This difference is evident for all years individually (not shown).

The differences in L/R-ratio likely coincide with biases in the reported FD12P precipitation intensity. Figure 6.2 shows the comparison of daily precipitation sums for the rain gauge and the FD12P at locations 260 and 261 in the period 2003-2006. The sums are calculated from 1-minute observations of precipitation intensity, if they are available for the sensor at both locations. A failing rain gauge is reported for location 260 by the department of Information Process Management (I-ID) of KNMI for the period October 7 – October 11, 2004. The data for these days are therefore not used.

It is clear that no significant differences should exist in the reported precipitation sums of locations 260 and 261, concerning the very good agreement in the scatter plot of the rain gauges. However, the FD12P at location 261 demonstrates significantly lower daily precipitation sums than the FD12P at location 260 in the considered period. The l.s.q. fit $y = ax + b$ has coefficients a=0.997 and b=0.010 for the rain gauges (R^2=1.00) and a=0.89 and b=0.003 for the FD12P sensors (R^2=0.99). A l.s.q. fit for the mutual comparison of the FD12P and the rain gauge at both locations (not shown) delivers coefficients a=0.78 and b=-0.071 for location 260 (R^2=0.98) and a=0.87 and b=-0.039 for location 261 (R^2=0.97).

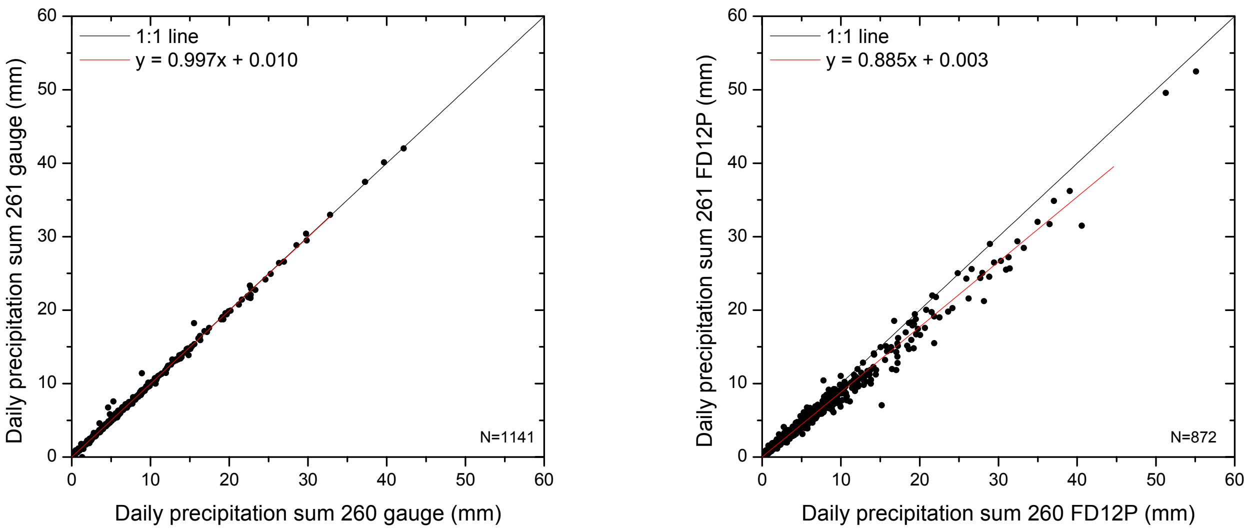

Figure 6.2. Scatter plots of the daily precipitation sums for location 260 versus 261 in De Bilt, period 2003-2006. The sums are calculated from coinciding 1-minute precipitation intensities reported by the rain gauge (left, N=1141) and the FD12P (right, N=872).

The bias in the slope (a) was already recognized in an exploration of the quality of the FD12P precipitation intensity (Wauben, 2007), where the FD12P sensors in De Bilt both reported more precipitation than the rain gauges and the FD12P sensor at location 261 reported 10 to 20% lower yearly precipitation sums than the FD12P at location 260. It was proposed that KNMI considers the rescaling of the reported intensity during maintenance, to make the results more consistent. The scale factor could be derived from field data for each location with a FD12P. According to Vaisala, an implementation of the scale factor (RAIN

INTENSITY SCALE) will also have a slight effect on the reported precipitation type. Hence the observed differences in L/R-ratio are expected to get smaller when a rescaling is carried out. Further analysis is difficult because a strong relationship between the L/R-ratio and the ratio of the precipitation sums by the rain gauge and the FD12P is not established for other locations.

6.3 Spatial variation of precipitation type observations at Schiphol

The locations of the ten FD12P sensors in use at Schiphol are shown in Figure 6.3, together with the location of the rain gauge at the observation field. An exploration of the spatial dependency of the observed precipitation type by the FD12P is presented in this section. The observations from location 18R touchdown west (18Rtw) are compared to the observations at – in order of increasing distance – 18R touchdown east (18Rte), 18R middle north (18Rmn), 18R middle south (18Rms), 36L touchdown (36Lt), 18C touchdown (18Ct) and 22 touchdown (22t). The distance between these locations and location 18Rtw is 240, 940, 1875, 2825, 3750 and 6750 m, respectively. The three most southerly FD12P sensors along runway 18C have only recently been installed and are therefore not included in the analysis.

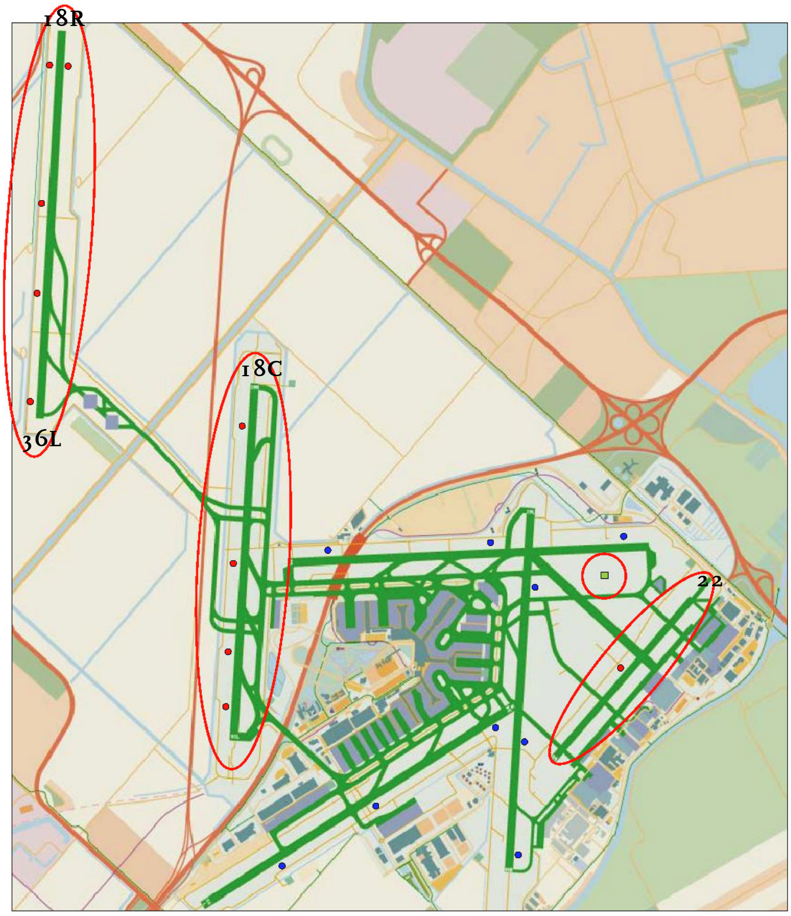

Figure 6.3. Overview of locations of sensors at Schiphol airport. The green square indicates the observation field and a red or blue dot represents a FD12P sensor or transmissometer, respectively (from: Wauben, 2007).

A set of 10-minute PWc codes for the seven locations is generated from the 1-minute PWc codes available in the civil airport database at KNMI for the period January 1, 2003 – December 31, 2006. No human observations are involved in the analysis. Compared to the previous comparison for the two collocated sites in De Bilt, the spatial dependency is expected to be seen in more detail.

The verification scores for the precipitation classes are listed in Table 6.2. The location of the second FD12P in the comparison is noted after the 'VAM18Rtw-' string for each case, with the cases listed in order of increasing distance. Note that the number of relevant events (N) for each class generally increases with increasing distance, since the number of false alarms and misses is significantly higher for sensors that are further away from the reference location. Location 22t however does not fit into this behavior, because observations from this location are not available until December 15, 2003.

The sensor at 18Rte is the closest to reference location 18Rtw and indicates CSI scores for liquid, freezing and solid precipitation of 88%, 22% and 73%, respectively. These come close to the scores found in the comparison of the collocated sensors in De Bilt in Section 6.2 (91%, 33%, 84%). The CSI scores calculated for the sensor at location 22t, which is located approximately 6750 m from 18Rtw, are only 59%, 5% and 48%, respectively. Coinciding observations of the same precipitation type will have to come from showers or rainfall occurring on a large spatial scale for this location. Passing precipitation zones will often cause a timing inconsistency for sensors further away, which is seen very well in the lower scores.

Table 6.2. Scores for the precipitation classes measured by the FD12P sensors at Schiphol, compared to the FD12P at location 18Rtw. The observations used are 10-minute PWc codes in the period 2003-2006.

	Precipitation						*Liquid*						*Freezing*						*Solid*					
Case	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**
VAM18Rtw-18Rte	95%	9%	88%	93%	1.04	24876	95%	8%	88%	93%	1.03	22342	29%	50%	22%	37%	0.58	76	89%	19%	73%	84%	1.10	1739
VAM18Rtw-18Rmn	91%	10%	83%	89%	1.00	25053	91%	10%	83%	89%	1.00	22666	75%	55%	39%	56%	1.64	112	82%	17%	70%	82%	0.99	1680
VAM18Rtw-18Rms	90%	16%	77%	85%	1.07	26666	90%	15%	77%	86%	1.06	24018	46%	65%	25%	40%	1.31	109	83%	22%	67%	80%	1.07	1777
VAM18Rtw-36Lt	86%	16%	74%	83%	1.03	26693	86%	17%	74%	83%	1.04	24271	59%	82%	16%	28%	3.25	216	71%	19%	60%	75%	0.87	1676
VAM18Rtw-18Ct	86%	20%	70%	80%	1.08	27807	85%	20%	70%	80%	1.06	25042	25%	86%	10%	18%	1.85	153	79%	29%	60%	75%	1.10	1890
VAM18Rtw-22t	73%	24%	59%	71%	0.97	20021	73%	24%	59%	71%	0.96	18144	9%	91%	5%	9%	1.00	63	65%	36%	48%	64%	1.01	1400

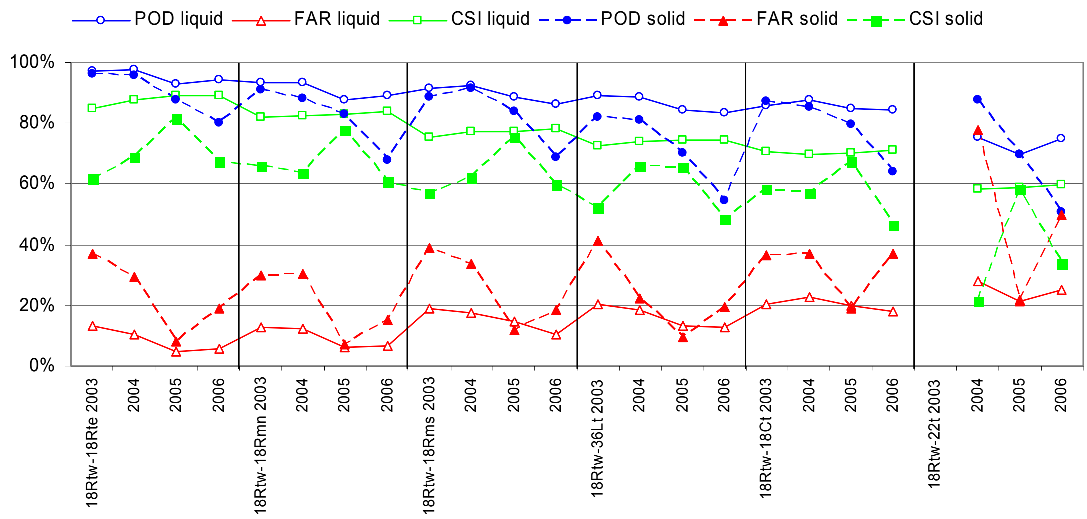

Figure 6.4. POD, FAR and CSI scores for the 10-minute liquid and solid PWc observations (2003-2006) from the FD12P sensors at Schiphol, compared to the FD12P at reference location 18Rtw.

The annual POD, FAR and CSI scores for the agreement in liquid and solid precipitation detection are presented in Figure 6.4. The scores for each location show year-to-year variations although these variations are quite similar for each location. Contrary to the scores for liquid precipitation, it is observed that the scores for solid precipitation depend strongly on the yearly number of events. A maximum in POD and CSI and minimum in FAR for this class is seen for 2005, in which 45% of the total number of relevant solid precipitation events for the whole period (2003-2006) occurred. The CSI score for solid precipitation even gets close to the CSI for liquid precipitation observed in this year. This is significant, since these scores differ about 20 to 30% on average. Another remarkable feature is seen in the 2003-2006 time series for liquid precipitation for each sensor location. A constantly decreasing POD and an even stronger decreasing FAR lead to an increasing value for the CSI, which is 2 to 4% higher in 2006 than it is in 2003.

Table 6.2 and Figure 6.4 demonstrate that generally the POD decreases and the FAR increases with increasing distance, which leads to significantly decreasing CSI and HSS scores for the sensors further away from the reference sensor. Only for freezing precipitation, the listed scores are more variable due to the low number of events. The corresponding BIAS fluctuates strongly and is often significantly lower or higher than 1. Further analysis of the occurrence of freezing precipitation on a 1-minute basis at Schiphol airport is presented in Section 6.4. The observed BIAS for the other precipitation classes is fairly close to 1.

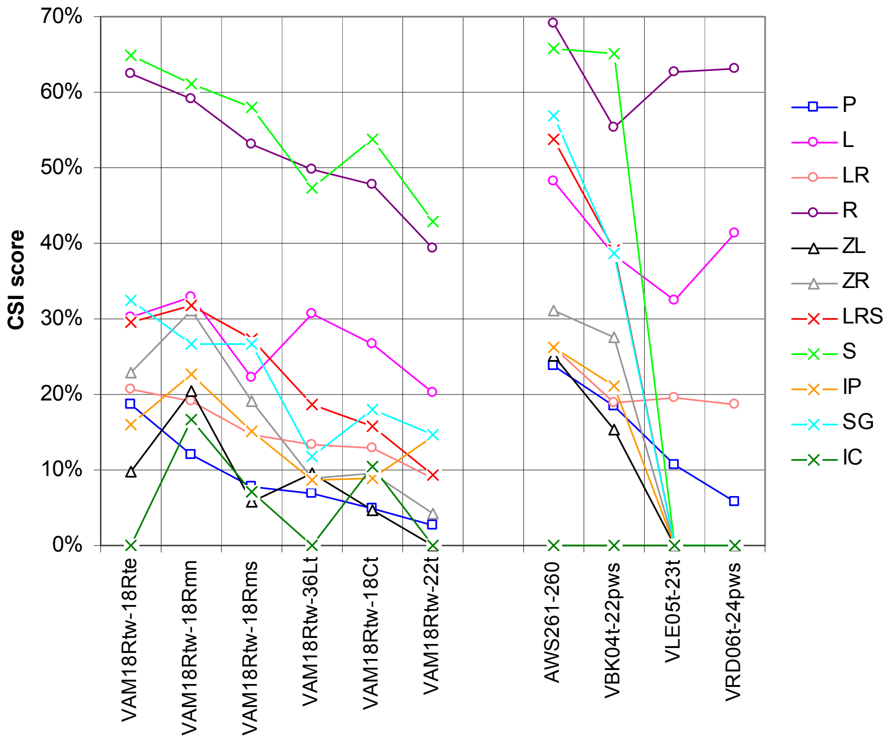

Figure 6.5. CSI scores for the 10-minute PWc observations (2003-2006) from the FD12P sensors at Schiphol, compared to the FD12P at reference location 18Rtw. The scores for the comparison between the locations 261 and 260 in De Bilt and the different sensor locations at the civil airports of Beek, Lelystad and Rotterdam are presented on the right half of the figure.

Figure 6.5 shows the CSI scores for 11 different 10-minute corrected precipitation types reported for the six locations at Schiphol, with respect to the reference location 18Rtw. Two types are not shown in the figure, SP (snow pellets) does not occur at all and for A (hail) there are no hits in the mutual comparisons (i.e. CSI=0). The trend of generally decreasing scores with increasing distance is demonstrated here as well, especially for the established scores for rain and snow. These precipitation types occur most frequently in the liquid and solid precipitation classes, respectively. The CSI score for rain decreases from an initial value of 62% (POD=80%, FAR=26%) for the closest FD12P at 18Rte to a CSI score of 39% (POD=55%, FAR=42%) for the FD12P at location 22t. For snow, the CSI decreases from 65% to 43% for the same two locations compared. Note that for many precipitation types the CSI score is strongly variable and for example increases when going from location 18Rte to location 18Rmn. The reason for this behavior is unclear, but the low frequency of occurrence for some types and local influences on the precipitation type may certainly play a role.

Scores for the closely collocated sensors at 261 and 260 in De Bilt and the FD12Ps at the civil airports in Beek (VBK), Lelystad (VLE) and Rotterdam (VRD) are visible on the right half of Figure 6.5. The scores for Lelystad and Rotterdam are however somewhat distorted, since coinciding observations from the FD12Ps are only available as from June 8, 2006 and September 28, 2006, respectively. This is well observed in the missing CSI scores for freezing and solid precipitation for these airports. The comparison for Beek is based on logged data starting September 29, 2003. The closely collocated sensors at De Bilt, only 30 m away from each other, show higher CSI scores compared to the closest comparison at Schiphol (240 m). Particularly the agreement for drizzle, the drizzle/rain and snow mixture (LRS) and snow grains is much better in De Bilt. The distances between the FD12P sensors at Beek, Lelystad and Rotterdam are approximately 1500 m, 1050 m and 1000 m, respectively. The corresponding CSI scores for the liquid precipitation types (L, LR and R) are close to or even higher than the scores for the 18Rtw-18Rte comparison at Schiphol.

6.4 Freezing precipitation at Schiphol

The spatial representativeness of precipitation type observations for De Bilt and Schiphol was discussed in the previous section. It was inferred that the mutual distance between two FD12P sensors strongly determines the agreement on their reports of precipitation type. The distances between the operational FD12P sensors at Schiphol range between 240 m and 6750 m.

Freezing precipitation is an important precipitation class which is not always reported correctly by the automated system (see Section 4.2). One of the KNMI PWc correction steps (PWc1, Table 4.1) turns liquid precipitation into freezing precipitation if the wet bulb temperature TW is equal to or below 0°C, whereas freezing precipitation is converted into liquid precipitation if TW is above 0°C. The wet bulb temperature is calculated from the air temperature, relative humidity and pressure on the site. Consequently, it is important to have representative measurements of these parameters to carry out the correction for freezing precipitation correctly.

Ten FD12P sensors are presently in operational use at Schiphol, with some more coming up in the near future as the replacement of a transmissometer. Nevertheless, the operational values for air temperature, relative humidity and pressure at Schiphol are obtained only from the observation field, situated near the touchdown zone of runway 27 (location 18Cm27). This location is indicated by a green square in Figure 6.3. These operational values are used in the correction of the precipitation type of all FD12P sensors at Schiphol. This implies that – in the most extreme case – the precipitation type at location 18Rtw is corrected by making use of a wet bulb temperature that is representative for a location 6600 m away.

Backup sensors for temperature, relative humidity and pressure measurements are placed at location 18Rtw, but not used in any PWc correction. In this section the performance of freezing precipitation observations is examined, based on the wet bulb temperatures from the operational (18Cm27) and backup (18Rtw) sites. Note that the processing of 1-minute observations at civil airports is slightly different from the processing at other automated stations in the observation network of KNMI. The main difference for the precipitation type is the execution of the PWc correction on each 12-second PW code, whereafter a running average 1-minute PWc is determined from five successive 12-second values of PWc.

A data set with 1-minute automated observations at Schiphol is analyzed for the period December 15, 2003 to December 31, 2006. The frequency of occurrence of freezing precipitation in simultaneously available observations at the seven locations is presented in Figure 6.6. The total number of included minutes is 1,495,748. The frequency of occurrence is calculated for uncorrected PW codes, PWc codes and PWc codes corrected by the wet bulb temperature at 18Rtw. The lower occurrence of the last mentioned precipitation type indicates the higher wet bulb temperatures which are generally observed at location 18Rtw during these events. According to the corrected precipitation types, most freezing precipitation events occur at location 36Lt, followed by 18Ct, 18Rmn and 18Rms. The lowest number of freezing precipitation events is found for the locations along the touchdown zone of runway 18R, i.e. 18Rtw and 18Rte, and for location 22t situated in the southeastern corner of Schiphol.

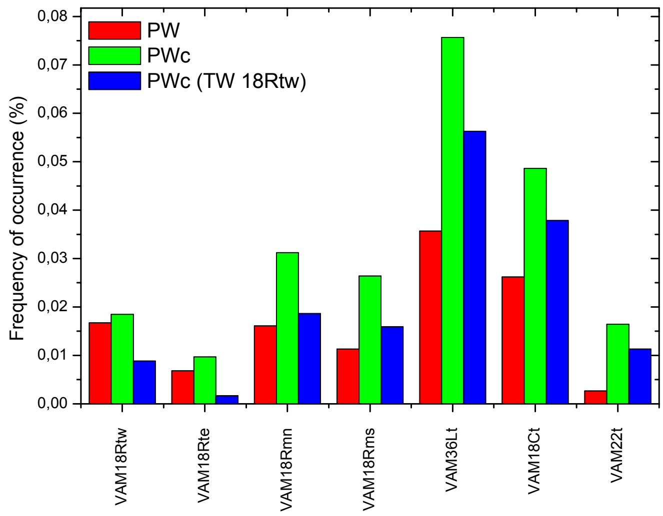

Figure 6.6. Frequency of occurrence of 1-minute freezing precipitation reports for different locations at Schiphol in the period December 15, 2003 – December 31, 2006. Results are presented for the PW code (red), the PWc code (green) and the PW code corrected by the wet bulb temperature at location 18Rtw (blue).

The observed frequency of occurrence of 0.076% for PWc at location 36Lt corresponds to a number of 1132 1-minute events, or almost 19 hours of freezing precipitation. During these 1132 events, the automated observation of PWc at location 18Rtw reports freezing precipitation in 137 cases (12.1%). It is furthermore mainly solid precipitation which is reported (52.0%), followed by no precipitation (29.6%) and unknown precipitation (6.3%).

Table 6.3 lists two contingency matrices for the occurrence of freezing precipitation. The 'true' PWc code for location 18Rtw is logically the PW code corrected by the wet bulb temperature at 18Rtw. A number of 132 PWc codes which indicate the presence of freezing precipitation is found. This observation is firstly compared to the PWc code at 18Rtw where the wet bulb temperature at the observation field 18Cm27 is used for correction. In fact this depicts the current situation at Schiphol. The POD for these observations is 92%, but also a high number of false alarms is observed (FAR=56%). This leads to a CSI score of only 43%, which seriously questions the representativeness of the wet bulb temperature at 18Cm27 for location 18Rtw. The wet bulb temperature is on average lower at location 18Cm27, generally leading to more freezing precipitation events. Consequently a BIAS of 2.09 is found, indicating that the PWc at 18Rtw reports freezing precipitation about twice as much when it is corrected with TW at 18Cm27 than when it is corrected with TW measured by the closely collocated sensors at 18Rtw.

Secondly, the table lists the results of a comparison with the uncorrected PW code at 18Rtw. The corresponding POD, FAR and CSI scores are 41%, 78% and 16%. Since the CSI score is lower than for the PWc corrected by TW at 18Cm27, the use of the uncorrected precipitation type is not preferred.

Table 6.3. Scores for the agreement on freezing precipitation on location 18Rtw at Schiphol. The location of the used wet bulb temperature in the PWc correction is indicated between brackets. The PWc corrected by the wet bulb temperature at 18Rtw is used as the truth.

		PWc (TW 18Cm27)			*PW*	
		yes	no		yes	no
PWc	yes	122	10	yes	54	78
(TW 18Rtw)	no	154	1497845	no	196	1497803
	POD		92%	POD		41%
	FAR		56%	FAR		78%
	CSI		43%	CSI		16%
	HSS		60%	HSS		28%
	BIAS		2.09	BIAS		1.89
	N		286	N		328

7 Hourly data validation

7.1 Introduction

One of the tasks of the department of Information Process Management (I-ID) at KNMI is to validate hourly observations from all stations in the meteorological observation network in the Netherlands. The purpose is to generate consistent hourly observations of high quality for climatological analysis, monitoring and further research. Automated validation procedures are based on the coherence between different parameters and the behavior of meteorological phenomena in time. Observations labeled as suspected are investigated and if they are invalid they are manually corrected based on data from different sources, like the 10-minute observations on the site or at surrounding stations, information from human observers, radar and satellite images or the perception of the general meteorological situation.

7.2 Detection of validation events for 14 Dutch stations (2003-2006)

Unvalidated 10-minute automated observations of PWc at hh:00 are compared with hourly automated w_aw_a-codes which have undergone the validation process in the period April 1, 2003 to December 31, 2006. Any inconsistency with the corresponding PWc code indicates a correction applied by I-ID. Contingency matrices and skill scores for the precipitation classes are presented in Table 7.1a and 7.1b. The stations in the analysis are Valkenburg (210), De Kooy (235), Schiphol (240), Terschelling (251), De Bilt (260), Stavoren (267), Lelystad (269), Deelen (275), Eelde (280), Vlissingen (310), Rotterdam (344), Gilze-Rijen (350), Ell (377) and Beek (380). A map with the locations of these stations can be found in Appendix A. Note that the data for the airbases Deelen and Gilze-Rijen are only available until September 22, 2004.

Table 7.1a. Contingency matrix of the unvalidated 10-minute data at hh:00 compared to validated hourly data at the 14 selected stations, April 1, 2003 - December 31, 2006.

	Unvalidated 10-min															
Validated	**N/A**	**C**	**P**	**L**	**LR**	**R**	**ZL**	**ZR**	**LRS**	**S**	**IP**	**SG**	**IC**	**SP**	**A**	**Sum**
N/A	3	89	1			3										96
C	51	370228	546	332	10	418	5	2	24	44	14	277	12			371963
P		21	5	24	48	738			2	6					3	847
L	1	190	248	10489		13	15	1	1			2				10960
LR		10	12	5	5528	55										5610
R	3	26	506	9	16	24993		9	1		1				6	25570
ZL			6	1			32									39
ZR			2			2	1	38			1					44
LRS			22			4	2	2	357		39					426
S		1	131				4	9		1688	121					1954
IP			4			1					14					19
SG		3	85				12	2		2	22	404				530
IC																0
SP																0
A															1	1
Sum	58	370568	1568	10860	5602	26227	71	63	385	1740	212	683	12	0	10	418059

N/A	0.0%	Band0	99.0%	Band0*	94.7%	Band1	99.1%
Band1*	95.3%						

Firstly, it must be remarked that the contingency matrix and resulting scores can not be interpreted in a same way as in the comparison with the human observer in Section 4.1. The results given here provide information on the most important types of corrections which are applied to the measurements of precipitation type in the validation process of I-ID. It is likely that the resulting hourly data are more reliable than the unvalidated 10-minute observations, but they can not be considered as a reference like for example observations from a human observer.

Table 7.1b. Scores for the precipitation classes, determined from the contingency matrix in Table 7.1a. The validated events are along the vertical.

Precipitation			*Liquid*			*Freezing*			*Solid*		
	yes	no		yes	no		yes	no		yes	no
yes	45745	251	yes	41108	1028	yes	71	12	yes	2648	282
no	1684	370228	no	1578	374194	no	63	417762	no	394	414584
POD		99%	POD		98%	POD		86%	POD		90%
FAR		4%	FAR		4%	FAR		47%	FAR		13%
CSI		96%	CSI		94%	CSI		49%	CSI		80%
HSS		98%	HSS		97%	HSS		65%	HSS		89%
BIAS		1.03	BIAS		1.01	BIAS		1.61	BIAS		1.04
N		47680	N		43714	N		146	N		3324

A total of 3289 corrections is found, which amounts to 0.8% of the total number of observations in the comparison. The cases with w_aw_a-code 92 are not accounted for in this number, since this code does not guarantee a unique translation. The description for this code (and w_aw_a-code 95) in WMO Table 4680 is ambiguous[3] and hence it is translated to a PW code 40, in conformity with Table 2.2. Most corrections occur for Lelystad, Stavoren and Terschelling (about 1.0 to 1.1%). Nearly half the corrections (1562 events) result in the classification of an unknown precipitation type.

The CSI for liquid precipitation is 94%. Corrections for this precipitation class are mainly related to inconsistencies in the detection of precipitation and the classification of unknown precipitation (P) into a specific liquid precipitation type. Remarkably, specified precipitation types from the sensor are also oppositely converted into unknown precipitation. The 738 events for which rain is classified as unknown precipitation coincide however with w_aw_a-code 92, and unfortunately have a significant impact on the scores presented here.

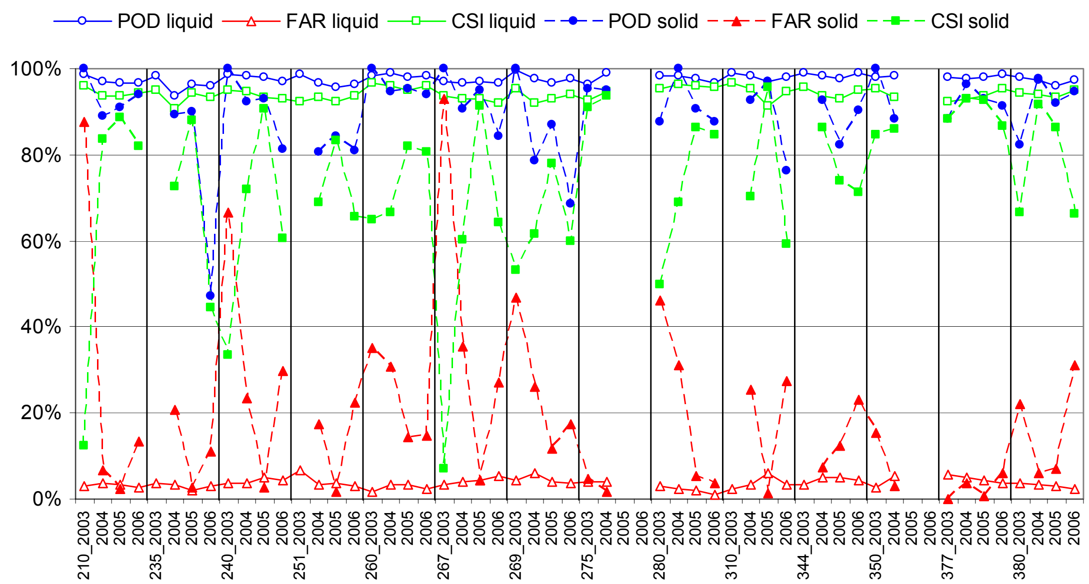

Figure 7.1. POD, FAR and CSI scores for the liquid and solid precipitation classes for the unvalidated 10-minute data at hh:00 compared to validated hourly data. Annual scores are presented for the 14 selected stations indicated by their WMO code, April 1, 2003 - December 31, 2006.

[3] 'Thunderstorm, slight or moderate, with showers of rain and/or snow'

A CSI score of 80% is found for solid precipitation. Some remarkable features are seen in the contingency matrix concerning this class. Firstly, there is a significant number of events where 10-minute observations of solid precipitation are modified to no precipitation (C), contributing strongly to the FAR of 13%. This occurs primarily for observations of snow (44 events) and snow grains (277 events). Furthermore it is clear that most of the 212 observations of ice pellets are faulty, but since they mainly result in another solid precipitation type after validation they do not affect the scores for the precipitation classes.

The annual POD, FAR and CSI scores for liquid and solid precipitation at the 14 stations are presented in Figure 7.1. The scores for liquid precipitation are fairly constant from year to year and for the 14 stations, but it is evident that the detection of solid precipitation requires more validation practices. The number of solid precipitation events ranges between 3 (Schiphol, 2003) and 203 (Beek, 2005). Like in the discussion on the spatial dependency at Schiphol in Section 6.3, the highest CSI scores are generally observed in the year 2005, for which a relatively high number of wintry precipitation events occurred. Table 7.2 lists the overall POD, FAR and CSI scores for the precipitation classes at each station. Note again that data from stations 275 and 350 is only available during a limited part of the analysis period.

Table 7.2. Scores for the precipitation classes for the unvalidated 10-minute data at hh:00 compared to validated hourly data.

		Precipitation						*Liquid*						*Freezing*						*Solid*					
	Station	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**	**POD**	**FAR**	**CSI**	**HSS**	**BIAS**	**N**
210	Valkenburg	99%	2%	97%	98%	1.01	3443	97%	3%	94%	97%	1.00	3230	100%	44%	56%	71%	1.80	9	91%	10%	83%	90%	1.01	185
235	De Kooy	98%	3%	95%	97%	1.01	3116	96%	3%	93%	96%	0.99	2907	83%	69%	29%	45%	2.67	17	85%	12%	76%	86%	0.97	161
240	Schiphol	100%	3%	96%	98%	1.03	3735	98%	4%	94%	97%	1.02	3466	83%	29%	63%	77%	1.17	8	91%	15%	79%	88%	1.07	230
251	Terschelling	100%	4%	96%	98%	1.04	3797	97%	4%	93%	96%	1.01	3485	67%	80%	18%	31%	3.33	11	83%	9%	76%	86%	0.91	261
260	De Bilt	100%	3%	97%	98%	1.03	4160	98%	3%	96%	98%	1.01	3815	67%	50%	40%	57%	1.33	10	95%	20%	77%	87%	1.19	303
267	Stavoren	100%	5%	94%	97%	1.05	3971	97%	4%	93%	96%	1.01	3627	100%	25%	75%	86%	1.33	8	93%	20%	75%	86%	1.16	268
269	Lelystad	100%	5%	95%	97%	1.05	4087	98%	5%	93%	96%	1.02	3716	100%	78%	22%	36%	4.50	18	83%	18%	70%	83%	1.01	284
275	Deelen	99%	3%	96%	98%	1.02	1473	98%	4%	94%	96%	1.02	1375	100%	0%	100%	100%	1.00	6	95%	3%	93%	96%	0.98	84
280	Eelde	100%	3%	97%	98%	1.03	4136	98%	2%	96%	98%	1.00	3756	88%	13%	78%	87%	1.00	18	91%	14%	79%	88%	1.07	308
310	Vlissingen	100%	4%	96%	98%	1.04	3401	98%	4%	94%	97%	1.02	3211	57%	20%	50%	67%	0.71	8	92%	15%	80%	89%	1.08	153
344	Rotterdam	100%	4%	96%	98%	1.03	4122	98%	4%	94%	97%	1.03	3859	83%	58%	38%	56%	2.00	13	87%	14%	76%	87%	1.01	217
350	Gilze-Rijen	99%	2%	97%	98%	1.02	1330	98%	4%	94%	97%	1.02	1231						0	90%	5%	86%	92%	0.94	91
377	Ell	99%	3%	97%	98%	1.02	3270	98%	5%	94%	96%	1.03	2932	100%	55%	45%	62%	2.20	11	94%	2%	92%	96%	0.95	315
380	Beek	99%	4%	95%	97%	1.03	3639	97%	3%	94%	97%	1.00	3104	86%	25%	67%	80%	1.14	9	94%	13%	82%	90%	1.08	464

The results regarding freezing precipitation cause the most concern in this analysis. The resulting scores from the comparison are 86%, 47% and 49% for the POD, FAR and CSI, respectively. The detections of freezing precipitation are judged as false alarms in about 50% of the cases. They are corrected to no precipitation (7 events), liquid precipitation (25 events) or solid precipitation (31 events). The misses of freezing precipitation coincide 8 times with unknown precipitation. Hence a strong bias towards reducing the number of freezing precipitation events is observed.

7.3 The main features

In Section 4.2 the comparison of the automated and manned observations led to an overview of shortcomings of the automated system for the purpose of precipitation type discrimination. This has given indications on the improvements that should be considered. If the most important features regarding the validation of hourly observations are gathered, the following list can be created:

1. Unknown precipitation is specified.

Unknown precipitation (P) is adjusted to a specific precipitation type by the validators in 1562 cases, mainly to rain (506 events), drizzle (248 events), snow (131 events) and snow grains (85 events). Corresponding $w_a w_a$ codes indicate that most of these cases coincide with low precipitation intensity. In 546 cases no precipitation (C) is reported after validation. This inconsistency is discussed in the next feature listed (detection).

A (TA,RH)-diagram for the unvalidated 10-minute observations of unknown precipitation is presented in Figure 7.2. Although the type after validation is not exactly specified in this diagram, it is clear that the isotherm for TW=1.5°C again appears to be very suitable to discriminate between events with liquid and solid precipitation. An uncertain area with detections of both classes is seen roughly between the isotherms of TW=0°C (not shown) and TW=1.5°C, but on the right side of the 1.5°C isotherm practically all observations of P are adjusted to drizzle, rain or a drizzle/rain mixture in the validated hourly observations. The hourly reports of a mixture of drizzle/rain and snow (PW code 67) are indicated by the green dots. These events are generally located in the uncertain area. Correction PWc+23 in Section 5.1 states that all events of unknown precipitation with an air temperature higher than 6°C are corrected to rain. Considering the diagram in Figure 7.2, this correction can obviously be adapted to the use of the wet bulb temperature, with threshold that is considerably lower than 6°C.

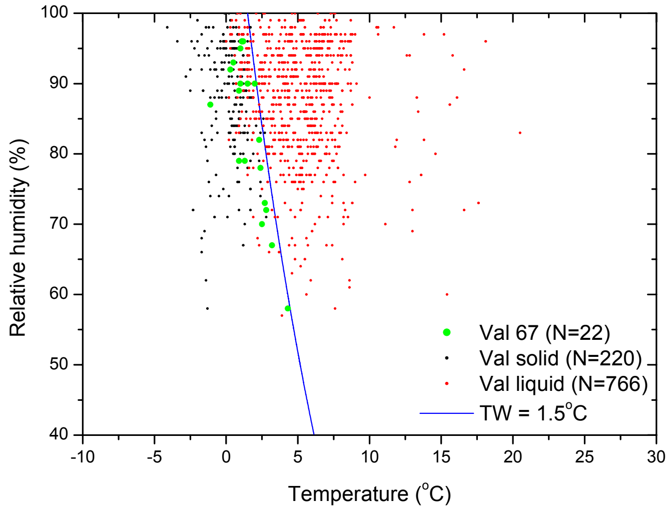

Figure 7.2. (TA,RH)-diagram for unvalidated observations of unknown precipitation (P), which are specified to a mixture of drizzle/rain and snow (green), or solid (black) and liquid (red) precipitation types in the validation by I-ID.

2. The detection of precipitation by the sensor is fallible.
False alarms of precipitation are found in the contingency matrix for 1684 events. These are events which are adjusted to no precipitation (C) in the validated hourly data, commonly coinciding with low 10-minute precipitation intensities observed for as well the FD12P as the rain gauge. Most false alarms occur for unknown precipitation (546 events), rain (418 events), drizzle (332 events) and snow grains (277 events).

The high false alarm rate for snow grains is quite remarkable, but an inconsistency of this type was already seen very frequently in the comparison with the human observer. In Section 4.2 this feature eventually led to the recognition that false alarms of solid precipitation were particularly seen during periods with low visibility. This resulted in correction PWc+21, which was found to be feasible in Section 5.2. The I-ID department has implemented an automatic correction for this type of events, where all w_aw_a-codes indicating precipitation are modified to w_aw_a-codes 32 to 35 (for fog and ice fog) if the observed MOR is below 200 m. Hence this results in the absence of actual precipitation in these cases in the validated hourly data. Histograms of the MOR for events with snow and snow grains are shown in Figure 7.3, in case the hourly observations are not changed (blue) or corrected to no precipitation (red).

The figure resembles Figure 4.3 to a large extent. False alarms of solid precipitation are frequently found for values of MOR up to approximately 400 m.

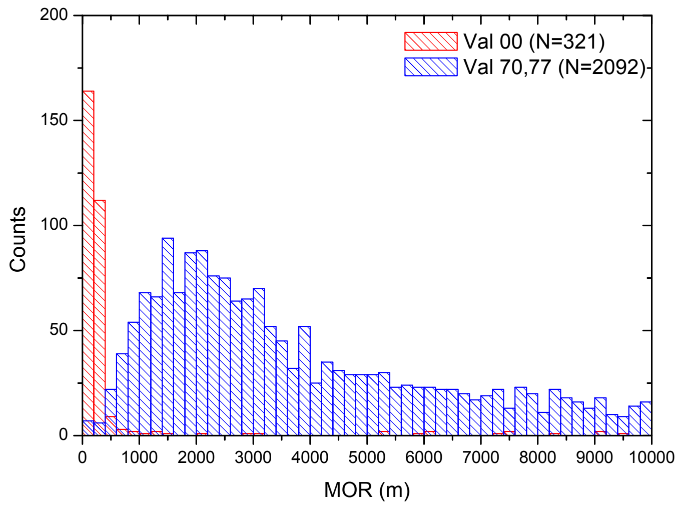

Figure 7.3. Histograms of Meteorological Optical Range (MOR) for unvalidated 10-minute observations of snow and snow grains, where the validated data is not corrected (blue) or corrected to no precipitation (red).

The detection of precipitation is also a marked feature the other way around, where 251 unvalidated observations of no precipitation (C) are corrected to a specific precipitation type in the validation. According to the experiences of the validators, this type of correction is often necessary for observations from coastal stations, where the rain gauge observes precipitation but the FD12P does not. It mainly occurs for drizzle (190 events) and rain (26 events). A strong bias however exists here towards reducing the number of events with precipitation, since the opposite occurs in 1684 cases.

It is stated in one of the shortcomings in Section 1.2 (Van der Meulen, 2003) that optical PW systems are sensitive to contamination and require regular maintenance. This is also a known feature for the FD12P (e.g. Wauben, 2003). The sensitivity of the sensor can be reduced due to contamination on the optical and capacitive units. FD12Ps on coastal sites are generally believed to be subject to enhanced contamination due to sea spray and bird excrements. For that purpose a data set with 10-minute observations from 16 stations with a FD12P and a KNMI rain gauge is analyzed to investigate this effect. Note that status and maintenance information are not available and hence this analysis is not conclusive. The period of analysis is April 1, 2003 to December 31, 2006. The 10-minute observations for the airbases Deelen (275) and Gilze-Rijen (350) are only available until September 22, 2004. A total of 1344 days remain for which data are simultaneously available at the other stations. The focus in the analysis will be on observed differences in precipitation duration, since the FD12P is the operational sensor for precipitation duration at KNMI, when it is available. Otherwise the rain gauge is used. Precipitation duration is reported by the SIAM sensor interface for each 12-second period with a 1-minute intensity higher than 0.05 mm/h.

Besides the possible effect of contamination on the FD12P, differences in precipitation duration and intensity between the two sensors can firstly be explained by their collocation. Larger differences can be expected for sensors that are more distant to each other at a station. Furthermore a well known problem of the KNMI rain gauge is related to solid precipitation. Solid precipitation particles regularly stick to the funnel of the gauge, since only the rim is slightly heated. This causes a delay and long periods of precipitation due to melting after the actual precipitation has already stopped. Hence differences can also be expected during solid precipitation events. Finally, malfunctioning in the operation of one of the two sensors at a certain station might also contribute to the differences observed here.

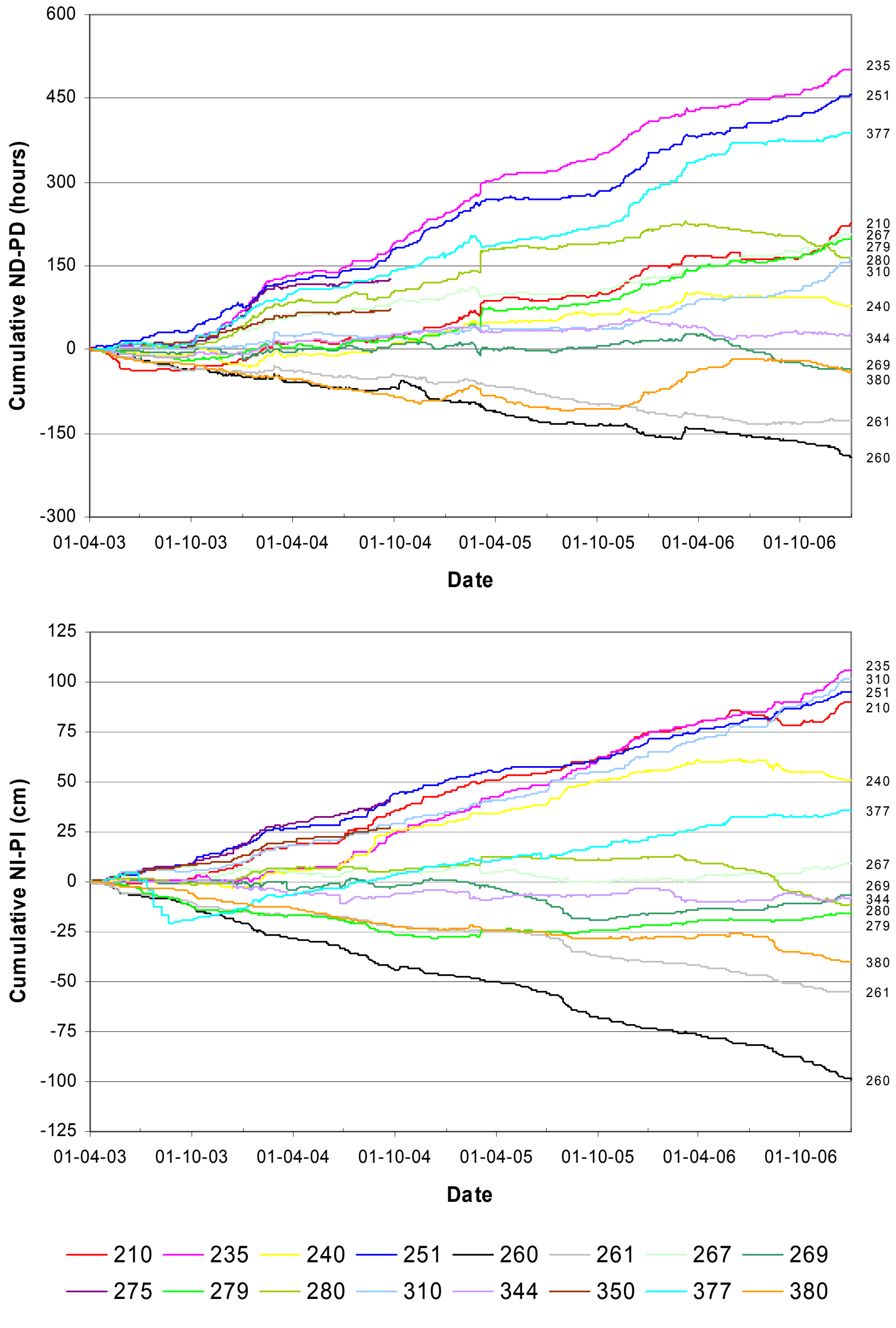

Figure 7.4. Cumulative difference of 10-minute precipitation duration (upper panel) and precipitation intensity (lower panel) measured by the rain gauge and the FD12P for 16 stations in the Netherlands. The period of analysis is April 1, 2003 - December 31, 2006.

Note that a possible exchange of one or both sensors is not accounted for. A rain gauge is normally exchanged every year, while the FD12P is exchanged every two years. Hence the analysis presented here is based on observations by several sensors for each station.

The cumulative differences of 10-minute precipitation duration and precipitation intensity measured by the rain gauge and the FD12P for the mentioned period are shown in Figure 7.4. It holds for both figures that a cumulative difference of zero at a certain time implies that the rain gauge and the FD12P report on average the same amounts of precipitation duration or precipitation intensity up to that time. Most of the 16 stations show a fairly monotonous increase of the cumulative differences. In that case the duration reported by the rain gauge is predominantly higher than the duration reported by the FD12P. Eventually this leads to the maximum cumulative difference in precipitation duration of 502 hours for De Kooy (235) at the end of the period, which amounts to an average difference over the whole period of 22 minutes a day. This can be expressed in a ND/PD-ratio of 1.28 for this station, which means that the precipitation duration of the rain gauge is on average 28% higher than the precipitation duration reported by the FD12P. The corresponding NI/PI-ratio for the precipitation intensity sums is also the highest for De Kooy, showing a value of 1.56. This agrees well with the findings in an exploration of the quality of the precipitation intensity reported by the FD12P (Wauben, 2007). A complete overview of the sums of precipitation duration, precipitation intensity and the related ratios over the considered period is found in Table 7.3, where stations are listed from high to low ND/PD-ratio. Other stations that have a high ND/PD-ratio are Terschelling (1.23), Ell (1.22), Deelen (1.15) and Valkenburg (1.11). Coincidence or not, the coastal stations of KNMI are ranked fairly high in the table with three stations among the first five. All four coastal stations are among the five stations with the highest NI/PI-ratio.

Table 7.3. Overview of the cumulative values derived from 10-minute precipitation duration and precipitation intensity measured by the rain gauge and the FD12P at 16 stations.

	Station	Type	#days	NDsum (hours)	PDsum (hours)	ND/PD	NIsum (cm)	PIsum (cm)	NI/PI	#L	#R	L/R
235	De Kooy	coast	1344	2317.2	1815.1	1.28	295.7	189.5	1.56	4970	10192	0.49
251	Terschelling	coast	1344	2493.6	2035.4	1.23	291.3	195.9	1.49	4355	13389	0.33
377	Ell	land	1344	2147.1	1757.8	1.22	258.3	222.2	1.16	4654	10323	0.45
275	Deelen	airbase	534	956.5	829.7	1.15	114.7	74.0	1.55	1344	5424	0.25
210	Valkenburg	coast	1344	2347.8	2119.0	1.11	314.3	224.1	1.40	5997	10829	0.55
267	Stavoren	land	1344	2303.9	2096.8	1.10	270.0	260.9	1.03	5991	12436	0.48
350	Gilze-Rijen	airbase	534	830.0	758.3	1.09	105.8	78.6	1.35	1345	4916	0.27
279	Hoogeveen	land	1344	2515.2	2315.0	1.09	292.0	307.3	0.95	5031	13114	0.38
310	Vlissingen	coast	1344	2177.7	2012.7	1.08	287.7	185.7	1.55	5127	11065	0.46
280	Eelde	airport	1344	2576.1	2413.5	1.07	291.9	303.4	0.96	6575	13158	0.50
240	Schiphol	airport	1344	2284.9	2207.8	1.03	323.6	272.7	1.19	4402	13223	0.33
344	Rotterdam	airport	1344	2327.3	2300.5	1.01	313.9	321.7	0.98	5526	13849	0.40
269	Lelystad	airport	1344	2334.4	2367.2	0.99	306.7	312.1	0.98	5458	13300	0.41
380	Beek	airport	1344	2175.0	2215.4	0.98	259.2	299.4	0.87	5235	10921	0.48
261	De Bilt Test	land	1344	2335.7	2461.7	0.95	293.8	349.1	0.84	4982	13523	0.37
260	De Bilt	land	1344	2429.8	2622.1	0.93	305.1	404.1	0.75	4313	15104	0.29

The values of the cumulative differences in De Bilt (260) and De Bilt Test (261) show an opposite behavior and decrease almost monotonously. Eventually the minimum cumulative difference in precipitation duration is observed for station 260, indicating a total deficit of 192 hours, which amounts to 9 minutes a day on average. The ND/PD- and NI/PI-ratios are 0.93 and 0.75, respectively. This implies that precipitation duration and precipitation intensity measured by the FD12P in De Bilt are on average 7% and 25% lower with respect to the collocated rain gauge, respectively. Other stations where the FD12P reports higher precipitation durations than the rain gauge on average are Beek (ND/PD=0.98) and Lelystad (0.99). The other airports (Rotterdam, Schiphol and Eelde) show ND/PD-ratios just above 1. A remarkable feature is seen for station Beek. It follows the strongly decreasing cumulative difference in precipitation duration of stations 260 and 261 quite well until approximately

November 2005, where it starts to increase and eventually ends just below 0. This feature seems to be related to the relocation of sensor positions at Beek which was finished on October 7, 2005. As a result, the distance between the rain gauge and the FD12P increased from some tens of meters to approximately 1475 m.

The ratio of the occurrence of drizzle and rain, or L/R-ratio, was introduced in Section 6.2. It is calculated here as well and listed in the last column of Table 7.3. Although no strong relationship with a reduced sensitivity to precipitation can be deduced, note that one but the lowest L/R-ratio (0.29) is observed for the most sensitive location with respect to precipitation detection by the FD12P, at De Bilt (260).

Figure 7.4 and Table 7.3 seem to indicate that the FD12P sensors at coastal stations suffer more from contamination than the sensors at other locations, which is expressed in a lower cumulative precipitation duration and amount with respect to the rain gauge. Contrary to these stations, the two locations in De Bilt (260 and 261) report higher precipitation duration and precipitation intensity than the rain gauge on average. Apparently the very close collocation (30 m) and the frequent cleaning of the sensors in De Bilt have significant impact on the results. Comparable results for the precipitation duration reported by the rain gauge and the FD12P are found for the airports in the analysis. The reason of the high ranks of the land stations Ell, Stavoren and Hoogeveen and the air bases Deelen and Gilze-Rijen is unknown. Unfortunately, maintenance information on cleaning or the replacement of sensors to verify any dependency on contamination of the FD12P was not made available during the project. A correlation with service dates (e.g. sensor exchange, cleaning) acquired from the department of Observation Systems Operations (I-WIS) at KNMI could add more information on this effect.

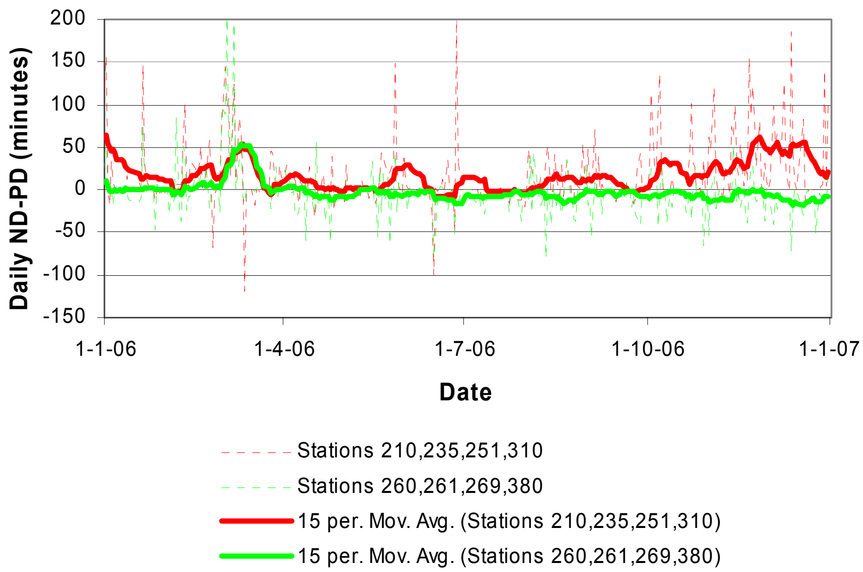

Figure 7.5. Daily precipitation duration difference for two sets of stations: 210, 235, 251 and 310 (red) and 260, 261, 269 and 380 (green). Results are splitted in daily values (dashed line) and 15 day moving averages (solid line).

As an example, two time series of daily precipitation duration difference in the year 2006 are presented in Figure 7.5. The red lines represent the average ND-PD for the 4 coastal stations (210, 235, 251 and 310), whereas the green lines correspond to the average ND-PD for the 4 stations lowest in rank in Table 7.3 (260, 261, 269 and 380).

Firstly the wintry precipitation period in the first half of March, as mentioned earlier, is nicely seen in the positive and fairly high values of ND-PD for both sets of stations. The average difference in precipitation duration amounts to about 50 minutes. The set of coastal stations predominantly shows values higher than zero for the rest of the year, while the set of other stations is mostly around or below zero. In particular during the first two months and the last three months of 2006 the underestimation of precipitation duration by the FD12Ps at the coastal stations is high, reaching daily values of up to 180 minutes and 60 minutes in the 15 day moving average. The validators of I-ID reported contamination warnings and significant underestimation of precipitation by the FD12P on November 1, 2006 for De Kooy, Valkenburg, Schiphol, Terschelling, Stavoren and Vlissingen. However, the daily difference in precipitation duration does not show extremely high values around this date.

Finally, the cumulative probabilities of 10-minute precipitation intensity reported by the rain gauge and the FD12P for the same two sets of stations are shown in Figure 7.6. The precipitation intensity is truncated at 5 mm/h, since 96 to 98% of the 10-minute observations with precipitation have an intensity below this value. Clearly the rain gauges at the coastal (210, 235, 251, 310) and other (260, 261, 269, 380) stations show a very good agreement in cumulative probability, with values of about 30% at 0.1 mm/h, 70% at 1.0 mm/h and 89% at 2.5 mm/h. It can be concluded from this marked resemblance that, according to the rain gauge, no significant differences in the distribution of the reported precipitation intensity should exist between coastal and other (inland) stations. The diagram for the FD12P precipitation intensity at the other stations agrees well with the rain gauges, but diverges a little to lower values for intensities up to approximately 2 mm/h and to higher values for intensities above 2 mm/h. However, it is evident that a more significant deviation exists for the FD12P precipitation intensity at the coastal stations, shifted to lower intensities for the whole domain. The cumulative probability indicates values of 42% at 0.1 mm/h, 82% at 1.0 mm/h and 94% at 2.5 mm/h. Hence the precipitation intensity reported by the FD12P sensors at the selected coastal stations is clearly reduced strongly.

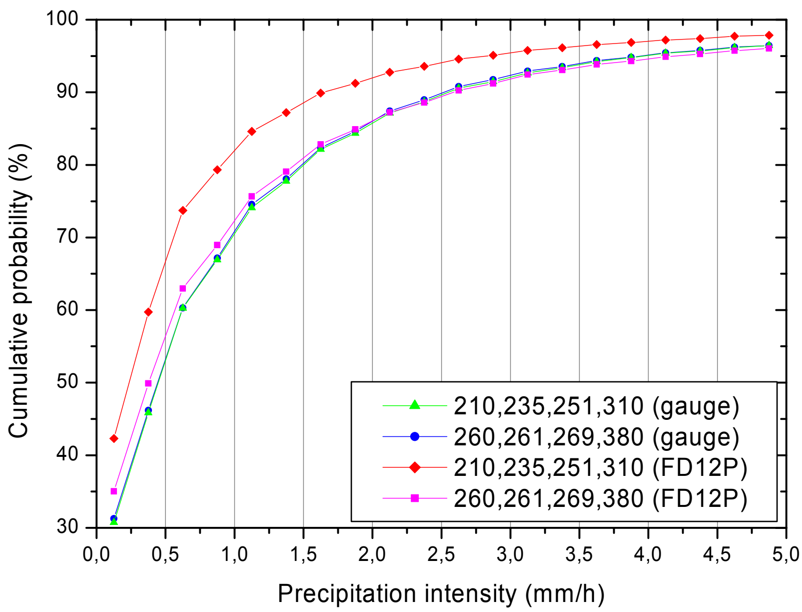

Figure 7.6 Cumulative probability of 10-minute precipitation intensity reported by the rain gauge and the FD12P for stations 210, 235, 251 and 310 (blue/red) and 260, 261, 269, 380 (green/magenta) in the period 2003-2006. A bin size of 0.25 mm/h is used.

3. The automated system has problems to identify freezing precipitation correctly.
False alarms of freezing precipitation appear in 25 cases during liquid precipitation and in 31 cases during solid precipitation. Nevertheless the focus is on the discrimination between liquid and freezing precipitation here, because there are no direct indications to solve the inconsistencies with solid precipitation. As noted earlier in the comparison with the human observer and in the analysis of freezing precipitation at Schiphol, the wet bulb temperature is used to discriminate between liquid and freezing precipitation.

Table 7.4. List with inconsistent observations of freezing precipitation between unvalidated 10-minute observations (PWc) and validated hourly observations (PW_WaWa) at hh:00, in the period 2003-2006.

WMO code	yymmdd	hhmm	PW_WaWa	PWc	PI	NI	TA	RH	TW
235	050304	2300	55	50	0.1	0.3	0.4	96	0.2
310	050304	2000	65	60	0.0	0.5	1.5	94	1.1
310	050304	2400	65	60	1.6	0.6	1.8	85	0.9
210	050127	0300	50	55	0.0	0.0	0.7	86	-0.1
210	050224	1000	60	65	0.0	0.0	0.2	91	-0.3
210	051126	0800	50	55	0.0	0.0	0.3	97	0.1
235	041125	2100	50	65	0.0	0.0	0.0	100	0.0
235	050124	2100	50	55	0.1	0.0	0.2	87	-0.5
235	050125	1600	60	65	0.4	0.4	0.5	94	0.2
235	060311	0400	60	65	0.0	0.0	0.4	88	-0.3
240	050127	0400	60	65	0.1	0.0	--	--	--
251	050223	0700	50	55	0.0	0.0	0.6	91	0.1
251	050226	1300	50	55	0.0	0.0	1.0	74	-0.5
251	050226	1500	60	65	0.2	0.0	0.4	87	-0.3
251	050228	2300	60	65	0.2	0.0	0.7	86	-0.1
260	050226	1800	60	65	0.0	0.0	0.4	82	-0.6
260	061227	1700	50	55	0.0	0.0	0.7	87	0.0
269	050301	1400	50	55	0.0	0.0	0.1	84	-0.8
269	050301	1500	50	55	0.0	0.0	0.5	84	-0.4
269	050301	1600	50	55	0.0	0.0	0.5	83	-0.5
269	050301	1700	50	55	0.0	0.0	0.2	85	-0.6
280	040122	1500	60	65	0.1	0.0	1.1	74	-0.5
310	050127	0500	50	55	0.0	0.0	0.5	90	-0.1
344	041203	0700	50	55	0.2	0.0	0.7	98	0.6
344	050301	1300	50	55	0.0	0.0	0.8	81	-0.3
344	051218	0500	60	65	1.0	0.9	1.7	90	1.1
377	050226	1900	50	55	0.0	0.0	0.5	89	-0.1
377	050226	2000	50	55	0.1	0.0	0.2	89	-0.4

Table 7.4 lists all the inconsistencies concerning freezing precipitation in the analyzed period. It should be noted that reported precipitation intensities are 10-minute averages with a resolution of only 0.1 mm/h. Hence if an intensity '0' is reported, the averaged precipitation intensity will actually be lower than 0.05 mm/h. Furthermore also the values for the air and wet bulb temperatures and relative humidity are 10-minute values, reported as the last 1-minute value in the 10-minute interval. Separate 1-minute values during the occurrence of liquid or freezing precipitation within the 10-minute interval should be studied in order to obtain all necessary information. A possible source for the inconsistent reports of freezing precipitation is the use of outdated temperature or humidity information from the previous 1-minute interval in the PWc correction at civil airports, related to the order of computations in the local processing system.

Three events are shown in the table for which liquid precipitation is turned into freezing precipitation after validation, all on March 4, 2005. In addition, there are 25 events for which an automated observation of freezing precipitation is corrected to liquid precipitation. Since the quality of the measurements of air temperature and relative humidity is also monitored by I-ID, inconsistencies concerning freezing precipitation type can arise from changed values of these quantities, leading to a different estimation of the wet bulb temperature.

As an example of this effect, a (TA,RH)-diagram with different isotherms is presented in Figure 7.7. The initial TW=0°C isotherm is indicated by the black line. The blue and red lines represent the minimum and maximum adjustments in the TW=0°C isotherm for an absolute error in the relative humidity of 3% and 5%, respectively. The green line corresponds to the isotherm for an error in the air temperature of 0.2°C. The error levels where chosen in conformity with WMO requirements for the accuracy to be achieved for synoptical measurements (WMO, 1996). KNMI handles absolute errors of 0.1°C and 3.5% for air temperature and relative humidity measurements, respectively.

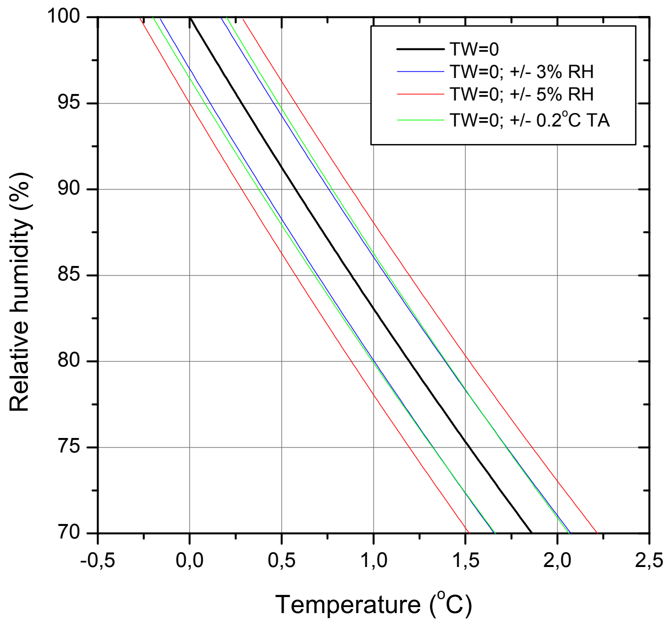

Figure 7.7. (TA,RH)-diagram for the TW=0°C isotherms, without errors in TA and RH (black), for an absolute error of 3% (blue) and 5% (red) in RH and for an error of 0.2°C in TA (green). The pressure is fixed at 1013.25 hPa.

It is clear from the figure that uncertainties in these parameters easily introduce a bias in the wet bulb temperature. At a fixed RH of 90% and an absolute error of 5% in RH for example, the air temperature corresponding to a wet bulb temperature of 0°C ranges between 0.28°C and 0.88°C. Note that an error of 3% in RH more or less generates the same deviation in TW as an error of 0.2°C in TA. The surface pressure PS is fixed in the diagram at a value of 1013.25 hPa.

4. The sensor reports too many events with ice pellets.
The detection of ice pellets has a FAR of 93% resulting in a very low CSI score of 6%. Validation practices have changed these detections mostly to snow (121 events), a mixture of drizzle/rain and snow (39 events) and snow grains (22 events). The high false alarm rate was also found in the comparison with the human observer, leading to correction PWc+24, correcting all detections of ice pellets into snow. If this correction is applied here, the CSI for snow increases from 84% to 86% (POD +7%, FAR+4%). Logically, the scores for ice pellets completely disappear because the automated system is then restrained from detecting this precipitation type.

Figure 7.8 presents A (TA,RH)-diagram for 198 unvalidated observations of ice pellets, alike Figure 4.8 in Section 4.2. All events which have been modified to another precipitation type (other than C or IP) are indicated by black dots, whereas the 14 events that remain classified as ice pellets after validation are indicated by green dots. Clearly TW can not be used to discriminate between IP and other types of precipitation, without adding more information.

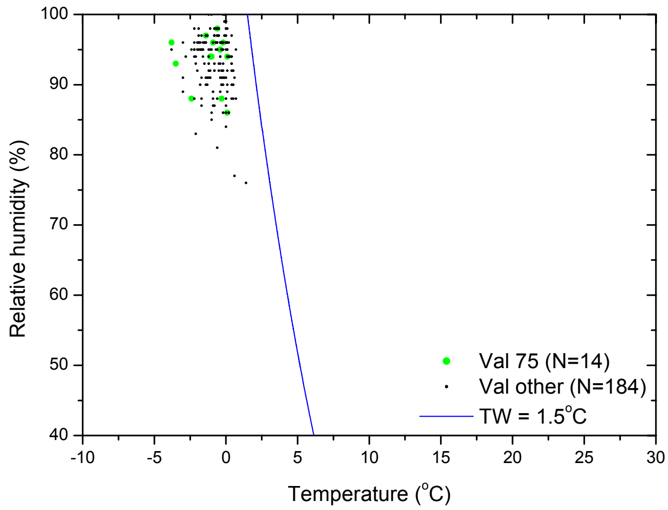

Figure 7.8. (TA,RH)-diagram for unvalidated observations of ice pellets (IP). Observations which are also classified as ice pellets after validation are denoted by green dots.

8 Precipitation typing with the NeSo method

8.1 The NeSo method

The NeSo method was developed at KNMI in the nineteen-eighties (Ivens, 1987) in order to improve the forecasts of precipitation type, especially for those cases in the transition area between liquid and solid precipitation. It uses the vertical profile of wet bulb temperature in the lower part of the atmosphere and the amount of forecasted or observed precipitation. Three versions are currently in use at KNMI. The first version uses the forecast of the HIRLAM model only, another combines the wet bulb temperature profile from the HIRLAM forecast with radar reflectance data. It is also possible to use vertical profiles obtained from radiosondes to evaluate the precipitation type with NeSo.

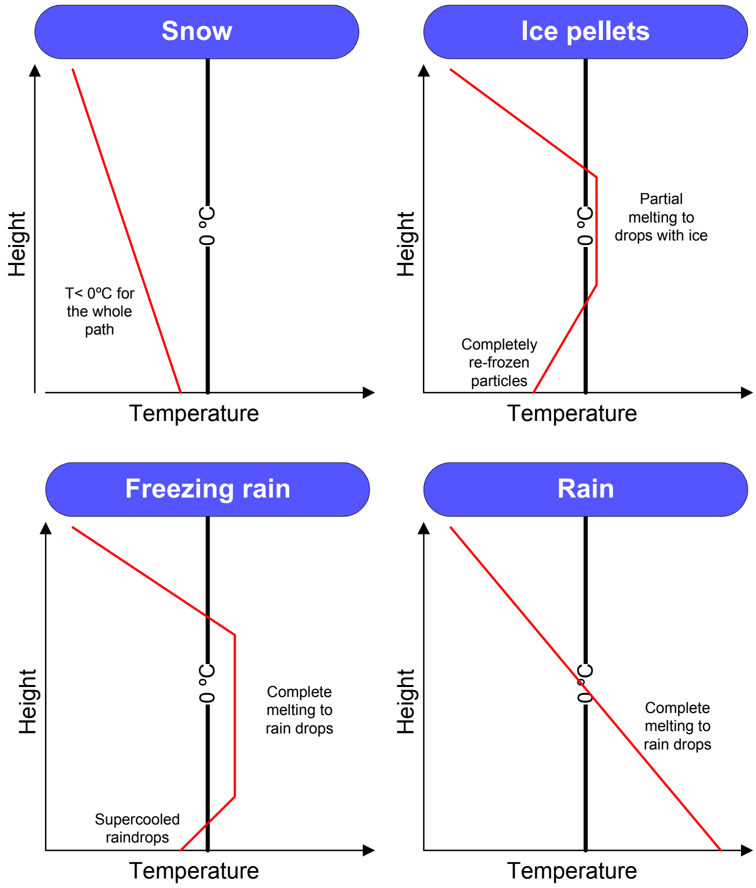

Figure 8.1. Examples of a typical temperature profile for snow, ice pellets, freezing rain and rain[4]. The NeSo method is able to discriminate between (combinations of) these types.

The NeSo method divides the path of the falling precipitation into warm and cold layers, and determines the critical precipitation amounts for freezing and melting of the entire layer. Hence an indication can be obtained of the precipitation phase at different altitudes. It is also possible to estimate whether ice pellets are likely. The reader is referred to Ivens (1987) for details on the method. Examples of a typical vertical temperature profile for four precipitation types are shown in Figure 8.1. The NeSo method uses a decision tree to classify precipitation into seven predefined classes, which generally consist of a number of precipitation types. A

[4] Partially after: Lantsheer, F., 2000: Algemene en operationele meteorologie – vorming van neerslag en neerslagsoorten. *Presentation*, KNMI, De Bilt, The Netherlands.

classification is only made if precipitation occurs according to the HIRLAM forecast or the radar reflectance, dependent on the version in use. These classes are:

0	rain
1	snow
2	rain and snow or snow
3	freezing precipitation
4	rain or ice pellets
5	rain, rain and snow or ice pellets
6	rain or rain and snow

8.2 Results

Vertical profiles of air temperature, relative humidity and pressure are extracted for 12 Dutch stations from the HIRLAM analyses at 00, 06, 12 and 18 UTC. The analysis period consists of three sets of winter months. Each period starts on November, 1 and ends on April, 30 in the years 2004, 2005 and 2006. A conversion to the wet bulb temperature profile is carried out and used together with the 10-minute precipitation intensity and precipitation duration reported by the FD12P sensor. The wet bulb temperature is analyzed from the highest model level at approximately 30 km to the lowest model level at about 30 m, on an interpolated vertical grid with a grid size of 10 m. The stations considered here are Valkenburg (210), De Kooy (235), Schiphol (240), Terschelling (251), De Bilt (260), Stavoren (267), Lelystad (269), Eelde (280), Vlissingen (310), Rotterdam (344), Ell (377) and Beek (380).

A number of 25601 events is analyzed for all stations together, during which the FD12P sensors reports a precipitation type in 3469 cases (13.6%). Table 8.1 shows the reported 10-minute PWc codes versus the NeSo class derived from the HIRLAM analyses. The precipitation types corresponding to each NeSo class are highlighted in green, to indicate the degree of agreement. Liquid precipitation is reported 2806 times by the FD12P, together with 199 observations of unknown, 16 observations of freezing and 448 observations of solid precipitation.

Table 8.1. Contingency table for the automated 10-minute (PWc) observations of precipitation type versus the NeSo class derived from the vertical wet bulb temperature profile from HIRLAM analyses for 12 Dutch stations. Analyses at 00, 06, 12 and 18 UTC are evaluated in three sets of winter months; from November, 1 until April, 30 in the years 2004, 2005 and 2006.

	FD12P PWc															
NeSo	**N/A**	**C**	**P**	**L**	**LR**	**R**	**ZL**	**ZR**	**LRS**	**S**	**IP**	**SG**	**IC**	**SP**	**A**	**Sum**
N/A																0
0			128	861	299	1071	1		5	2		11				2378
1			18	8		2	2	5	6	162	15	61	2			281
2			5	2	5	32		1	17	43	1	2				108
3						1				2	1	5				9
4			1	4		1	1	1		1	1	5				15
5				1	2	9										12
6			47	94	46	368	2	3	28	50	5	23				666
C	4	22128														22132
Sum	4	22128	199	970	352	1484	6	10	56	260	23	107	2	0	0	25601

NeSo classes

0	rain
1	snow
2	rain and snow or snow
3	freezing precipitation
4	rain or ice pellets
5	rain, rain and snow or ice pellets
6	rain or rain and snow

	#FD12P	PC
Total	3469	**88%**
Liquid	2806	**98%**
Freezing	16	**0%**
Solid	448	**70%**

The Percentage Correct (PC) score is hereby introduced as the number of sensor reports of a certain precipitation class which are in agreement with the precipitation types as described in the NeSo classes, divided by the total number of sensor reports of that precipitation class. The PC scores are presented below the contingency matrix. An overall score is calculated here (Total), but also separate scores are given for liquid, freezing and solid precipitation. The overall PC score for the HIRLAM analyses is 88%, indicating that almost 9 out of 10 observations is placed within the highlighted cells. The PC scores for liquid and solid precipitation amount to 98% and 70%. NeSo class 3 (freezing precipitation) does not agree a single time, which leads to a PC of 0%. Note that detailed information on the surface wet bulb temperature is needed for the discrimination of freezing precipitation. It may therefore not be expected that freezing precipitation is detected correctly by the NeSo method evaluated with HIRLAM profiles, where the lowest model level is located around 30 m. The implementation of the HIRLAM 2 m temperature in NeSo is however presently considered.

The discrimination between liquid and solid precipitation by means of NeSo classes 0 (rain) and 1 (snow) seems promising. Class 0 features 19 misses out of 2250 events, while class 1 has 40 misses out of 263 events. On the other hand, it is seen that for example NeSo class 2 introduces a higher degree of ambiguity, with 41 misses out of 108 events. Furthermore, classes 5 and 6 mainly coincide of FD12P observations of liquid precipitation, although their description is much broader. Class 6 also often coincides with automated observations of snow and snow grains. Clearly NeSo classes 4, 5 and 6 can be used for validation but not for a correction of PW codes, since they allow both liquid and solid precipitation types.

Vertical profiles of air temperature, absolute humidity and pressure from the radiosondes in De Bilt at 00 and 12 UTC are analyzed for the same three periods as in the comparison with the HIRLAM analyses. For some days, a 06 or 18 UTC sounding is also available and included in the analysis. The vertical profiles of wet bulb temperature are calculated and the 10-minute precipitation intensity and duration from the FD12P at station 260 are used as input parameters for the method. The wet bulb temperature is evaluated from the highest level at approximately 30 km to the lowest level at about 5 m, again on an interpolated vertical grid with a grid size of 10 m. A number of 1082 soundings is analyzed, during which the FD12P in De Bilt reports a precipitation type in 144 cases (13.3%). Table 8.2 shows the reported 10-minute PWc codes for each NeSo class derived for the considered radiosondes. A number of 19 events with solid and 3 events with unknown precipitation are reported. The overall percentage correct amounts to 92% for all events, 96% for liquid precipitation and 79% for solid precipitation.

Table 8.2. Same as Table 8.1, but for the NeSo method evaluated with radiosonde profiles.

	FD12P PWc															
NeSo	**N/A**	**C**	**P**	**L**	**LR**	**R**	**ZL**	**ZR**	**LRS**	**S**	**IP**	**SG**	**IC**	**SP**	**A**	**Sum**
N/A																0
0			3	25	18	52										98
1										7	2	4				13
2						4			2			1				7
3						1										1
4												1				1
5				1	1	2										4
6				2	1	15			1	1						20
C		938														938
Sum	0	938	3	28	20	74	0	0	3	8	2	6	0	0	0	1082

NeSo classes

0	rain
1	snow
2	rain and snow or snow
3	freezing precipitation
4	rain or ice pellets
5	rain, rain and snow or ice pellets
6	rain or rain and snow

	#FD12P	**PC**
Total	144	**92%**
Liquid	122	**96%**
Freezing		**N/A**
Solid	19	**79%**

Four misses are encountered for the 19 PWc codes coinciding with solid precipitation. Two of these events concern a report of ice pellets by the FD12P during NeSo class 1 (snow), one inconsistency is an observation of snow grains coinciding with class 4 (rain or ice pellets) and the last inconsistency is an observation of snow during class 6 (rain, rain and snow or ice pellets). None of these inconsistencies coincide with an event for which the weather code was modified in the hourly data during validation practices (see Section 7.1). Particularly the performance of the discrimination between liquid and solid precipitation by NeSo classes 0 and 1 again seems promising. Misses are observed, but not in another precipitation class. As mentioned in the discussion above, classes 5 and 6 mainly consist of FD12P observations of liquid precipitation, although their description also allows for solid precipitation types. When the FD12P data from station 261 in De Bilt are used, very similar results are found. The percentages correct for liquid and solid precipitation are 96% and 84%, respectively. However, when for example the NeSo method applied to the radiosondes in De Bilt are compared with the automated observations in Eelde and Beek, the PC scores for solid precipitation decrease to 62% and 57%, respectively.

The single event of freezing precipitation reported by NeSo class 3 is encountered for the 00 UTC sounding on December 31, 2005. Although the surface wet bulb temperature in De Bilt is just above zero and the automated system reported a PWc code 60 (rain) for stations 260 and 261, freezing precipitation is indeed reported in the 10-minute PWc codes at Stavoren and Lelystad at this time. This situation coincides with setting in thaw in the Netherlands from southwest to northeast, indicated by a 10-minute surface temperatures of 4.7°C in Vlissingen to -2.2°C in Eelde at the same time.

The scores for the 12 stations individually are shown in Table 9.3, together with those obtained for the comparison with the radiosonde in De Bilt (rds_260, rds_261). The relative frequency of occurrence of precipitation type reports by the FD12P ranges between 11.4% in De Kooy (235) and 15.6% in Lelystad (269). The percentage correct for liquid precipitation is 96% or higher for all stations, where Stavoren (267) and Vlissingen (310) even indicate a score of 100%. Freezing precipitation is observed at several stations with a maximum of three events per station, but no coinciding hits in NeSo class 3 were reported. Hence the listed PC scores for freezing precipitation do not exceed 0%.

Table 8.3. Overview of occurrences and percentage correct (PC) scores of NeSo classifications using HIRLAM analyses and radiosondes for 12 stations in the Netherlands.

Case	Station	# ppn	(rel.)	# liquid	PC	# freezing	PC	# solid	PC
hirlam_210	Valkenburg	277	(12.9%)	236	98%	1	0%	27	44%
hirlam_235	De Kooy	242	(11.4%)	205	98%	3	0%	18	39%
hirlam_240	Schiphol	272	(12.7%)	227	99%	0	N/A	35	66%
hirlam_251	Terschelling	300	(14.1%)	242	98%	0	N/A	36	61%
hirlam_260	De Bilt	301	(14.1%)	253	97%	1	0%	41	76%
hirlam_267	Stavoren	313	(14.7%)	245	100%	3	0%	38	74%
hirlam_269	Lelystad	332	(15.6%)	260	98%	3	0%	41	61%
hirlam_280	Eelde	331	(15.5%)	260	99%	2	0%	49	78%
hirlam_310	Vlissingen	244	(11.4%)	210	100%	0	N/A	20	65%
hirlam_344	Rotterdam	313	(14.6%)	270	97%	0	N/A	29	66%
hirlam_377	Ell	250	(11.8%)	191	97%	2	0%	48	88%
hirlam_380	Beek	294	(13.7%)	207	98%	1	0%	66	82%
rds_260	De Bilt	144	(13.3%)	122	96%	0	N/A	19	79%
rds_261	De Bilt	138	(13.2%)	119	96%	0	N/A	19	84%

The most interesting results are seen for solid precipitation. Again, most solid precipitation is generally reported by the stations in the eastern part of the Netherlands, i.e. in Beek (66 events), Eelde (49 events) and Ell (48 events). The percentage correct scores for these stations are 82%, 88% and 78%, respectively. On the other hand, the coastal stations De Kooy (18 events), Vlissingen (20 events) and Valkenburg (27 events) report the least events with solid precipitation. The PC scores for solid precipitation are at the same time lower for these stations, with values of 39%, 65% and 44%, respectively. Hence, again it can be inferred that the number of events in a certain precipitation class affects the measured performance to a large extent.

The PC scores for solid precipitation in the comparison with the radiosondes (79% and 84%) are not the highest in the table. The score achieved by the HIRLAM analyses in De Bilt approaches this score (76%), and the scores for Eelde, Beek and Ell are even higher, agreeing with the NeSo method on solid precipitation in 78%, 82% and 88% of the cases, respectively. The relatively temperate scores for the radiosondes can be explained by the limited number of 19 cases, but also the worse collocation of the radiosonde measurements for increasing altitude might play a role. The latter is the result of the fact that the sonde drifts from the launch site as soon as it is in the air and generally travels some tens to hundreds of kilometers from De Bilt. Note that the NeSo methods employed at KNMI use the HIRLAM forecast or radar images for the precipitation intensity, while the precipitation intensity and duration from the FD12P sensor were used here. Therefore this analysis does not include the detection of precipitation.

8.3 A case study with NeSo

Wintry precipitation was observed on a large scale in the Netherlands on December 23, 2003. A variety of different precipitation types was reported by the automated system at 12 UTC, with an increasing probability of solid precipitation from northwest to southeast. The surface temperatures ranged between 3.7°C in Rotterdam and 0.0°C in Beek.

Table 8.4 lists the reported PWc code and the surface temperature TA for the 8 stations with precipitation observed at 12 UTC. Furthermore, the NeSo class derived for the HIRLAM analyses and the radiosonde in De Bilt are given in the last two columns. Class 2 (rain and snow or snow) is determined from the radiosonde, as well as for the HIRLAM analyses for stations Ell and Beek. The other analyses lead to NeSo class 6, indicating that the expected precipitation types are rain or rain and snow. This agrees well with the reported PWc codes. Only Lelystad does not show agreement with respect to the precipitation types in this table, reporting a PWc code 77 (snow grains) where the NeSo class is 6.

Table 8.4. Overview of 10-minute observations of PWc code, air temperature and NeSo class for eight stations in the Netherlands with precipitation at 12 UTC on December 23, 2003.

Station	PWc	TA	NeSo HIRLAM	NeSo radiosonde
240 Schiphol	57	3.6	6	
251 Terschelling	60	3.4	6	
260 De Bilt	67	0.7	6	2
269 Lelystad	77	1.2	6	
280 Eelde	67	1.0	6	
344 Rotterdam	60	3.7	6	
377 Ell	70	0.3	2	
380 Beek	70	0.0	2	

The lower temperatures and snow reports at stations Ell and Beek, in the southeastern part of the Netherlands, are nicely represented by the different NeSo class (2) with respect to the other stations. The vertical profiles of wet bulb temperature from the HIRLAM analyses for stations 260, 344 and 380 and from the radiosonde in De Bilt (260) at 12 UTC on December 23, 2003 are given in Figure 8.2. The profiles are plotted between the surface and 7000 m, without any interpolation.

Clearly the wet bulb temperature from the HIRLAM analysis is significantly lower for Beek than for De Bilt, while Rotterdam generally shows a higher wet bulb temperature. This perfectly represents the situation which was sketched in Table 8.4, with PWc codes 70, 67 and 60 reported for Beek, De Bilt and Rotterdam, respectively. The profiles mainly diverge below 2500 m and above 4500 m, but are very close to each other in between. The surface observations of wet bulb temperature are given by the triangles at the surface. They fit very well to the values that may be expected from the lowest model level of HIRLAM, but for De Bilt the value observed at the surface is much lower. Nevertheless, the radiosonde profile for De Bilt fits very well to the surface observation and indicates that the HIRLAM profile for the lowest 600 m is likely overestimated. This also explains the inconsistency between the NeSo classes evaluated with the radiosonde (2: snow or rain and snow) and HIRLAM (6: rain or rain and snow) for station De Bilt.

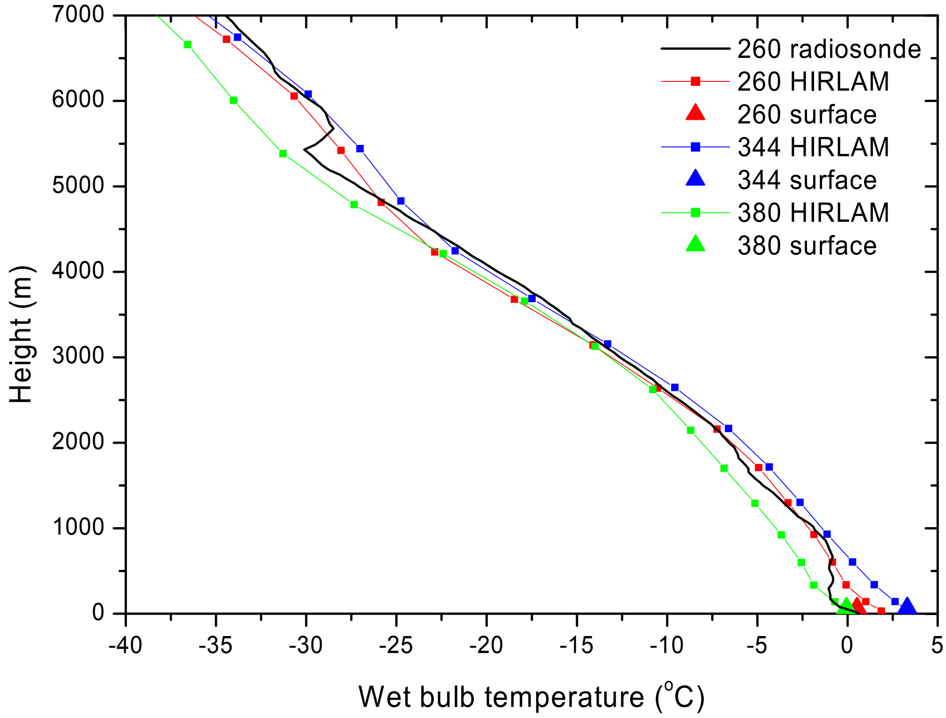

Figure 8.2. Wet bulb vertical profiles for three stations in the Netherlands for December 23, 2003 at 12 UTC. Presented profiles are from the radiosonde in De Bilt and the HIRLAM analyses for De Bilt (260), Rotterdam (344) and Beek (380). The triangles at the surface represent the surface observations of wet bulb temperature.

9 Conclusions and recommendations

9.1 Conclusions

The automated discrimination of precipitation type by the Vaisala FD12P present weather sensor at the Royal Netherlands Meteorological Institute (KNMI) was investigated in this report. The sensor has been introduced in the national meteorological observation network in the Netherlands as a part of the automation of visual observations. Nowadays it is used for nearly all observations of precipitation duration, type and visibility in the synoptical, climatological and aeronautical reports issued by KNMI. Since the introduction of the sensor, problems are encountered concerning the correct detection of precipitation type. These problems are recognized but not easily solved. Validation of automated observations is complex because the observation practices of the reference observations (i.e. a human observer) are very different and not faultless. Furthermore the coding of present weather observations is different for manned and for automated observations, introducing ambiguity in the interpretation of so-called ww- and w_aw_a-codes. A translation table is established for both weather codes to translate them adequately to the actual PW code.

Since details on the internal algorithm of the FD12P sensor are not available, this study particularly focuses on corrections which are employed in the processing algorithms. This practice follows an increasing trend in the automation of visual observations, since no improvement is likely to be achieved solely by sensor technology.

9.1.1 Comparison with a human observer

A comparison of automated and human observations of precipitation type was carried out for a period with overlapping data at six Dutch stations, in the years 2000 to 2002. Contingency matrices were constructed to investigate the performance of the uncorrected PW code from the FD12P. The scores for precipitation detection and the discrimination of the liquid, freezing and solid precipitation are listed in Table 9.1. The column '# events' indicates the total number of relevant events, i.e. the sum of the human and automated observations of an event.

Table 9.1. Scores for precipitation detection and discrimination of liquid, freezing and solid precipitation by the FD12P. Uncorrected 10-minute PW codes are compared to human observations for six stations in the Netherlands, 2000-2002.

	POD	FAR	CSI	BIAS	# events
Precipitation	82%	20%	68%	1.03	24553
Liquid	80%	22%	65%	1.03	22980
Freezing	34%	51%	25%	0.70	76
Solid	64%	28%	51%	0.88	1586

The main findings from this comparison are:

- The sensor reports precipitation when the human observer does not and vice versa.
- The sensor reports relatively many drizzle events at the expense of rain events.
- The sensor has problems to identify freezing precipitation correctly.
- The sensor reports too few events with solid precipitation and the mixture rain and snow.
- The sensor reports too many events with ice pellets.
- The sensor does not detect hail.

Most of these problems were already recognized in earlier work. They are discussed in more detail and an attempt is made to identify cross correlations based on measured meteorological parameters available in the analyzed data. The added value of the six existing KNMI PWc corrections and 16 additional (PWc+) corrections for improving the precipitation type from the FD12P was investigated. The additional corrections are mainly adopted from ICAO Document 9837 (ICAO, 2006), or identified during this study. The currently used KNMI PWc corrections are mainly executed in the discrimination of freezing and solid precipitation, leading to an increase in CSI for freezing and solid precipitation of 6% and 5%, respectively.

The additional PWc+ corrections also affect the detection of precipitation and the rain/drizzle discrimination. Furthermore, two corrections that omit false alarms of solid precipitation during low visibility and false alarms of ice pellets are tested. However, not all PWc+ corrections contribute positively. Hence some corrections must be selected before the actual improvement can be calculated. The PWc+ corrections which contributed positively in this study are listed in Table 9.2. The overall scores for the precipitation classes after application of the PWc and the selected PWc+ corrections are shown in Table 9.3. Correction PWc+17 is not incorporated there because it creates a large imbalance in the rain/drizzle discrimination. It is clear that in particular the POD for freezing precipitation has increased and the FAR for solid precipitation has decreased. However, even with these corrections the automated system reports 25% less solid precipitation than the human observer.

Table 9.2. Overview of additional PWc+ corrections which were found feasible in this study. The abbreviation 'ppn' must be read as 'any type of precipitation'.

Name and description	Condition(s)	Correction(s)
PWc+1 No ppn if TA-TG>3 over 20 min. period	TA-TG>3	ppn→C
PWc+5 No ppn if vis>40000 for 5 min. period	ZM>40000	ppn→C
PWC+10 Snow with TA>4 is very rare	TA>4	S,SG→P
PWc+13 Snow is not observed when TW>1.5	TW>1.5	S,SG→R
PWc+15 Drizzle occurs only if RH>90	RH<90	L→R
PWc+17 Drizzle occurs only if C1<1000	C1>1000	L→R
PWc+19 Drizzle occurs only if ZM<10000	ZM>10000	L→R
PWc+21 Correct for precipitation at low ZM	ZM<400	P,LRS,S,IP,SG→C
PWc+24 Change detections of ice pellets	TW≤3 TW>3	IP→S IP→R
PWc+26 10% rule for the mixture LRS	S + at least 1x L,LR,R	S→LRS

Table 9.3 Scores for precipitation detection and discrimination of liquid, freezing and solid precipitation by the FD12P. 10-minute PW codes corrected by PWc and selected PWc+ corrections are compared to human observations for six stations in the Netherlands, 2000-2002.

	POD	FAR	CSI	BIAS	# events
Precipitation	82%	20%	68%	1.02	24393
Liquid	80%	22%	66%	1.03	22932
Freezing	50%	54%	31%	1.09	89
Solid	63%	14%	57%	0.74	1408

The increased CSI scores due to the application of the PWc and the selected PWc+ corrections result in an overall increase in the CSI of 44% for all precipitation types together, due to a total of 4089 adjustments. The performance has increased most for the mixture of drizzle/rain and snow (+14%), freezing rain (+9%), rain (+8%) and snow (+6%). However, with respect to the existing KNMI PWc corrections, the PWc+ corrections improve the scores only marginally and contribute mainly to the correct discrimination of liquid precipitation types. However, they also reduce the number of false alarms of solid precipitation during periods with low visibility and completely omit the detections of ice pellets.

9.1.2 Analysis of collocated sensors

Collocated 10-minute observations of corrected precipitation type from identical FD12P sensors were studied for two closely collocated sites in De Bilt (260 and 261) and for seven FD12P sensors at Schiphol airport. Such an analysis indicates the inevitable errors introduced by the sensor characteristics, as well as the spatial dependency of the measurements. Good agreement was found for the two sensors in De Bilt, especially for liquid (CSI=91%) and solid (CSI=84%) precipitation. The scores are worse for freezing precipitation (CSI=33%), with the sensor at 260 reporting about 1.5 times more freezing precipitation than the one at 261. However, this precipitation class has the lowest frequency of occurrence and the scores are therefore unreliable. Most of the inconsistencies during freezing precipitation events occur where the other location reports no precipitation at all, or unknown or solid precipitation. Inconsistencies with liquid precipitation occur due to differences in the wet bulb temperature for the two collocated sites.

The comparison of the precipitation type observations for the seven sensors at Schiphol indicate that generally the CSI scores decrease with increasing distance. Finally an exploration of the occurrence of freezing precipitation at Schiphol was carried out, since the operational values of air temperature and relative humidity at the observation field on location 18Cm27 are used in the correction of the precipitation type of all FD12P sensors at Schiphol. Using the air temperature and relative humidity at location 18Rtw as a true reference, it is shown that the 10-minute PWc codes at this location in combination with the values from 18Cm27 report about twice too much events with freezing precipitation, where the POD, FAR and CSI have values of 92%, 56% and 43%, respectively. The use of an uncorrected PW code at location 18Rtw is however worse. Hence the use of more closely located observations of air temperature and relative humidity could improve the discrimination of freezing precipitation significantly.

9.1.3 Hourly data validation for monitoring and climatological services

The I-ID department of KNMI validates observations on a hourly basis for climatological and monitoring purposes. Unvalidated observations of precipitation type from the FD12P were compared on a hourly basis with validated observations for 14 stations in the Netherlands (2003-2006). A total of 3289 corrections is found, which amounts to 0.8% of the total number of observations. The main features in this comparison are:

- Unknown precipitation is specified.
- The detection of precipitation by the sensor is fallible.
- The automated system has problems to identify freezing precipitation correctly.
- The sensor reports too many events with ice pellets.

Concerning the second point in this list, an analysis of the cumulative differences in precipitation duration and intensity between the FD12P and the rain gauge on the same site was performed. It is evident that in particular coastal stations show large differences, with the rain gauge reporting a higher precipitation duration and intensity, generally. During the analysis period of about 45 months, the cumulative surpluses for stations De Kooy (235) and Terschelling (251) increase to around 450 hours and 100 cm for precipitation duration and amount, respectively. Stations 260 and 261, both located in De Bilt, show opposite results, with the FD12P reporting a higher precipitation duration and intensity than the rain gauge on average. It is expected that this difference could be related to the more frequent cleaning of these sensors with respect to the sensors at coastal locations. Unfortunately, maintenance information on cleaning or the replacement of sensors to verify any dependency was not made available during the project. However, also other effects play a role here, like the distance between the rain gauge and the FD12P or the time lag experienced by the rain gauge during events of solid precipitation. The cumulative probability of the reported 10-minute precipitation intensity by the FD12Ps at coastal stations is clearly shifted towards lower intensities with respect to the FD12Ps at land stations and the rain gauges at land and coastal stations.

9.1.4 Precipitation typing with the NeSo method

It is evident from the exploration of the NeSo method that the agreement between the FD12P PWc codes and the NeSo classes derived from HIRLAM analyses or radiosondes is quite good. The comparison is however ambiguous, because the seven NeSo classes generally contain more than one precipitation type, in some cases of a different phase. Hence NeSo only gives a rather incomplete precipitation type in these situations. The overall percentage correct is 88% for the HIRLAM analyses and 92% for the radiosondes. The scores for liquid precipitation are high, but this is mainly because it has a high frequency of occurrence and moreover, rain is included in 4 of the 7 classes. Detailed information on the surface wet bulb temperature is needed for the discrimination of freezing precipitation. However, the lowest model level in HIRLAM is located around 30 m. This likely suppresses the chance on agreement for freezing precipitation, together with the fact that the frequency of occurrence is very low. The use of the HIRLAM 2 m temperature in the NeSo method is however currently considered. The most interesting scores are seen for solid precipitation. The percentage correct is 70% for the HIRLAM analyses and 79% for the radiosondes. In the individual scores for the 12 stations it is evident that stations reporting more solid precipitation events show a better performance for this precipitation class. These stations are primarily located in the eastern part of the Netherlands.

NeSo evaluations of HIRLAM profiles can be made available every hour in the current set up, but the added value for automated observations of precipitation type in the KNMI observation network is questionable. Moreover, the classes include generally several precipitation types, which introduces ambiguity in the determination.

9.2 Recommendations

- Consider implementation of (some of) the positively contributing PWc+ corrections in the processing algorithms of the automated precipitation type observations at KNMI. An additional exploration on the effect of the application sequence of the corrections should be carried out.
- Consider the use of collocated temperature and humidity measurements in the PWc correction at Schiphol, for a more accurate detection of freezing precipitation. The surface pressure can still be obtained from the observation field at 18Cm27, as this parameter has little effect on the wet bulb temperature. The collocation of sensors, e.g. of a ceilometer, PWS, temperature and humidity sensor, is essential for a PWc+ correction involving multi-sensor algorithms.
- Acquire service dates from the I-WIS department of KNMI and correlate them with the remarkable features observed in the differences of precipitation duration and/or intensity measured by the rain gauge and FD12P at the same station.
- Explore the effect of contamination on the FD12P and its impact on the reported precipitation amount and type. This could be achieved for example by placing a contaminated sensor on return from another location at the test field in De Bilt and compare this sensor with the other units before and after cleaning. Ways of checking the sensitivity of the DRD12 capacitive detector prior to and after cleaning should be

considered. Cleaning the DRD12 should be included in the maintenance schedule of the FD12P.

- Explore the possibilities of using a disdrometer operationally in the national meteorological observation network. This is a promising sensor to improve particularly the identification of precipitation particles individually and the detection of precipitation at low intensities.
- Manufacturers of present weather sensors should try a different approach to the output of present weather observations, in order to provide users with more detailed information. For example, sensor output in terms of probabilities for each precipitation type should be preferred above the traditional “yes/no” measurements. Additional algorithms in use at the meteorological institutes could eventually provide the users with more reliable automated observations.

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References

Bijma, J.R., 2006: DZ4-SIAM Vaisala FD12P PW-sensor, versie 1.1, 12 juni 2006. *Internal document,* KNMI, De Bilt, The Netherlands.

Bloemink, H.I., 2004: Precipitation type detection Present Weather Sensor. Final report. *Technical report TR-259*, KNMI, De Bilt, The Netherlands.

Bloemink, H.I. and E. Lanzinger, 2005: Precipitation type from the Thies disdrometer. Paper presented at the WMO Technical Conference on Instruments and Methods of Observation (TECO-2005), Bucharest, Romania, 4-7 May 2005, IOM 82 (TD1265).

ICAO, 2006: Manual on automatic meteorological observing systems at aerodromes. Doc. 9837 (first edition), International Civil Aviation Organization, Quebec, Canada.

Ivens, R.A.A.M., 1987: Forecasting the kind of precipitation in winter. Proc. Symp. Mesoscale Analysis & Forecasting, Vancouver, Canada, 17-19 August 1987, ESA SP-282.

Kok, C.J., 2000: On the behaviour of a few popular verification scores in yes/no forecasting. *Scientific report WR-2000-04*, KNMI, De Bilt, The Netherlands.

Leroy, M. and C. Bellevaux, 1998: PREWIC; The WMO intercomparison on present weather sensors/systems (Canada and France, 1993-1995). Final report. WMO, Geneva, Switzerland, IOM 73 (TD887).

McRobbie, S.G., 2002: Automated present weather reporting, issue 1.0. *Technical report TR21*, UK Met Office, Exeter, United Kingdom.

McRobbie, S.G., M.J. Molyneux and P.D.Shearn, 2002: Improvements to automated present weather reporting in the Met Office. Paper presented at the WMO Technical Conference on Instruments and Methods of Observation (TECO-2002), Bratislava, Slovakia, 23 September-3 October 2002, IOM 75 (TD1123).

Meulen, J.P. van der, 1994: A comparison of two present weather systems with human observations. Paper presented at the WMO Technical Conference on Instruments and Methods of Observation (TECO-1994), Geneva, Switzerland, 28 February-2 March 1994, IOM 57 (TD588).

Meulen, J.P. van der, 2003: Exploratory actions on automatic present weather observations. Final report. *EUMETNET PWS-SCI report*, De Bilt, The Netherlands.

Meulen, J.P. van der, 2006: The challenge to increase the performance of an AWS. Paper presented at the 4th International Conference on Experiences with Automatic Weather Stations (ICEAWS-4), Lisbon, Portugal, 24-26 May 2006.

Vaisala, 1998: Weather sensor FD12P user's guide, FD12P-U106en-1.2. August 25, 1998, Vaisala Oyj, Helsinki, Finland.

Vaisala, 2000: FD12P weather sensor software description, DOC010016. August 1, 2000, Vaisala Oyj, Helsinki, Finland.

Shearn, P.D., 2002: Overview of Met Office Vaisala FD-12P present weather sensor consistency trial. Paper presented at the WMO Technical Conference on Instruments and Methods of Observation (TECO-2002), Bratislava, Slovakia, 23 September-3 October 2002, IOM 75 (TD1123).

Sluijter, R. and J. Nellestijn, 2002: Klimaatatlas van Nederland. Normaalperiode 1971-2000. 182 pp.

Wauben, W.M.F., 2001: Algoritmen RIS. Versie 3.0: 28/08/01. *Internal report*, KNMI, De Bilt, The Netherlands.

Wauben, W.M.F., 2002: Automation of visual observations at KNMI; (I) Comparison of present weather. Paper presented at the Symposium on Observations, Data Assimilation, and Probabilistic Prediction, Orlando, Florida, 13-17 January 2002, American Meteorological Society.

Wauben, W.M.F., F. Kuik and T. Haig, 2002: The new meteorological observation network in the Netherlands. Paper presented at the WMO Technical Conference on Instruments and Methods of Observation (TECO-2002), Bratislava, Slovakia, 23 September-3 October 2002, IOM 75 (TD1123).

Wauben, W.M.F., 2003: Duurtest LD40 en FD12P op Meetpost Noordwijk. *Technical report TR-256*, KNMI, De Bilt, The Netherlands.

Wauben, W.M.F., 2007: An exploration of the quality of the precipitation intensity reported by the FD12P. *Memo*, KNMI, De Bilt, The Netherlands.

WMO, 1995: Manual on Codes – Volume 1: International Codes. *WMO No. 306*, WMO, Geneva, Switzerland.

WMO, 1996: Guide to meteorological instruments and methods of observation. 6th edition. *WMO No. 8*, WMO, Geneva, Switzerland.

Appendix A Overview of used stations

Figure A.1. Map with used stations containing a FD12P sensor in the KNMI observation network in the Netherlands.

Appendix B WMO code tables

B.1 Present weather from a manned station (Table 4677)

Only the codes indicating the occurrence of precipitation are listed.

20-29	**Precipitation, fog, ice fog or thunderstorm at the station during the preceding hour but not at the time of observation**	
20	Drizzle (not freezing) or snow grains	
21	Rain (not freezing)	
22	Snow	
23	Rain and snow or ice pellets	
24	Freezing drizzle or freezing rain	
25	Shower(s) of rain	
26	Shower(s) of snow, or of rain and snow	
27	Shower(s) of hail, or of rain and hail	
29	Thunderstorm (with or without precipitation)	
50-99	**Precipitation at the time of observation**	
50-59	**Drizzle**	
50	Drizzle, not freezing, intermittent	} slight at time
51	Drizzle, not freezing, continuous	} of observation
52	Drizzle, not freezing, intermittent	} moderate at time
53	Drizzle, not freezing, continuous	} of observation
54	Drizzle, not freezing, intermittent	} heavy at time
55	Drizzle, not freezing, continuous	} of observation
56	Drizzle, freezing, slight	
57	Drizzle, freezing, moderate or heavy	
58	Drizzle and rain, slight	
59	Drizzle and rain, moderate or heavy	
60-69	**Rain**	
60	Rain, not freezing, intermittent	} slight at time
61	Rain, not freezing, continuous	} of observation
62	Rain, not freezing, intermittent	} moderate at time
63	Rain, not freezing, continuous	} of observation
64	Rain, not freezing, intermittent	} heavy at time
65	Rain, not freezing, continuous	} of observation
66	Rain, freezing, slight	
67	Rain, freezing, moderate or heavy	
68	Rain or drizzle and snow, slight	
69	Rain or drizzle and snow, moderate or heavy	
70-79	**Solid precipitation, not in showers**	
70	Intermittent fall of snowflakes	} slight at time
71	Continuous fall of snowflakes	} of observation
72	Intermittent fall of snowflakes	} moderate at time
73	Continuous fall of snowflakes	} of observation
74	Intermittent fall of snowflakes	} heavy at time
75	Continuous fall of snowflakes	} of observation
76	Diamond dust (with or without fog)	
77	Snow grains (with or without fog)	
78	Isolated star-like snow crystals (with or without fog)	
79	Ice pellets	
80-99	**Showery precipitation, or precipitation with current or recent thunderstorm**	
80	Rain shower(s), slight	

81 Rain shower(s), moderate or heavy
82 Rain shower(s), violent
83 Shower(s) of rain and snow, mixed, slight
84 Shower(s) of rain and snow, mixed, moderate or heavy
85 Snow shower(s), slight
86 Snow shower(s), moderate or heavy
87 { Shower(s) of snow pellets or small hail, } slight
88 { with or without rain or rain and snow mixed } moderate or heavy
89 { Shower(s) of hail, with or without rain or } slight
90 { rain and snow mixed, not associated with thunder } moderate or heavy
91 Slight rain at time of observation
92 Moderate or heavy rain at time of observation
93 Slight snow, or rain and snow mixed, or hail at time of observation
94 Moderate or heavy snow, or rain and snow mixed, or hail at time of observation
95 Thunderstorm, slight or moderate, without hail but with rain and/or snow at time of observation
96 Thunderstorm, slight or moderate, with hail at time of observation
97 Thunderstorm, heavy, without hail but with rain and/or snow at time of observation
98 Thunderstorm, combined with duststorm or sandstorm at time of observation
99 Thunderstorm, heavy, with hail at time of observation

B.2 Present weather from an automated station (Table 4680)

Only the codes indicating the occurrence of precipitation are listed.

21 Precipitation in past hour but not at time of observation
22 Drizzle (non-freezing) or snow grains in past hour but not at time of observation
23 Rain (non-freezing) in past hour but not at time of observation
24 Snow in past hour but not at time of observation
25 Freezing drizzle or rain in past hour but not at time of observation
26 Thunderstorm (with or without precipitation) in past hour but not at time of observation
27 Blowing/drifting snow or sand
28 Blowing/drifting snow or sand, visibility is equal to or higher than 1 km
29 Blowing/drifting snow or sand, visibility is less than 1 km

40 Precipitation
41 Precipitation, slight or moderate
42 Precipitation, heavy
43 Liquid precipitation, slight or moderate
44 Liquid precipitation, heavy
45 Solid precipitation, slight or moderate
46 Solid precipitation, heavy
47 Freezing precipitation, slight or moderate
48 Freezing precipitation, heavy
50 Drizzle
51 Drizzle, not freezing, slight
52 Drizzle, not freezing, moderate
53 Drizzle, not freezing, heavy
54 Drizzle, freezing, slight
55 Drizzle, freezing, moderate
56 Drizzle, freezing, heavy
57 Drizzle and rain mixed, slight
58 Drizzle and rain mixed, moderate or heavy
60 Rain

61 Rain, not freezing, slight
62 Rain, not freezing, moderate
63 Rain, not freezing, heavy
64 Rain, freezing, slight
65 Rain, freezing, moderate
66 Rain, freezing, heavy
67 Rain/drizzle and snow mixed, slight
68 Rain/drizzle and snow mixed, moderate or heavy
70 Snow
71 Snow, slight
72 Snow, moderate
73 Snow, heavy
74 Ice pellets, slight
75 Ice pellets, moderate
76 Ice pellets, heavy
77 Snow grains
78 Ice crystals
80 Intermittent precipitation
81 Intermittent rain, slight
82 Intermittent rain, moderate
83 Intermittent rain, heavy
84 Intermittent rain, violent
85 Intermittent snow, slight
86 Intermittent snow, moderate
87 Intermittent snow, heavy
89 Hail
92 Thunderstorm, slight or moderate, with showers of rain and/or snow
93 Thunderstorm, slight or moderate, with hail
95 Thunderstorm, heavy, with showers of rain and/or snow
96 Thunderstorm, heavy, with hail

Appendix C Case studies

Legend of 1-minute variables:

Blue	Background luminance FD12P (cd/m²)
Black	Meteorological Optical Range FD12P (m)
Red	PW code FD12P (-)
Green	Precipitation intensity FD12P (mm/h)
Orange	Precipitation intensity rain gauge (mm/h)
Magenta	Wet bulb temperature (°C)

Precipitation intensity values are truncated at 8 mm/h.

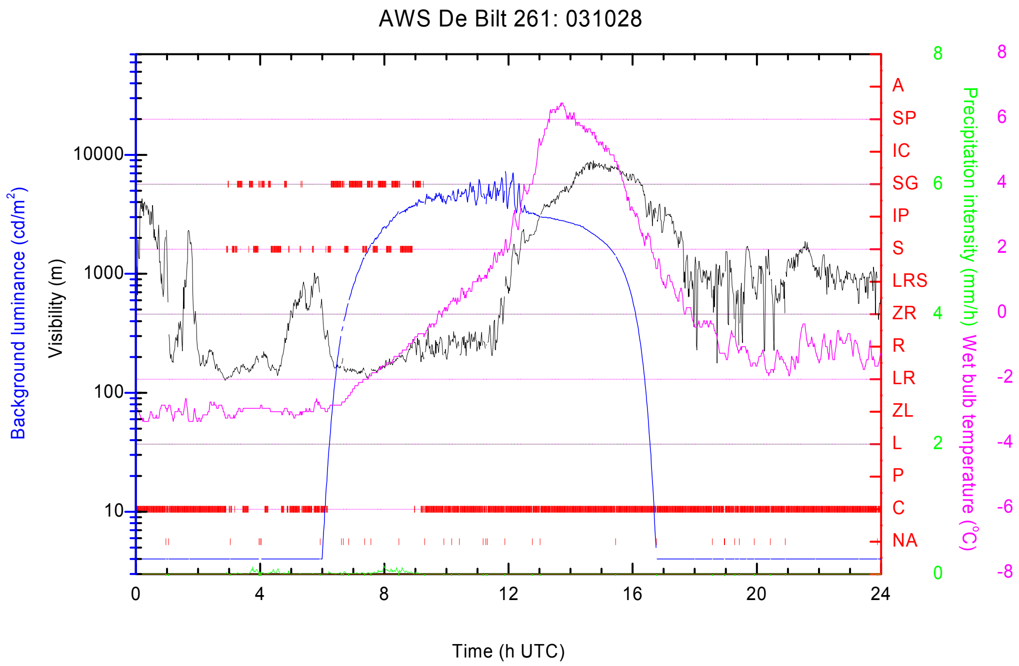

Figure C.1. Time series of 1-minute variables on October 28, 2003 for station De Bilt 261.

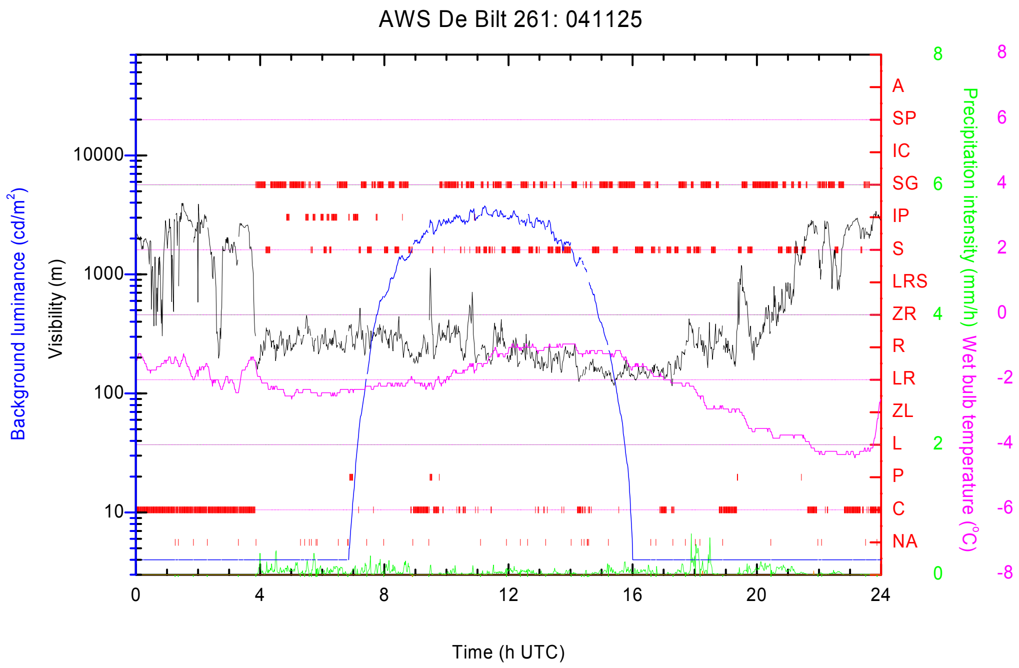

Figure C.2. Time series of 1-minute variables on November 25, 2004 for station De Bilt 261.

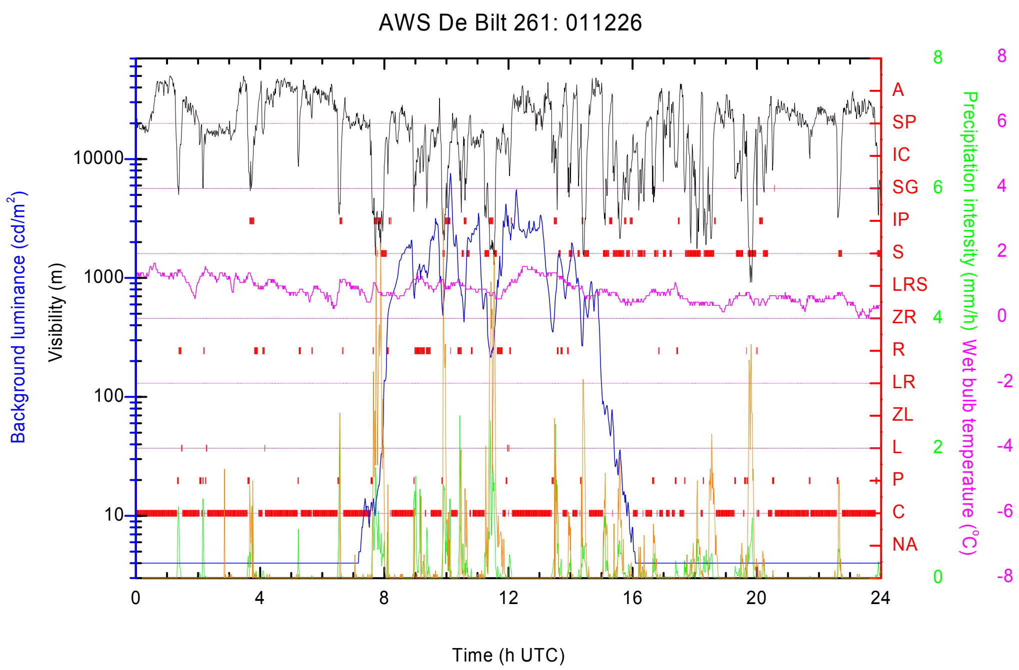

Figure C.3. Time series of 1-minute variables on February 26, 2001 for station De Bilt 261.

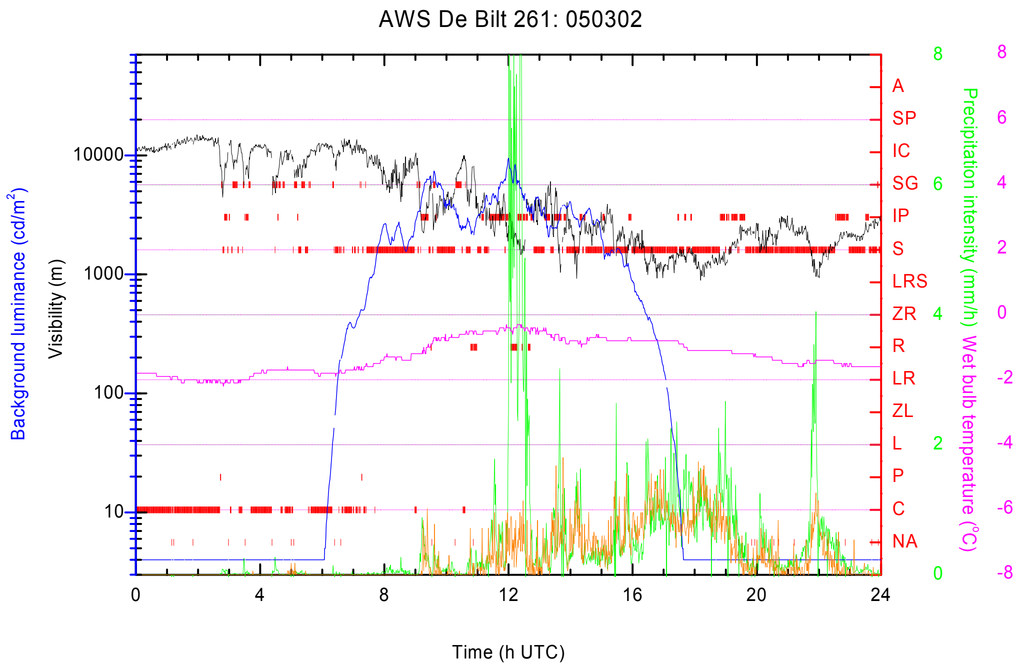

Figure C.4. Time series of 1-minute variables on March 2, 2005 for station De Bilt 261.

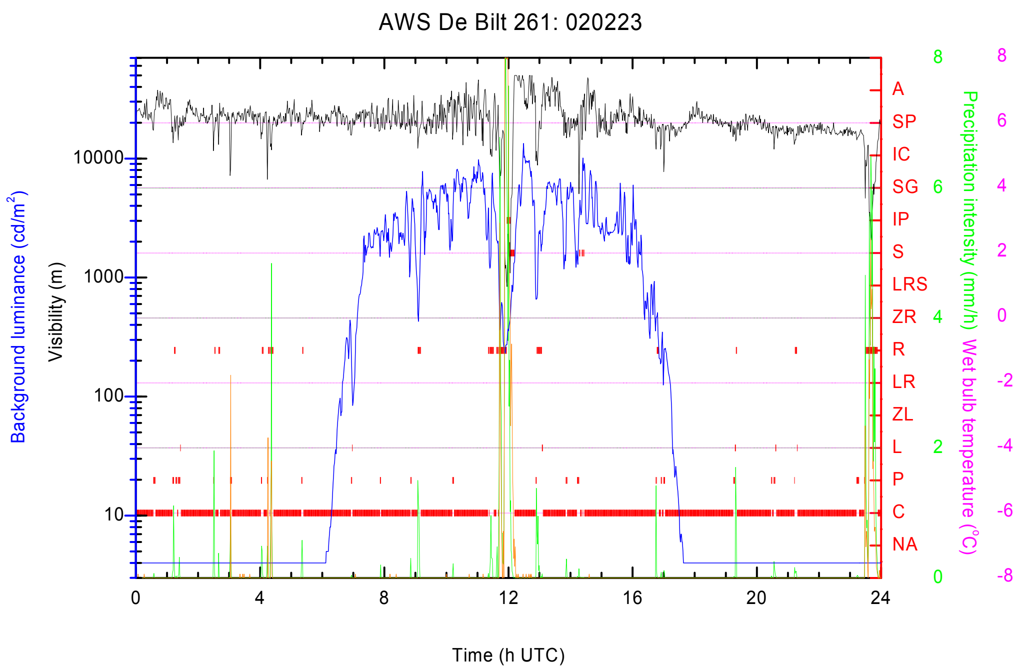

Figure C.5. Time series of 1-minute variables on February 23, 2002 for station De Bilt 261.