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Effect of using local temperature measurements on the determination of freezing precipitation and fog

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Contents

1 Introduction

In aviation, meteorological observations are crucial to the operations of an airfield. These observations are more and more automated. In the Netherlands, there are only human observers at Schiphol airport; all the other airports use automatic observations.

One of the observables used in the aeronautical reports is the so-called present weather which includes the precipitation type. KNMI uses the Vaisala FD12P Present Weather Sensor for this purpose. Although this sensor generally works quite well there are a few issues that can be improved upon (Wauben, 2002 and Haij, de and Wauben, 2010). One of these is the precipitation type determination around 0 °C, in particular the detection of rain/snow mixtures. KNMI has performed a number of investigations into improving this issue (Bloemink and Lanzinger, 2005; Haij, de, 2007; Haij, de and Wauben, 2010).

Another issue in the determination of the precipitation type is the detection of freezing precipitation. Freezing precipitation is defined as super cooled precipitation (WMO, 2010). KNMI does not employ a dedicated sensor for the detection of icing (Wauben, 2007), instead freezing precipitation is reported when liquid precipitation occurs and the wet bulb temperature is below 0 °C. Note that this is and has been the practise for reporting freezing precipitation at manned locations of KNMI.

KNMI does not use the freezing precipitation reported by the Vaisala FD12P Present Weather Sensor, which is determined by a temperature sensor in the mast of this sensor, directly. Instead the wet-bulb temperature as derived from the ambient air temperature and the relative humidity sensor, both in a radiation screen, is used to determine whether the liquid precipitation is freezing or not.

At airports, present weather (along with visibility) is generally measured a various positions along the runway(s). Relative humidity and air temperature is generally only measured at the measurement field although recently backup sensors are installed at the other end of the runway of civil airports. So the wet-bulb temperature that is used to correct the FD12P in the determination of freezing precipitation may be located at a different site than the FD12P itself. The current investigation is set up to investigate if this difference between using a central or the local temperature is relevant to the determination of freezing precipitation.

In order to comply with the general interpretation of the WMO recommendations, KNMI has recently changed the temperature correction for the detection of freezing precipitation. The dry bulb (air) temperature is now used, rather than the wet bulb temperature. Therefore, also the difference between using the wet bulb and the dry bulb temperature will be investigated.

Freezing fog (FZFG) is defined as fog consisting predominantly of water droplets at ambient air (dry bulb) temperatures below 0 °C. This is independent on whether it is depositing rime ice or not (WMO, 2010). In this study the effect of using local temperature sensors on the determination of freezing fog will also be investigated.

2 Measurements

At Mestreech Aoke[1] Airport, two FD12P sensors which are not located near the measurement field have been equipped with additional temperature and humidity sensors. In this setup, the difference in de determination of freezing rain using locally determined and centrally determined wet-bulb temperatures can be investigated. Freezing precipitation determined by the FD12P using the local wet-bulb temperature serves as the reference and will be compared to the freezing precipitation reported directly by the FD12P sensor and the freezing precipitation reported by the FD12P by using a non-local wet-bulb temperature.
By definition, the quality of freezing precipitation measurements is determined by capability of liquid precipitation detection of FD12P and accuracy of wet bulb temperature measurement.

2.1 Sensors

FD12P Present Weather Sensor

This sensor measures the scattering of light of a small volume of the atmosphere. If there are precipitation particles present in this volume, they will lead to peaks in the scattered light. These peaks are related to (the size of) the particles. Separately, the FD12P has a capacitive sensor (DRD12) that measures the water content of the precipitation. Combining these two quantities leads to a discrimination between large particles with low water content (*i.e.* snow) and small particles with high water content (rain). The ratio of these signals is shown in Figure 1 (the y-scale).

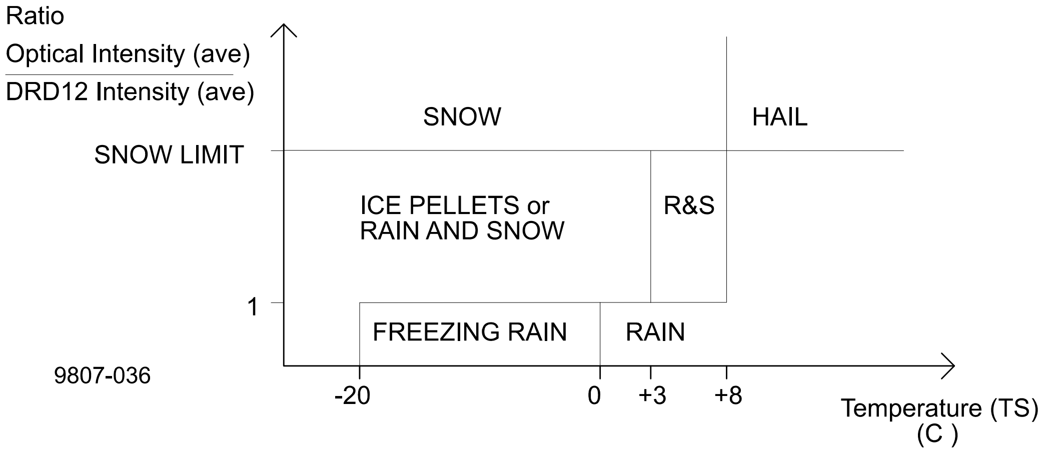

Figure 1. ***Principal precipitation type determination of the FD12P (Vaisala, 2002).***

Further discrimination of precipitation type involves temperature constraints of the internal sensor (TS, the x-scale in Figure 1), maximum particle size and a selection algorithm to determine the most significant precipitation type. The precipitation discrimination scheme is shown in Figure 1. More details can, for instance, be found in the FD12P User's Guide (Vaisala, 2002). The possible precipitation types (PW codes) reported by the FD12P are shown in Table 1.

PW code	METAR code	Precipitation type
00		no precipitation
40	UP	unknown precipitation
50	DZ	drizzle
55	FZDZ	freezing drizzle
57	RA DZ	drizzle and rain

[1] Maastricht Aachen Airport

60	RA	rain
65	FZRA	freezing rain
67	SN RA	rain and snow
70	SN	snow
75	IP	ice pellets
77	SG	snow grains
78	IC	ice crystals
87	SP	snow pellets
89	GR	hail

Table 1.Present Weather codes from the FD12P.

In addition to the determination of the precipitation type by the FD12P, KNMI employs a number of corrections. In one of these, the wet bulb temperature is used to discriminate between freezing (wet bulb temperature below or equal to 0 °C) and non-freezing (wet bulb temperature above 0 °C) liquid precipitation. As mentioned before, the wet bulb temperature is determined using the operational temperature and humidity sensors in a radiation screen.

Next to the present weather output, the FD12P also measures visibility. The amount of scatter is a measure for the Meteorological Optical Range (MOR). In aviation, aeronautical visibility (VIS) is used, which is based on the measurement of MOR. In the current analysis, MOR is used.

HMP233 humidity sensor
The humidity sensors that are used in this investigation are Vaisala HMP233 sensors.
Their accuracy is given as 3 %RH (KNMI, 2005). They are placed at 1.5 m in standard KNMI radiation screens with natural ventilation.

Pt500 temperature sensor
The temperature sensors are the standard KNMI Pt500 sensors, placed at 1.5 m in the standard KNMI radiation screens. The accuracy of these sensors is 0.1 °C (KNMI, 2005).

2.2 Locations

All sensors are placed at Maastricht Aachen Airport (EHBK, WMO station number 380) along runway 03-21. The location of the instruments is indicated in Figure 2.

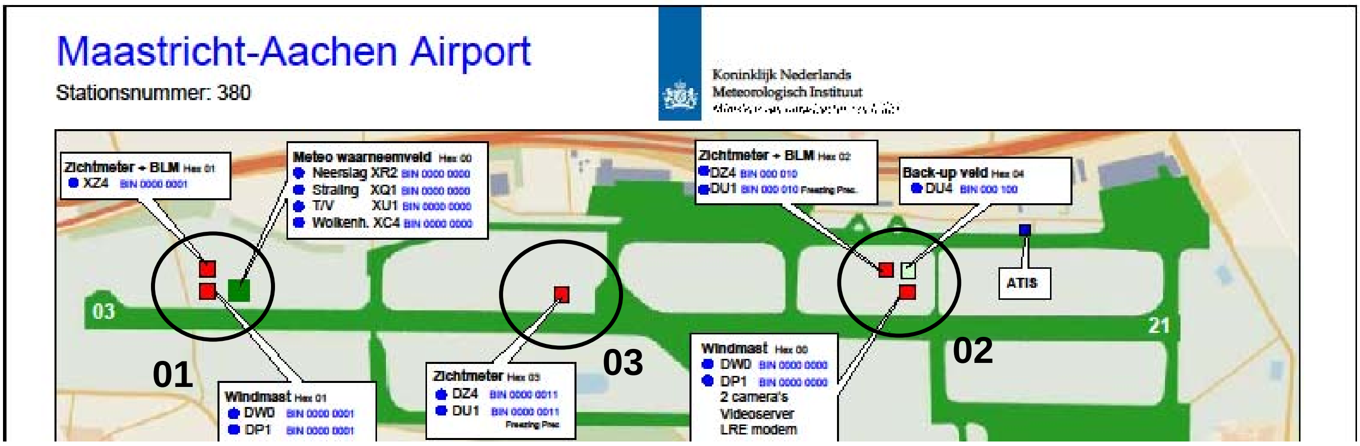

Figure 2. ***Overview of the instrumentation at Maastricht Aachen Airport. "Zichtmeter" = FD12P, "T/V" = temperature and relative humidity. See text for more details.***

There are 3 locations with an FD12P and temperature and humidity sensors. These are indicated in Figure 2 with the circles and numbers “01”, “02” and “03”. “01” is near the touch-down zone 03 and the location of the AWS, “03” is near the mid point of the runway and “02” is near the touch-down zone 21. The labels “01”, “02” and “03” are chosen because these are the indication of the FD12P’s in the sensor interface (SIAM) messages.

The distance between location 01 and location 03 is 711 m, and the distance between location 03 and location 02 is 780 m.

The FD12P sensors are placed at the standard height for aviation VIS/RVR measurements of 2.5 m (of the measuring volume). All temperature and humidity sensors are placed at the height of 1.5 m. The additional temperature and humidity sensors at locations 02 and 03 are fixed to the mast of the respective FD12P, and placed in a single radiation screen. This can be seen in Figure 3. Note that for position 01, the temperature and humidity measurements from the measurement field are used which means that they have separate radiation screens.

Figure 3. FD12P at Maastricht Aachen Airport with the additional temperature and humidity sensor in the attached radiation screen.

2.3 Data

Data are available from 16/7/2009, so two winters worth of data can be used for the evaluation. To make a nice round number, exactly 2 years of data are considered: from 16/7/2009 – 15/7/2011.

1-minute data are used in this investigation. These are based on the raw, 12 second data from the sensor interface.

In these data, the wet-bulb temperature is not yet calculated. For the current analysis, this is done off-line using the algorithm shown in Appendix B. Furthermore, the correction for freezing precipitation using the wet-bulb temperature has not yet taken place. This is therefore done off line as well.

2.4 Reference

Freezing precipitation determined by the FD12P using the local wet-bulb temperature serves as the reference and will be compared to the freezing precipitation reported directly by the FD12P sensor and the freezing precipitation reported by the FD12P by using the non-local wet-bulb temperature. Obviously the reference is not a true reference but a working reference, by which the effect of temperature and precipitation detection on the determination of freezing precipitation can be determined.
By definition, the quality of freezing precipitation measurements is determined by capability of liquid precipitation detection of FD12P and accuracy of the wet bulb temperature measurement.

3 Results

3.1 Freezing precipitation

In this analysis, liquid precipitation is defined as PW codes 50, 55, 57, 60, 65 or 67 (see Table 1). PW code 40, unknown precipitation (UP), can also be reported as freezing. Unknown precipitation occurs quite often at the onset of light precipitation, but in the aeronautical reports it is overruled by any other precipitation type. UP may contain liquid and solid precipitation types. In the distinction between liquid precipitation and freezing (liquid) precipitation, this may taint the results. Therefore UP is not considered in this study.

The bulk of the results (and analysis) is based on using the wet bulb temperature for the determination of freezing precipitation. As stated earlier, freezing precipitation is indicated if the liquid precipitation occurs at a (wet bulb) temperature < 0 °C (as opposed to ≤ 0 °C), in accordance with WMO guidelines (WMO, 2010). A separate section (3.1.4) deals with the use of the dry bulb temperature for the determination of freezing precipitation.

3.1.1 Statistics

In the 2 years of data considered, there are 1,051,200 1-minute data points where the results of all sensors (FD12P and temperature) are available and valid. Table 2 shows how often the three PW sensors reported liquid precipitation during this period.

	number of 1-minute liquid precipitation reports	**% of all cases**
PW sensor 01	71699	6.8
PW sensor 02	87943	8.4
PW sensor 03	90247	8.6
PW sensor 01 or 02 or 03	98136	9.3
PW sensor 01 and 02 and 03	67160	6.4

Table 2. Number of 1-minute liquid precipitation reports in 2 years of data reported by PW sensor 01, PW sensor 02, PW sensor 03, 1 of the three sensors and all of the three sensors.

Note that the different PW sensors do not report the same amount of liquid precipitation. Especially PW sensor 01 reports significantly less liquid precipitation than the other two sensors (about 20 % less) over the two years considered.

Next, the number of (1-minute) cases with liquid precipitation and a local wet bulb temperature less than 0 °C is considered. The number of data for this subset is shown in Table 3.

	number of 1-minute liquid precipitation reports and local T_{wb} < 0 °C.	**% of liquid precipitation cases**	**% of all cases**
PW sensor 01	801	1.1	0.08
PW sensor 02	1430	1.6	0.13
PW sensor 03	1548	1.7	0.15
PW sensor 01 or 02 or 03	2289	2.3	0.22
PW sensor 01 and 02 and 03	367	0.5	0.03

Table 3. Number of liquid precipitation cases with the local wet bulb temperature (T_{wb}) < 0 °C.

Note that there are significant differences between the three locations. At location 01, the wet bulb temperature is below 0 °C in 1.1 % of the liquid precipitation cases, whereas at locations 01 and 03 this is 1.6 and 1.7 %, respectively.
This can be largely attributed to the fact that, for some unknown reason, PW sensor 01 barely reports PW code 67 (sleet). PW sensors 02 and 03 report sleet about 800 (PW03) – 1000 (PW02) times when the local wet bulb temperature is below 0 °C (out of about 1300 – 1500 reports for all temperatures). PW sensor 01 only reports 2 cases of sleet, both at non-freezing temperatures.

The next thing to investigate is how often the FD12P was right in determining freezing precipitation. This can be done by considering the cases in the 2nd column of the previous Table (the "true" freezing precipitation cases), and determine for how many of these cases the FD12P initially reported non-freezing precipitation. The next table shows the number of 1-minute cases when the FD12P sensor reports freezing precipitation, i.e. the FD12P temperature sensor has detected a temperature below 0 °C. If the FD12P temperature is above 0 °C, but the wet bulb temperature is below 0 °C, the PD12P report of liquid precipitation is corrected to freezing precipitation. The numbers for these cases where freezing precipitation is missed by the FD12P due to temperature are shown in the next table.

	number of 1-minute freezing precipitation reports by FD12P	**number of 1-minute liquid precipitation reports corrected to freezing precipitation using local T_{wb}**	**% corrected**
PW sensor 01	726	75	9.4
PW sensor 02	281	1149	80.3
PW sensor 03	631	917	59.2

Table 4. Number of missed freezing liquid precipitation cases by the FD12P sensor due to local T_{wb}. for the subset of Table 3.

So the FD12P output is corrected to freezing precipitation in 9 % of the cases for location 01, in 80 % of the cases for location 02 and in 59 % of the cases for location 03. The reason for these large differences can again be found in the reporting of sleet: in the FD12P PW output, sleet is not denoted as freezing precipitation.

Additionally, a freezing precipitation report from the FD12P may be corrected to liquid if the local wet bulb temperature is equal or above 0 °C. The numbers for these cases where faulty freezing precipitation is reported by the FD12P due to temperature are in the next table.

	number of 1-minute freezing precipitation reports by FD12P	**number of 1-minute freezing precipitation reports corrected to liquid precipitation using local T_{wb}**	**% corrected**
PW sensor 01	757	31	4.1
PW sensor 02	322	41	12.7
PW sensor 03	668	37	5.5

Table 5. Number of faulty freezing liquid precipitation cases by the FD12P sensor due to local T_{wb}.

The correction from freezing to liquid precipitation does not occur as often; about 4 % of the cases for location 01, 13 % for location 02 and 6 % for location 03. On average, the wet bulb temperature correction has been relevant in about 40 1-minute rain reports in 2 years of data. This corresponds to about 0.05 % of the liquid precipitation cases.

Next, the effect of using a non-local T_{wb} for determining freezing precipitation is investigated. This is summarized in the next table where the number of corrections from liquid to freezing precipitation is given for each PW sensor using the different T_{wb} values indicated, where Twb01 is the calculated wet bulb temperature using the temperature and humidity values from location 01, etc.

	number of 1-minute liquid precipitation reports corrected to freezing precipitation		
	PW sensor 01	PW sensor 02	PW sensor 03
using Twb01	**75**	1224	763
using Twb02	88	**1149**	725
using Twb03	143	1394	**917**

Table 6. Number of freezing liquid precipitation cases missed by the FD12P sensor due to T_{wb} as indicated.

For location 01, using the local Twb01 or the wet bulb temperature at location 02 does not make a large difference to the number of times the wet bulb temperature correction is applied (75 vs 88). Using Twb03 gives results in a larger number (143). These differences occur when Twb01 is only marginally below 0 °C (–0.1 to – 0.3 °C). The fact that PW code 67 (sleet) is not reported may influence these results compared to the other two locations.

For locations 02 and 03, using the local Twb or the wet bulb temperature at another location does not make a large difference to the number of times the wet bulb temperature correction is applied (about 20%). Where there is a difference, the local Twb is only marginally below 0 °C (–0.1 to – 0.3 °C).

A clear trend is that using Twb03 results in the largest amount of freezing precipitation.

In the table below, the number of cases correcting from freezing to liquid precipitation is given for using non-local T_{wb} numbers.

	number of 1-minute freezing precipitation reports corrected to liquid precipitation		
	PW sensor 01	PW sensor 02	PW sensor 03
using Twb01	**31**	41	36
using Twb02	26	**41**	38
using Twb03	19	41	**37**

Table 7. Number of faulty freezing liquid precipitation cases by the FD12P sensor due to T_{wb} as indicated.

For location 01, using a non-local wet bulb temperature reduces the number of wet bulb temperature corrections somewhat, but the numbers are small. For locations 02 and 03, using the local wet bulb temperature or the wet bulb temperature at the other locations barely makes a difference to the number of times the wet bulb temperature correction is applied.

3.1.2 Case studies

In the period considered, three significant freezing precipitation events took place: on 11 January 2010 from 13 – 23 UTC; 22 December 2010 from about 21 – 22 UTC; and 1 February 2011 from 19 – 23 UTC. Some freezing rain was also reported on 23 December 2010 from 5 – 8 UTC. On 15 February 2010 from 10 – 14 UTC, the PW sensors reported rain, but at temperatures below 0 °C. On 31 December 2009, some rain was reported when one of the wet bulb temperatures was just below 0 °C. The measurements for all these days are shown in Appendix B. They are discussed below.

Case study 1: 31 December 2009: small effect local Twet
Snow and snow grains (PW codes 70 and 77) are reported first. This changes to drizzle and rain (PW codes 50, 60) at about 8:30 UTC. Most (wet bulb) temperatures at the three locations are just above 0 °C (up to 0.3 °C), but at location 03, the wet bulb temperature dips just below 0 °C from time to time. This means that this is a case where there will be an effect of using a local wet bulb temperature for location 03. However, the wet bulb temperature at location 03 has a

minimum of −0.2 °C and the estimated measurement uncertainty in Twb is 0.3 °C (see Appendix B). This is seen often: when there is an effect of using a local wet bulb temperature, the local wet bulb temperature is only marginally below 0 °C.

Case study 2: 11 January 2010: no effect local Twet

Freezing rain (PW codes 55 and 65) is reported between 12 UTC and 23 UTC, see Figure 6. Snow, ice pellets and snow grains (PW codes 70, 75 and 77) are reported before this event, and occasionally during the event as well. Many reports of sleet (PW code 67) are also reported before, and during the event. PW code 40, unknown precipitation, is also reported during the event. Interestingly, PW sensor 02 reports much more sleet than the other two sensors. This means that the differences in the PW discrimination by the various PW sensors determine the results for freezing precipitation.
During the entire period, the air temperatures and the wet bulb temperatures measured at all three locations remain below 0 °C (– 0.5 to – 2 °C, see the lower plot of Figure 6). This means that there is no effect of using local wet bulb temperature or the ambient temperature in the determination of the freezing precipitation because the PW sensor already reports freezing precipitation and a temperature correction is not needed.

Case study 3: 15 February 2010

Rain (PW codes 50 and 60) is reported by all three PW sensors intermittently between 10 and 14 UTC, see Figure 7. These reports occur during a snow period. The air temperatures and the web bulb temperatures at all three locations are clearly below 0 °C. Between 12 and 13.5 UTC, when the rain is reported, the air temperature and wet bulb temperatures show values between – 3 and – 1 °C, and there are relatively large fluctuations (see the lower plot of Figure 7). The differences between the 3 locations are up to 2 °C, but at all locations, the air temperature remains below 0 °C.
It follows from Figure 1 that the only reason the FD12P can report rain, is that the FD12P temperature sensor measures a temperature at or above 0 °C. This temperature sensor is located near the top of the pole mast to which the cross arm is attached. Unfortunately, this temperature is not made available by the sensor interface.
Apart from a few minutes of data on the previous day, this is the only such occurrence in the 2 years of data considered.

Case study 4: 22 December 2010

Freezing rain (PW code 65) is reported between roughly 21 and 22 UTC, see Figure 8. This occurs in between a snow event (PW codes 70, 77) and sleet (PW code 67). The air and wet bulb temperatures at all three locations are between – 1 and – 2 °C. Because they are all below 0 °C, there is no effect of using local wet bulb temperature or ambient temperature in the determination of the freezing rain. This is because the PW sensor already reports freezing precipitation (sensor temperature below 0 °C) and so the wet bulb temperature correction is not needed. The differences between the reported freezing precipitation events are again the result of differences in the identification of liquid precipitation by the FD12P sensors.

Case study 5: 23 December 2010

The next day, the snow event continues. But between 5 and 8 UTC, one of the PW sensors (01) reports some freezing rain (PW code 55), whereas the other two PW sensors report snow (PW codes 70, 77) intermittingly. Sometimes unknown precipitation (PW code 40) is reported. This can be seen in Figure 9. The air and wet bulb temperatures for the three locations are all between – 2 and – 3 °C, so well below 0 °C.
So in this case, the initial PW determination of the FD12P is causing the differences between the PW sensors.

Case study 6: 1 February 2011

Freezing rain (PW codes 55, 65) is reported intermittingly by all three PW sensors between 19 and 23 UTC, see Figure 10. Also reported is unknown precipitation (PW code 40), a few reports of snow/ice pellets (PW codes 70, 75, 77) and sleet (PW code 67). The latter is mostly reported

by PW sensor 02, a little by sensor 03 and not at all by sensor 01. It is interesting to notice that, as in the fist case study on 11 January 2010, PW sensor 02 reports sleet more often than the other 2 PW sensors.
The air and wet bulb temperatures at all three locations are between – 2 and – 0.5 °C. And so also in this case, there is no effect of using local wet bulb temperature in the determination of the freezing rain.

During all three significant freezing rain events (case studies 2, 4 and 6) that took place in the two years considered, the air temperature (and thus also the wet bulb temperature) is below 0 °C. Hence the differences between the reported freezing precipitation events are solely the result of differences in the identification of liquid precipitation by the FD12P sensors.

3.1.3 Skill scores

A different way to present the results is by way of skill scores (Kok, 2000). These can be defined using a 2x2 contingency matrix which can be made for the results of each combination of "yes/no" events:

Sensor y/n

		Yes	No
Reference y/n	Yes	**a**: correct detection	**b**: missed events
	No	**c**: false alarm	**d**: correct rejection

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

The skill scores can now be expressed as a function of the values in the matrix:

Probability of Detection (POD) = a/(a+b)
The POD indicates the fraction of the total number the reference reports of an event that is correctly reported by the sensor.
False Alarm Ratio (FAR) = c/(c+d)
The FAR indicates the fraction of the number of sensor observations that is not reported by the reference.
Critical Success Index (CSI) = 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.

As a reference, a combination of the three PW sensors with their local wet bulb temperatures is chosen. If at least one of the PW sensors indicates liquid precipitation (PW codes 50, 55, 57, 60, 65 or 67) while the local wet bulb temperatures is below 0 °C, then the reference is set to freezing precipitation. Note that the disadvantage of this choice is that the (local) measurements are not fully independent of the reference. But lacking an independent reference, this is the best possible working reference.

Three cases are considered. For the three locations 01, 02 and 03, the number of 1-minute reports with the different states (liquid, freezing, other) are shown in Appendix C. Also, a combination of the 3 PW sensors, denoted as 010203 is used: if at least one indicates liquid or freezing precipitation, this is used. From these results, the skill scores can be determined for the detection of freezing precipitation. The error margins are a result of the uncertainty in the temperature and humidity measurements, and thus in the wet bulb temperature (see Appendix

B). The FAR is always very small (below 0.004) so that the CSI is close to the POD. Hence only the POD is discussed below.

The three cases are defined as:

Case 1: using no wet bulb temperature correction, only PW sensor output
Note that in this case, because there is no correction using the wet bulb temperature, there is also no effect of the measurement uncertainties in temperature and humidity. Therefore, no error margins are indicated.
Case 2: using the wet bulb temperature from the measuring field (01)
Case 3: using the local wet bulb temperature

The resulting POD scores are:

	POD case1	POD case 2	POD case 3
location 01	0.30	0.33 ± 0.01	0.33 ± 0.01
location 02	0.11	0.61 ± 0.06	0.58 ± 0.07
location 03	0.25	0.57 ± 0.06	0.63 ± 0.10
01 or 02 or 03	0.45	0.93 ± 0.09	1

Table 8. POD for freezing precipitation, for the cases indicated. Case 1: no temperature correction, case 2: correction using Tb01, case 3: correction using local Tb.

These results are discussed in the next chapter.

3.1.4 Effects of using the dry bulb temperature

If the dry bulb (air) temperature is used for the determination of freezing precipitation, the statistics obviously change. The reference is again a combination of the three PW sensors, but now in combination with the local air temperatures. If at least one of the PW sensors indicates liquid precipitation (PW codes 50, 55, 57, 60, 65 or 67), and the local air temperatures is below 0 °C, then the reference is set to freezing precipitation.

The distribution of the air temperatures for this reference is shown in the next Figure.

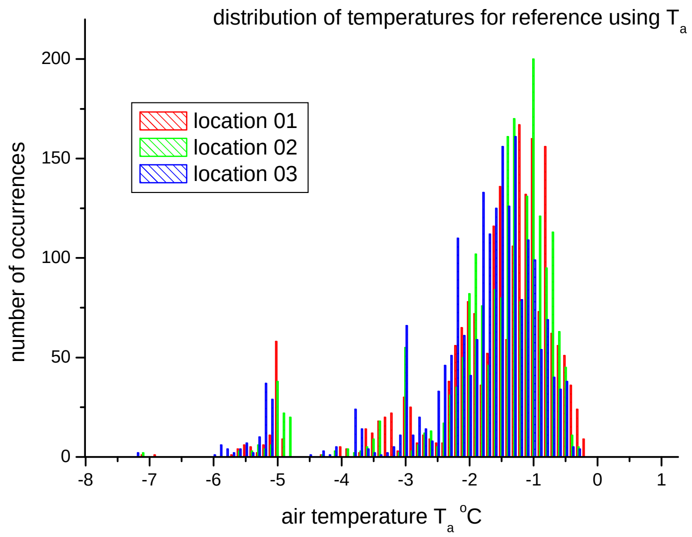

Figure 4. Distribution of the air temperatures at the three locations indicated for the reference using T_a.

For the liquid precipitation events with any ambient temperature below 0 °C, all three sensors agree that the temperature is below or equal to 0 °C. Since no liquid precipitation occurred when the air temperature was between – 0.2 °C and 0.1 °C and the estimated measurement uncertainty is 0.1 °C, incorporating the measurement uncertainty will not influence the results. For the three cases, the skill scores are determined (see Appendix D). The POD of freezing precipitation for the three cases are:

	POD case 1	POD case 2	POD case 3
location 01	0.36	0.38	0.38
location 02	0.14	0.64	0.64
location 03	0.31	0.61	0.61
01 or 02 or 03	0.54	1.00	1

Table 9. POD for freezing precipitation for the cases indicated. Case 1: no temperature correction, case 2: correction using Ta01, case 3: correction using local Ta.

The POD for case 2 and 3 are identical since all air temperatures are always below 0 °C. However it should be noted that most freezing precipitation cases during the period considered are well below zero. This study did not investigate how typical these freezing precipitation conditions are for Maastricht Aachen Airport or for other locations in the Netherlands.

3.2 Freezing fog

3.2.1 Statistics

As mentioned in the previous section, there are 1,051,200 1-minute data points in the 2 years of data considered. In order to evaluate the determination of freezing fog, the next table shows how often the three PW sensors reported fog: MOR below 1000 m.

	number of 1-minute fog reports	% of all cases
PW sensor 01	18584	1.8
PW sensor 02	19523	1.9
PW sensor 03	21956	2.1
PW sensor 01 or 02 or 03	25023	2.4
PW sensor 01 and 02 and 03	15329	1.5

Table 10. Number of 1-minute fog reports in 2 years of data.

Because freezing fog is defined as fog which occurs at an air temperature below 0 °C, next the number of 1-minute fog reports with a local air temperature below 0 °C is determined. This can be found in Table 11.

	number of 1-minute fog reports with local T_a < 0 °C.	% of fog cases	% of all cases
PW sensor 01	3850	20.7	0.37
PW sensor 02	3798	19.5	0.36
PW sensor 03	5372	24.5	0.51
PW sensor 01 or 02 or 03	6253	25.0	0.59
PW sensor 01 and 02 and 03	2622	17.1	0.25

Table 11. Number of 1-minute fog reports with the local air temperature (T_a) < 0 °C.

The effect of using a non-local T_a is summarized in the next table.

	Number of 1-minute fog reports with T_a < 0 °C		
	PW sensor 01	PW sensor 02	PW sensor 03
Ta01	**3850**	4169	5449
Ta02	3330	**3798**	4881
Ta03	3734	4070	**5372**

Table 12. Number of 1-minute fog reports with the indicated air temperatures below 0 °C.

The number of freezing fog events obtained by using Ta01 and Ta03 are similar, but using Ta02 results in fewer freezing fog cases. This may (partly) be due to the fact that on average the air temperature Ta02 is 0.15 °C above the other two air temperature measurements when one of the sensors reports fog. Note that such a temperature offset did not occur during the freezing precipitation events.

3.2.2 Skill scores

Again, the results can also be presented in terms of skill scores. As a reference, a combination of the three PW sensors and the local air temperatures is chosen. If at least one of the PW sensors indicates fog (MOR below 1000 m) while the local air temperatures is below 0 °C, then the reference is set to freezing fog. Note that, as was the case with the freezing precipitation, the disadvantage of this choice is that the (local) measurements are not fully independent of the reference. But lacking an independent reference, this again is the best possible reference.

Two cases are considered. These are called cases 2 and 3 to keep in line with the names used for the cases in the freezing precipitation analysis. For the three locations 01, 02 and 03, the number of 1-minute reports with the different fog states (fog, freezing fog, other) are shown in Appendix E. Error margins are determined in a similar way to the freezing rain analysis, but in this case only the uncertainty of the air temperature of 0.1 °C is relevant. The results of the scores with the error margins are also shown in Appendix E. From all these results, the following skill scores have been determined for the detection of freezing fog. Here only the POD and FAR are reported since CSI is very similar to POD.

	case 2, using Ta01		case 3, using local Ta	
	POD	FAR*	POD	FAR*
01	0.62 ± 0.04	0 – 0.025	0.62 ± 0.06	0 - 0.025
02	0.66 ± 0.05	0 – 0.023	0.61 ± 0.03	0 - 0.005
03	0.86 ± 0.05	0 – 0.027	0.86 ± 0.06	0 - 0.018
01 or 02 or 03	0.98 ± 0.05	0 – 0.032	1	0

* since FAR cannot be less than 0, the range in FAR indicates the range of the results using the maximum measurement uncertainties

Table 13. POD and FAR for freezing fog for case 2 and case 3.

All these results are discussed in the next chapter.

4 Evaluation and discussion

4.1 Freezing precipitation

Overall, the three present weather sensors report liquid precipitation (defined as PW codes 50, 55, 57, 60 , 65 or 67) about 8 % of the time in the 2 year period considered at Maastricht Aachen Airport (see Table 2). The different PW sensors do not report the same amount of liquid precipitation, with differences up to 20 % for one sensor. This is probably caused by differences in the sensitivity between the sensors. However, this falls outside the scope of the current investigation.

Freezing precipitation, defined as the combination of liquid precipitation reported by the PW sensor and the local wet bulb temperature below 0 °C occurs about 1.1 % to 1.7 % of the liquid precipitation cases (see Table 3).

Corrections of non-freezing liquid precipitation reported by the present weather sensor to freezing precipitation because the local wet bulb temperature is below 0 °C occur very frequently, up to 80 % of the liquid precipitation cases (Table 4). This large number is due to the fact that PW code 67, sleet, is initially not denoted as freezing precipitation. Relatively often during sleet, the wet bulb temperature is below 0 °C, resulting is these large numbers. Because PW sensor 01 does not report sleet, the corrections occur less often (9 %). Corrections in the other direction (freezing precipitation to non-freezing) occur for about 7 % of the freezing precipitation cases reported by the PW sensor (Table 5).

Next, the effect of using a non-local wet bulb temperature is investigated. The effect of using a non-local web bulb temperature only has an impact when it is close to 0 °C. Again, there are differences for the different locations, but the overall picture shows that the impact of using a non-local wet bulb temperature is of the order of 20 % (see Table 6). For these cases, the wet bulb temperature is close to 0 °C. Values of down to – 0.3 °C are found. These are within the estimated uncertainty, which is 0.3 °C (see Appendix B).

The main freezing precipitation events show that differences in reporting freezing precipitation mostly occur due to the differences in precipitation detection and discrimination. For example one sensor might reports liquid precipitation while another report solid or unknown precipitation or no precipitation. During one major event one PW sensor reported drizzle while all temperature sensors indicated that the temperature was below 0 °C, whereas the other 2 PW sensors report solid precipitation and some unknown precipitation.

Considering the skill scores, the choice of reference is important here. Because the reference is a combination of the three locations, the reference is not fully independent. Still the POD results from the three locations can be compared and give insight in the impact of various factors involved in the determination of freezing precipitation.

When only the PW sensor output is considered the POD values for each location are 0.30, 0.11 and 0.25 indicating a large contribution of each PW sensor either due to local differences or due to differences in the precipitation type detection and discrimination. When the wet bulb temperature of the measurement field is used the POD improves to 0.33, 0.61 and 0.57. Using the local wet bulb temperature only shows an increase of the score for locations 02 and 03 (0.58 and 0.63). The scores are affected by the uncertainty of the wet bulb temperature of 0.3 °C by about ±0.05.

When the results of the 3 PW sensors are combined the POD is 0.45 and determining freezing precipitation with the wet bulb temperature (±0.3 °C uncertainty) of the measurement field increases the POD to 0.93(±0.09). Using the local wet bulb temperature gives by definition of the references a POD of 1.

Next the dry bulb (air) temperature rather than the wet bulb temperature is considered for the freezing precipitation determination. Using the air temperature also changes the reference. In this case for the reference, all air temperatures at the three locations are – 0.2 °C or less (see Figure 4). This means that within the measurement uncertainty (which is 0.1 °C for the air temperature) it does not matter from which location the temperature is used, it will always be below 0 °C. So there is no effect of using the local temperature measurements for the freezing precipitation determination. The POD for each PW sensor are 0.36, 0.14 and 0.31 and 0.54 for all three sensors combined. When the central air temperature is used (or any other) the POD are 0.38, 0.64 and 0.61 and 1.00 for all three sensors combined. Because there is no effect of using a local temperature correction, the differences between the three locations are due to different precipitation type reports from the PW sensors.

4.2 Freezing fog

It important to realize that a large variability in MOR over short distances and short time scales can occur, especially in case of fog patches. So a certain amount of differences in MOR between the three locations can be expected as a result of natural variability. This is illustrated in Table 10: fog occurs at the 3 PW sensors simultaneously about 15000 times, and at one or more of the three locations 25000 times. Another thing to realize is that air temperature also may vary quite strongly. Even though the measurement uncertainty of the sensor is 0.1 °C, this does not include the effect of difference due to local illumination conditions or errors introduced by an inadequate ventilation of the radiation screen, which relies on natural ventilation.

Overall, fog (defined as MOR < 1000 m) occurs about 2 % of the time (Table 10) in the 2 years period considered at Maastricht Aachen Airport. Freezing fog occurs about 0.4 % of the time, or roughly 4000 1-minute data points (Table 11), but there are large differences between the 3 locations. Using MOR and Ta of location 03, freezing fog is reported 0.51 % of the time, whereas using the measurements at location 02 results in freezing fog being reported only 0.36 % of the time. The reason for this is two-fold: PW sensor 03 reports more fog cases than PW sensor 02 (2433 more 1-minute fog reports in two years), and at location 03 a higher percentage of these cases is identified as freezing fog (24 %) than at location 02 (20 %).

This latter difference will be partly due to the fact that the air temperature measured at location 02 is, on average, 0.15 °C higher than at the other two locations during fog situations.

The next thing to investigate is the effect of using local temperatures to determine the presence of freezing fog. These results can be found in Table 12. Generally, using temperature sensors at different locations results in roughly the same determination of freezing fog events. The differences are about 500 (13%). Largest differences occur when using Ta02, which can be understood by considering the fact that the air temperature measured at location 02 is, on average, 0.15 °C higher than at the other two locations. If for this reason only the results for Ta at locations 01 and 03 are considered, Table 12 shows that the differences are small. i.e. 3.0 %, 2.4% and 1.4 % for locations 01, 02 and 03, respectively. Note that the offset of 0.15 °C of Ta02 equals the uncertainty between two temperature sensors and is close to the output resolution of the temperature sensor of 0.1 °C.

Considering the skill scores (Table 13) gives a similar picture. Using the visibility of each visibility sensor and the central air temperature gives a POD of 0.98±0.05, whereas the individual visibility sensors have a POD of 0.62±0.04, 0.66±0.05 and 0.86±0.05. Using the local air temperature gives POD of 1.00±0.05 and 0.62±0.06, 0.61±0.03 and 0.86±0.05.

Clearly, within the margin of error of the air temperature, using the local Ta for the air temperature correction does not result in significantly improved freezing fog discrimination. The contributions of individual visibility sensors is much larger.

5 Conclusions and recommendations

In this report, the difference in the determination of freezing precipitation using multiple present weather sensors in combination with locally and centrally determined wet-bulb temperatures has been investigated. The evaluation has been performed with three present weather sensors along the runway of Maastricht Aachen Airport for a two year evaluation period. The results are based on a working reference that has been derived from the liquid precipitation discrimination of each present weather sensor in combination with the local wet bulb temperature below 0 °C. The results show that the detection of freezing precipitation is mainly determined by the present weather sensor, i.e. either local difference between the actual presence of liquid precipitation, but often also differences between detection and discrimination of liquid precipitation between the sensors. Using a central wet bulb temperature improves the detection scores, but using a local instead of a central wet bulb temperature has little impact. Within the measurement uncertainty of the wet bulb temperature, there is no difference in using a central or a local wet bulb temperature for the conditions encountered during the 2 year evaluation at Maastricht Aachen Airport with a distance of about 1 500 m between the PW sensor and the location where the central wet bulb temperature is determined. This is supported by the finding that during all three significant freezing rain events in the 2 years period considered, the air and wet bulb temperatures at all three locations considered were all below 0 °C.
Differences in the precipitation type reported by the different PW sensor have been observed, especially around and below 0 °C. These type of differences have been observed before in previous research. Therefore, an improvement in precipitation type determination by PW sensors can lead to an improvement in the determination of freezing precipitation.

In case of freezing fog, using local air temperature measurements to distinguish between freezing and non-freezing cases rather than a centrally measured air temperature does not influence the freezing fog determination. It was found that in the determination of freezing fog, the accuracy of the measurement of the air temperature has some impact, but the main factor is the detection of fog by the present weather sensor due to local variations in visibility.

Recommendations:

- It is recommended that there will be no investment in local (i.e. at the location of the PW sensor) temperature and relative humidity measurements in order to improve freezing precipitation determination. The usage of a central temperature for indentifying the liquid precipitation reported by the present weather sensor as freezing is satisfactory at an airport with a single runway.
- It is recommended to continue work on the improvement of precipitation detection and discrimination of precipitation type by present weather sensors in order to improve freezing precipitation detection.
- Also for the determination of freezing fog, it is recommended not to invest in local temperature measurements at an airport with a single runway.
- The occurrences of freezing precipitation and fog are largely determined by the present weather sensor. Therefore the usage of either a local or a central present weather sensor or a combination of these sensors to determine and report these events needs to be considered with care.

It is important to note that the results of this study are based on an evaluation of freezing precipitation and fog events by using a working reference. The evaluation only covers one site and a period of 2 years while freezing events do not occur very often. The temperatures during the main freezing precipitation events and all freezing fog events is below 0 °C so the impact of using a central or local temperature is small. During freezing precipitation and fog events around 0 °C, this impact will be larger. But even then the difference between the temperature measurements will be within the measurement uncertainty. In addition, the shortcomings of the present weather sensor with respect to precipitation detection and discrimination at temperatures around 0 °C remains a determining factor. Although the results are lacking a solid basis in terms of reference and statistics it is believed that the above conclusions and recommendations are valid for all airports with a single runway, and periods. Note that this does not include Schiphol due the large distances between the sensors.

6 References

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Appendix A: case studies freezing precipitation

Case study 1: 31 December 2009

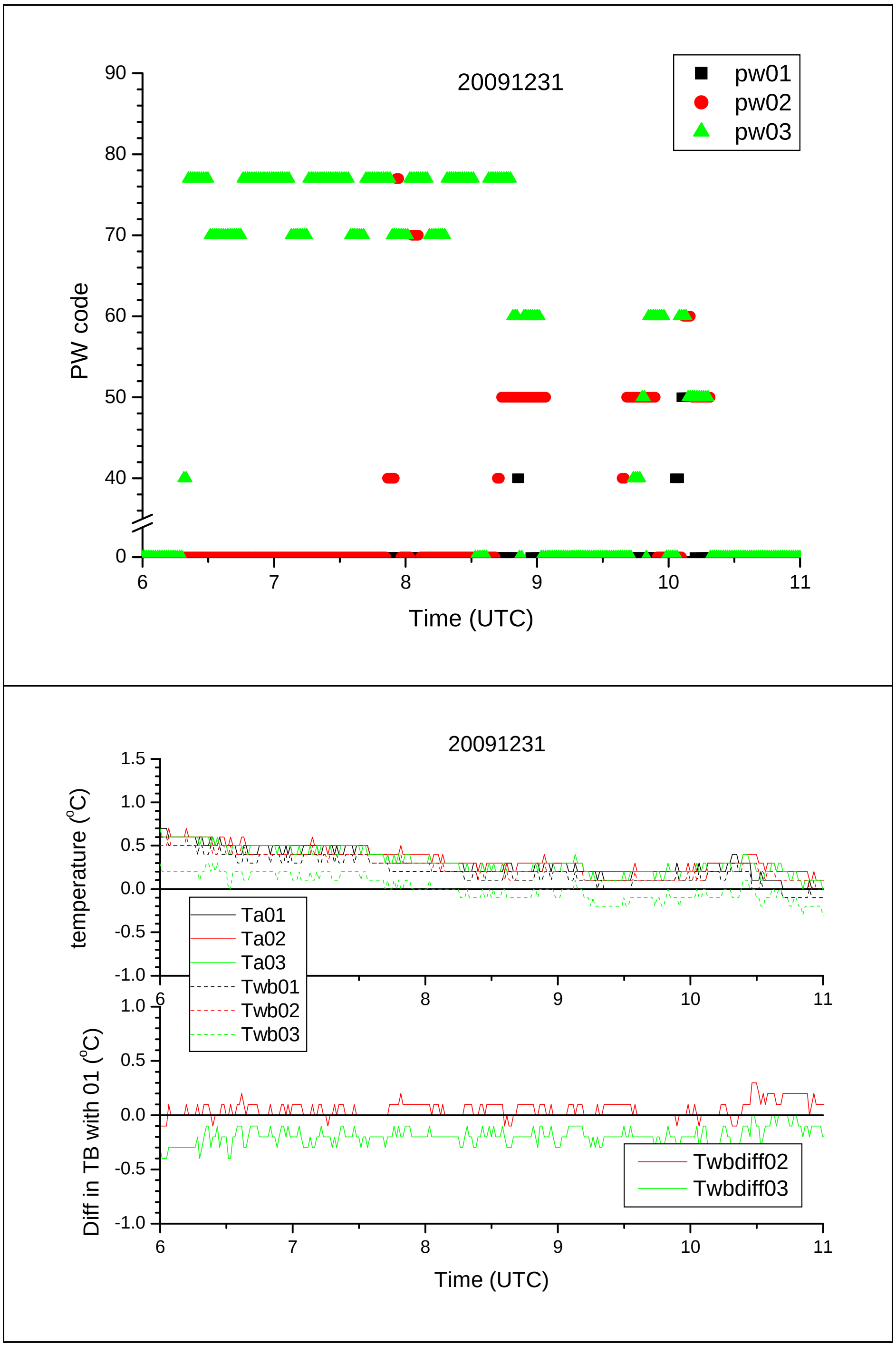

Figure 5. Data for 31 December 2009. In the top figure the PW code reported by the PW sensors indicated, in the lower plot the air temperature (Ta) and wet bulb temperature (Twb) for the three locations and the difference with the wet bulb temperature of location 01.

Case study 2: 11 January 2010

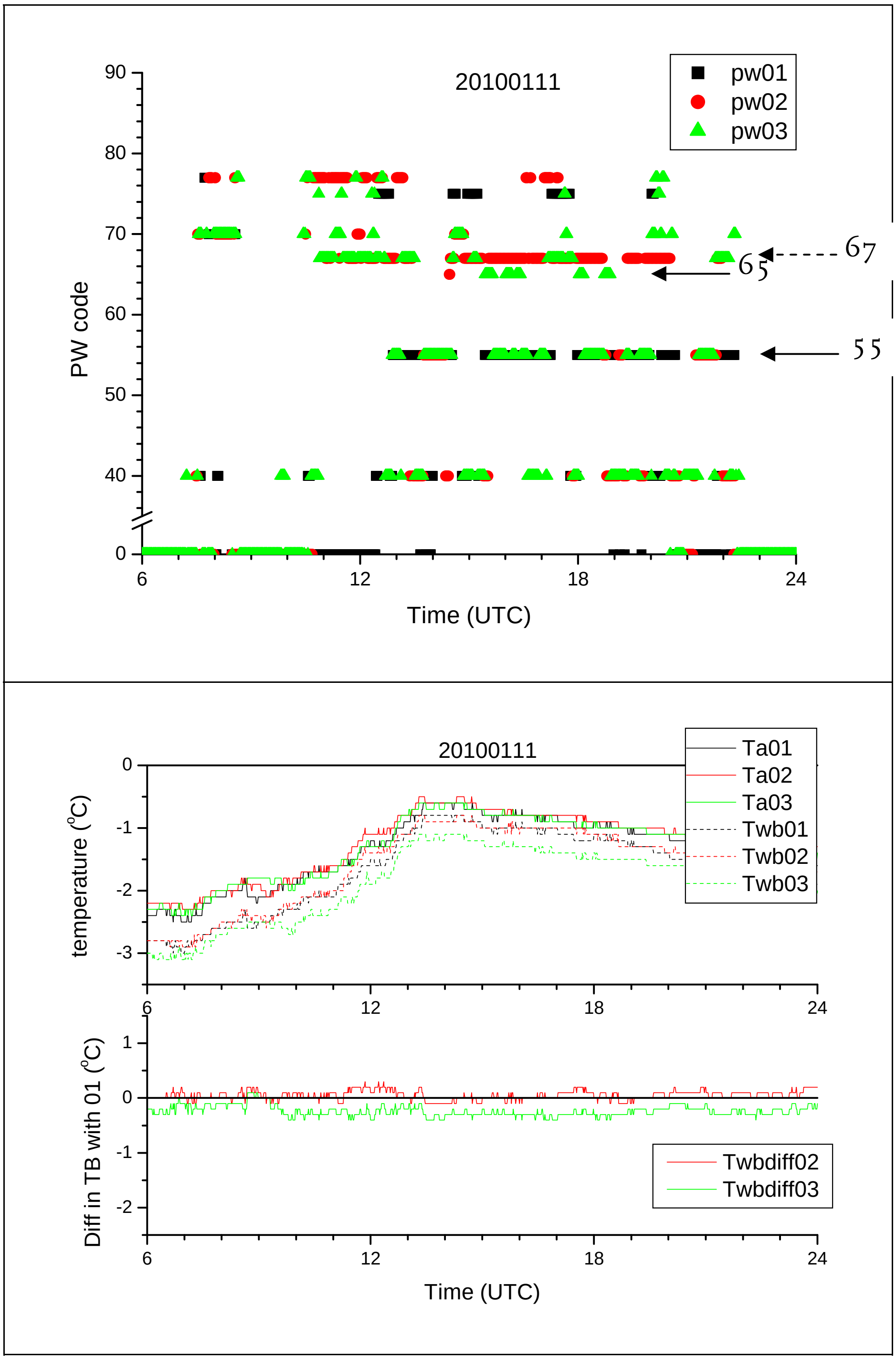

Figure 6. Data for 11 January 2010. In the top figure the PW code reported by the PW sensors indicated, in the lower plot the air temperature (Ta) and wet bulb temperature (Twb) for the three locations and the difference with the wet bulb temperature of location 01.

Case study 2: 15 February 2010

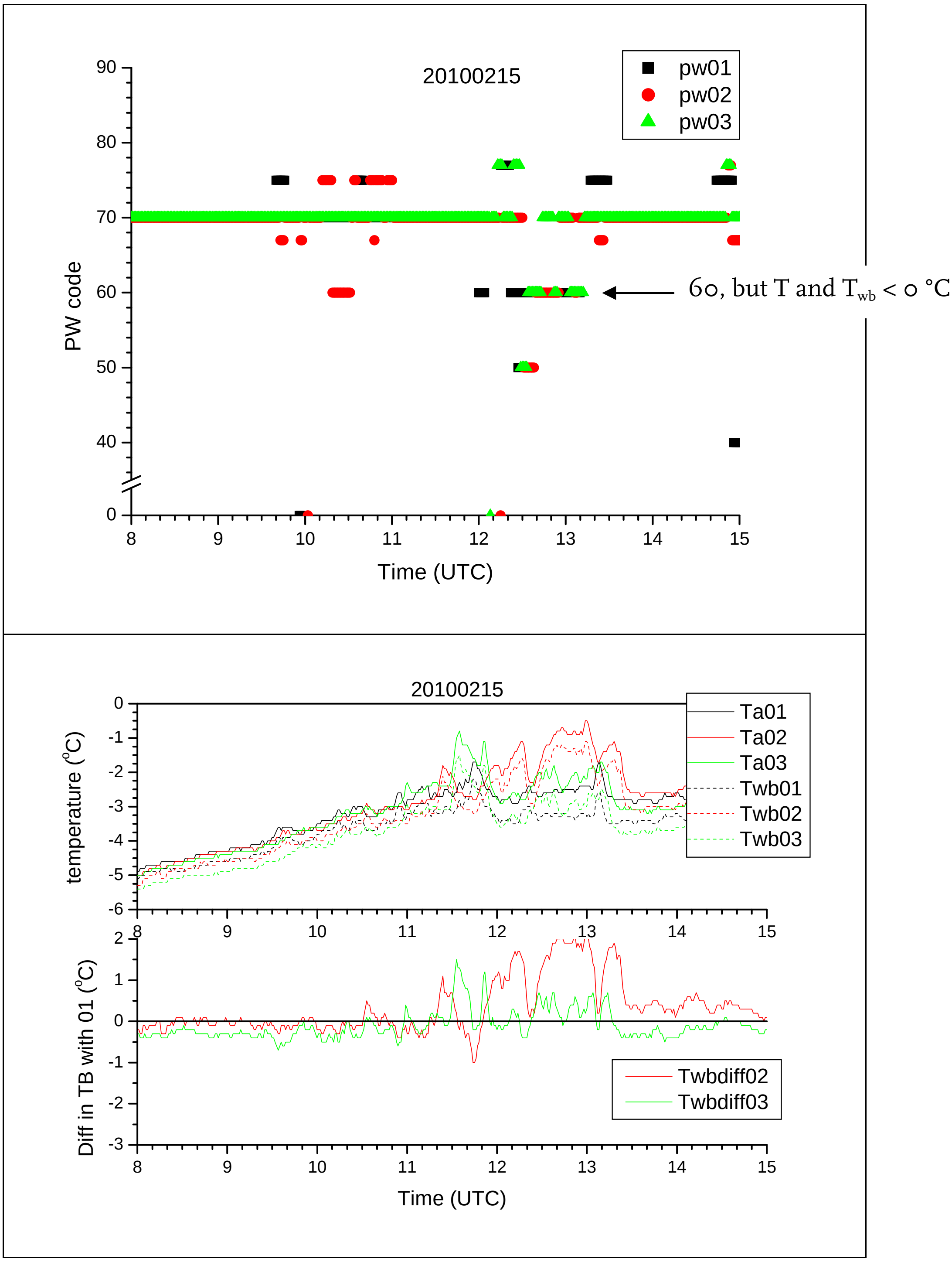

Figure 7. Data for 15 February 2010. In the top figure the PW code reported by the PW sensors indicated, in the lower plot the air temperature (Ta) and wet bulb temperature (Twb) for the three locations and the difference with the wet bulb temperature of location 01.

Case study 4: 22 December 2010

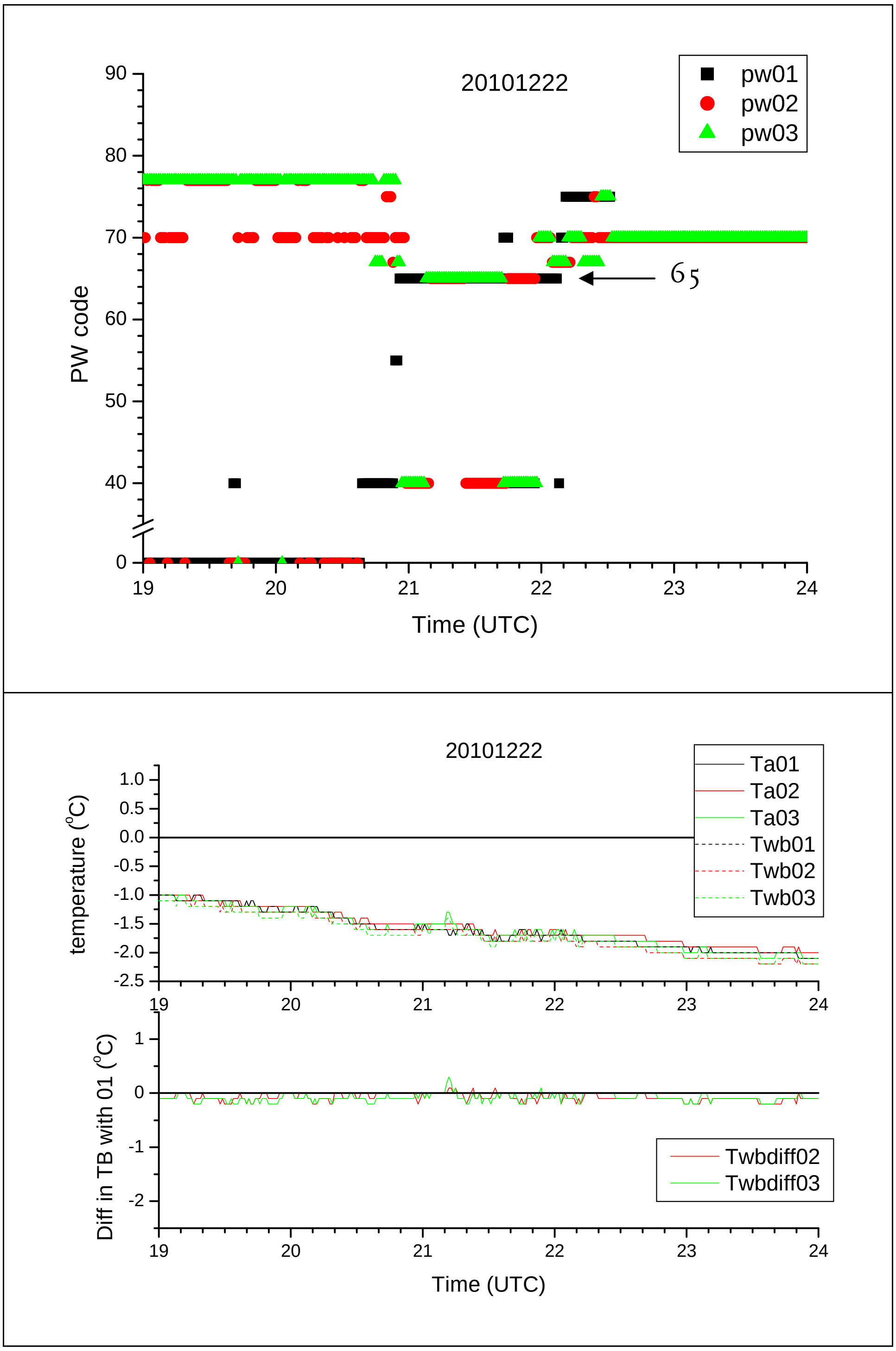

Figure 8. Data for 22 December 2010. In the top figure the PW code reported by the PW sensors indicated, in the lower plot the air temperature (Ta) and wet bulb temperature (Twb) for the three locations and the difference with the wet bulb temperature of location 01.

Case study 5: 23 December 2010

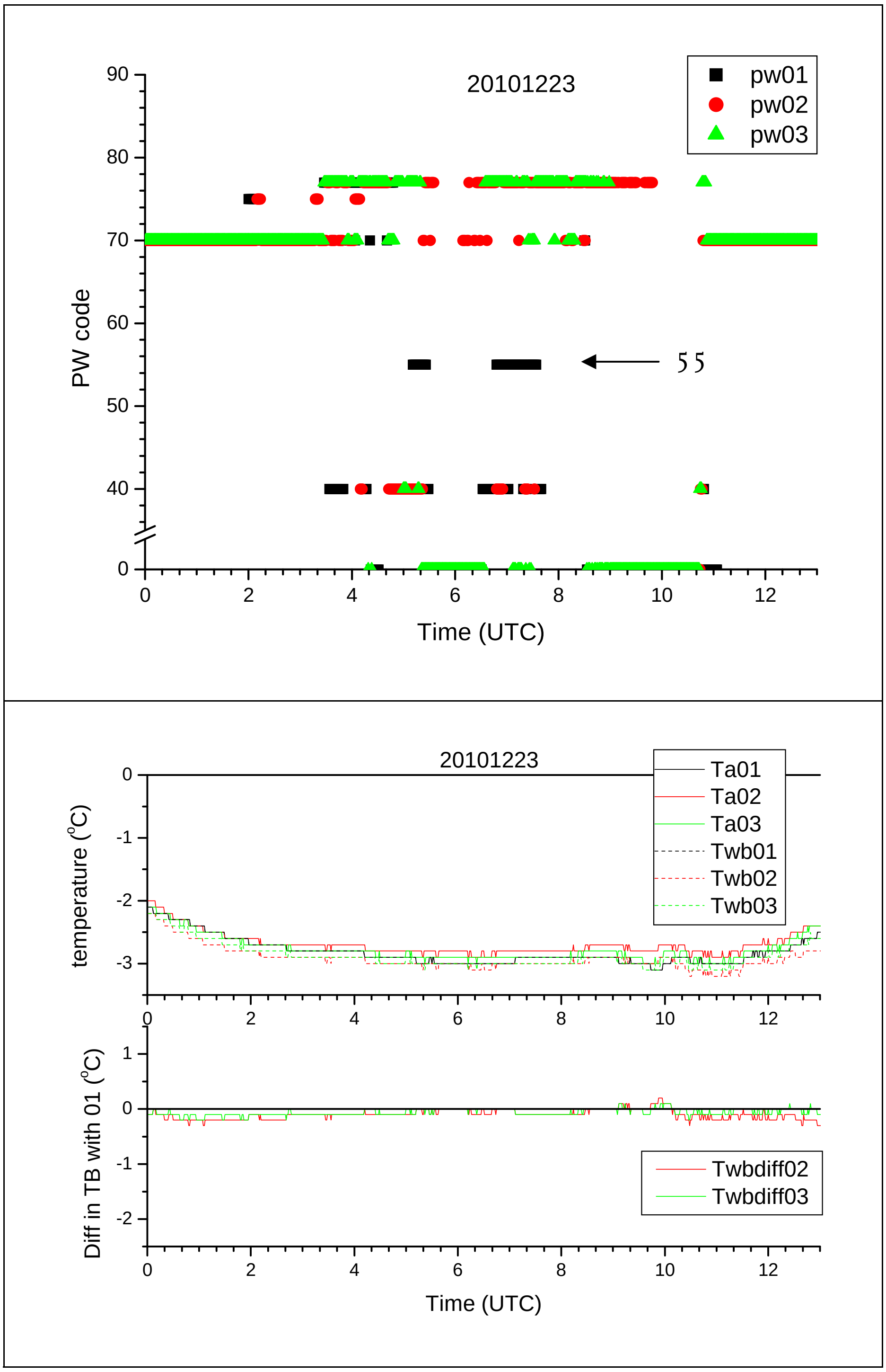

Figure 9. Data for 23 December 2010. In the top figure the PW code reported by the PW sensors indicated, in the lower plot the air temperature (Ta) and wet bulb temperature (Twb) for the three locations and the difference with the wet bulb temperature of location 01.

Case study 6: 1 February 2011

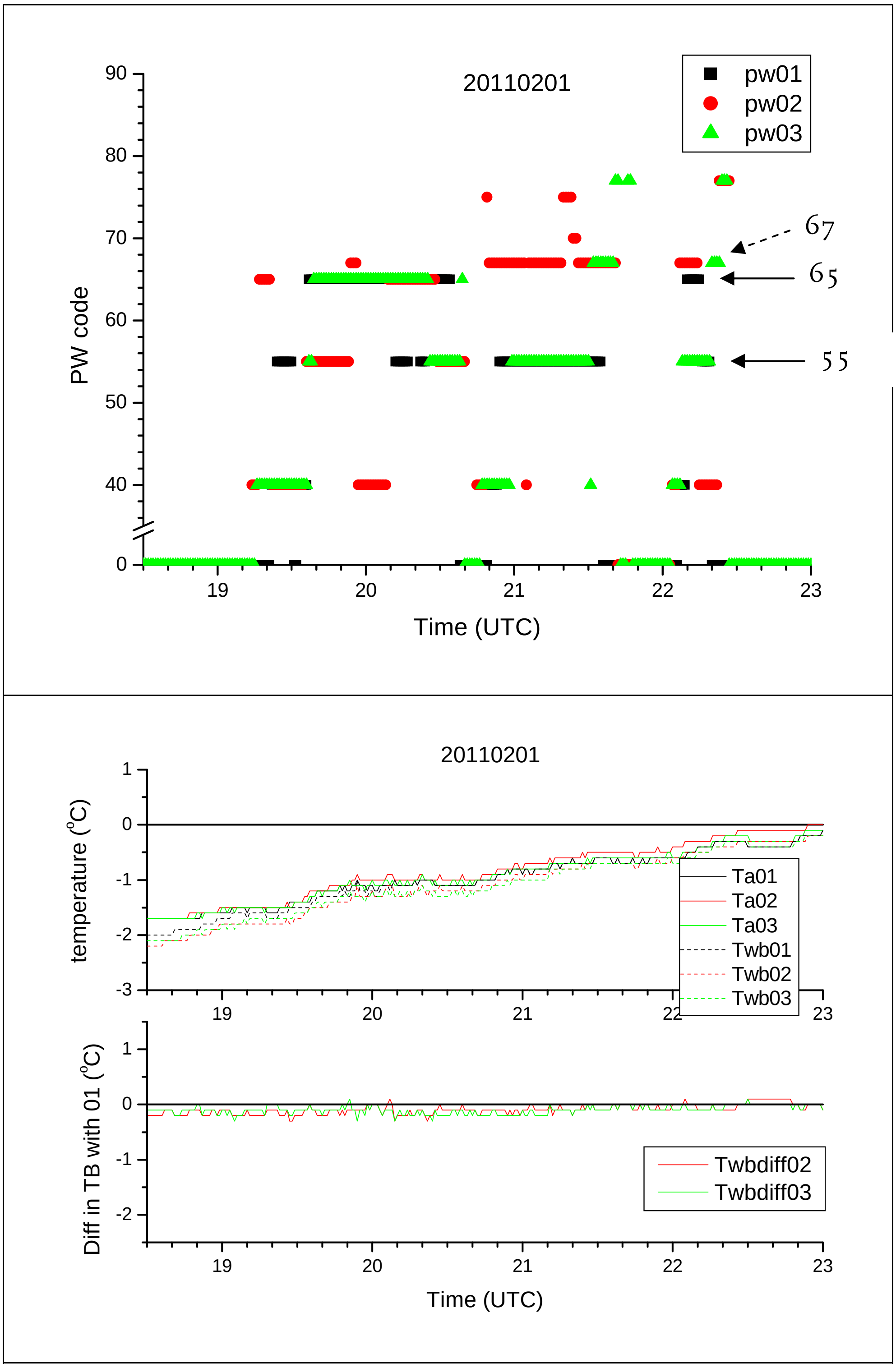

Figure 10. Data for 1 February 2011. In the top figure the PW code reported by the PW sensors indicated, in the lower plot the air temperature (Ta) and wet bulb temperature (Twb) for the three locations and the difference with the wet bulb temperature of location 01.

Appendix B: calculation of the wet-bulb temperature

The wet bulb temperature *Twb* depends on the air temperature *Ta* and the relative humidity *RH*. There is also a small dependence on air pressure (*Ps*) (see WMO, 2008).

In the calculations, all temperatures are in °C and the air pressure is in hPa. The calculation uses the saturated vapour pressure over water *Ew*:

$$Ew(Ta) \approx 6.11213 \exp\left|\frac{17.5043Ta}{241.2+Ta}\right|,$$

The relation between the relative humidity, vapour pressure and saturation vapour pressure:

$$RH = 100\frac{e'(Ta,Twb)}{Ew(Ta)},$$

and the psychrometric relation:

$$e'(Ta,Twb) = Ew(Twb) - 0.000646Ps(Ta - Twb).$$

The wet bulb temperature can be extracted from the above relation, but an iterative calculation is needed. The Taylor expansion:

$$e'(Ta,Tb) = e'(Ta,T) + \left.\frac{de'(Ta,T)}{dT}\right|_{Tb}(Tb - T)$$

using the derivative

$$\left.\frac{de'(Ta,T)}{dT}\right|_{Tb} = \frac{5419Ew(Tb)}{(Tb+273.15)^2} + 0.000646Ps.$$

As a first choice, *T*=*Ta*=*Tb* which leads to a new value for *Tb* using the above equations: *Tb*=*T*+*(Tb–T)*=*T-F*. This is in turn used for the next iteration for *T*.

The relation between *Ta* and *Twb* is illustrated in the following Figure.

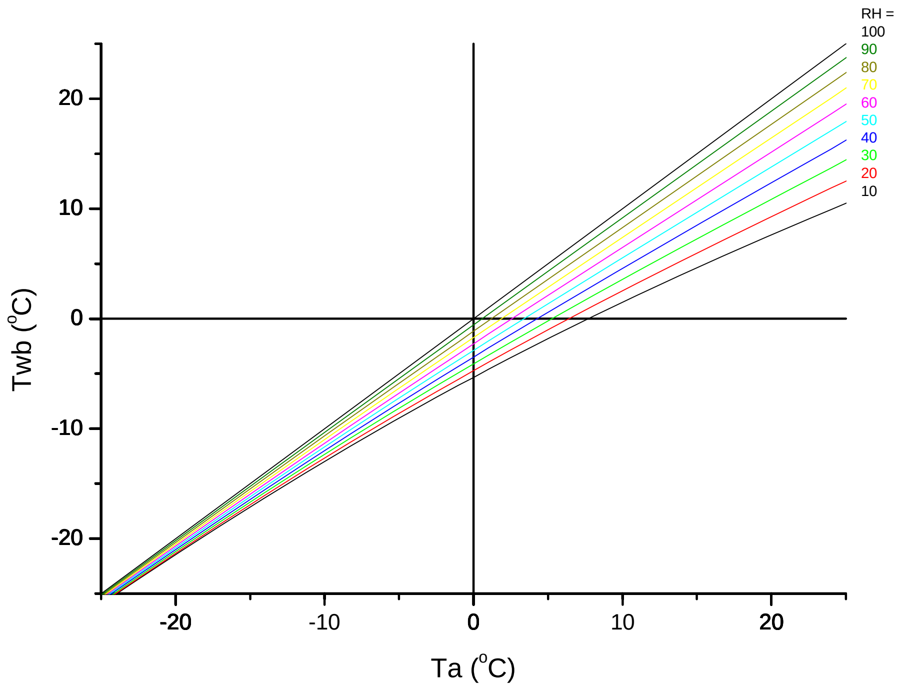

Figure 11. The wet bulb temperature Twb as a function of the air temperature T, for the given relative humidity (RH) indicated. Air pressure was assumed constant at 1013.25 hPa.

The uncertainty in the wet bulb temperature depends on the uncertainty in the air temperature and the relative humidity. Using the above relation and assuming an uncertainty of 0.1 °C in the air temperature results in an uncertainty in the wet bulb temperature of between 0.05 and 0.1 °C. Using the above relation and assuming an error in the relative humidity of 3 %RH, results in an error in the wet bulb temperature shown in the next figure.

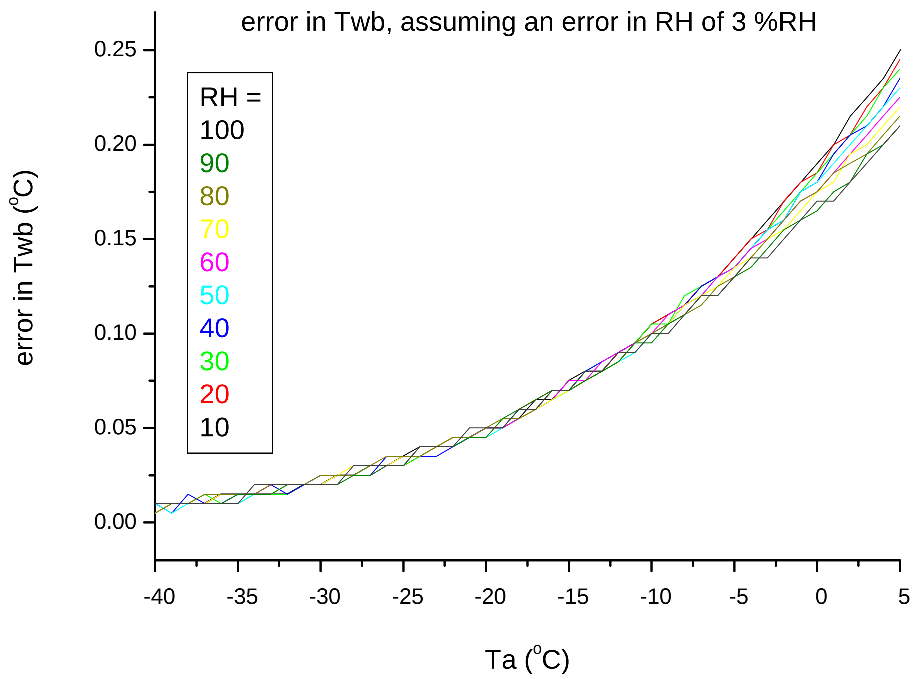

Figure 12. Calculated error in the wet bulb temperature Twb (in C) assuming an error of 3 %RH in the relative humidity, as a function of air temperature Ta (°C).

The uncertainty in Twb due to the uncertainty in RH depends on the air temperature and to a lesser extent on the relative humidity. For air temperature values up to about 5 °C, (when freezing precipitation may occur), the uncertainty in Twb is up to about 0.25 °C.

Combining the 2 uncertainties, an estimation of the uncertainty in the wet bulb temperature is estimated to be up to 0.3 °C.

Appendix C: statistics for freezing precipitation using Twb

This appendix contains the statistics used to calculate the skill scores for freezing precipitation detection. See section 3.1 for more details, including the definition of the three cases. In the tables, "liquid" is defined as non-freezing liquid precipitation, "freezing" is defined as PW codes 55 and/or 65, and "other" is defined as all other possible precipitation types (solid and unknown) and cases without precipitation.

For these data, the wet bulb temperature is used in the determination of freezing precipitation.

Case 1: PWS only

For the three locations 01, 02 and 03, the number of cases with the different states (liquid, freezing, other) are shown below.

	ref liquid	ref freezing
01 other	24865	1572
01 liquid	70792	150
01 freezing	28	729

	ref liquid	ref freezing
02 other	9361	832
02 liquid	86283	1338
02 freezing	41	281

	ref liquid	ref freezing
03 other	0	888
03 liquid	95622	932
03 freezing	63	631

	ref liquid	ref freezing
010203 other	0	0
010203 liquid	95622	1340
010203 freezing	63	1111

The resulting skill scores for freezing precipitation are:

	POD	FAR	CSI
01	0.30	0.0003	0.29
02	0.11	0.0004	0.11
03	0.25	0.0007	0.25
010203	0.45	0.0007	0.44

Case 2: PWS and Twb01

For the three locations 01, 02 and 03, the number of cases with the different states (liquid, freezing, other) are shown below.

	ref liquid	ref freezing
01 other	24865	1572
01 liquid	70820	78
01 freezing	0	801

	ref liquid	ref freezing
02 other	9361	832
02 liquid	86315	123
02 freezing	9	1496

	ref liquid	ref freezing
03 other	7001	888
03 liquid	88681	171
03 freezing	3	1392

	ref liquid	ref freezing
010203 other	0	0
010203 liquid	95673	174
010203 freezing	12	2277

The resulting skill scores for freezing precipitation are:

	POD	FAR	CSI
01	0.33	0	0.33
02	0.61	0.004	0.61
03	0.57	0.001	0.57
010203	0.93	0.005	0.92

Case 3: PWS and local Twb

For the three locations 01, 02 and 03, the number of cases with the different states (liquid, freezing, other) are shown below.

	ref liquid	ref freezing
01 other	26865	1572
01 liquid	70820	78
01 freezing	0	801

	ref liquid	ref freezing
02 other	9361	832
02 liquid	86324	189
02 freezing	0	1430

	ref liquid	ref freezing
03 other	7001	888
03 liquid	88684	15
03 freezing	0	1548

The resulting skill scores for freezing precipitation are:

	POD	FAR	CSI
01	0.33	0	0.33
02	0.58	0	0.58
03	0.63	0	0.63

In order to determine the effect of the measurement uncertainty in the air temperature and the humidity measurements (and thus in the wet bulb temperature: 0.3 °C, see Appendix B) on these results, the previous statistics are recalculated using the maximum and minimum range for the wet bulb temperature.

T_{wb} + 0.3 °C:

Similar calculations are performed. The resulting skill scores are:

Case 2:

	POD	FAR	CSI
01	0.32	0	0.32
02	0.54	0	0.54
03	0.51	0	0.51
010203	0.84	0	0.84

Case 3:

	POD	FAR	CSI
01	0.32	0	0.32
02	0.57	0	0.57
03	0.53	0	0.53

T_{wb} – 0.3 °C:
Similar calculations are performed. The resulting skill scores are:

Case 2:

	POD	FAR	CSI
01	0.34	0.0008	0.33
02	0.65	0.0021	0.60
03	0.62	0.0013	0.59
010203	0.98	0.0025	0.90

Case 3:

	POD	FAR	CSI
01	0.34	0.0008	0.33
02	0.65	0.0019	0.60
03	0.63	0.0042	0.54

Appendix D: statistics for freezing precipitation using Ta

This appendix contains the statistics used to calculate the skill scores for freezing precipitation detection. See section 3.1.4 for more details, including the definition of the four cases. In the tables, “liquid” is defined as non-freezing liquid precipitation, “freezing” is defined as PW codes 55 and/or 65, and “other” is defined as all other possible precipitation types and cases without precipitation.

For these data, the dry bulb (air) temperature is used in the determination of freezing precipitation.

Case 1

For the three locations 01, 02 and 03, the number of cases with the different states (liquid, freezing, other) are shown below.

	ref liquid	ref freezing
01 other	25181	1256
01 liquid	70883	59
01 freezing	31	726

	ref liquid	ref freezing
02 other	9454	739
02 liquid	86600	1021
02 freezing	41	281

	ref liquid	ref freezing
03 other	7097	792
03 liquid	88960	619
03 freezing	38	630

	ref liquid	ref freezing
010203 other	0	0
010203 liquid	96028	934
010203 freezing	67	1107

The resulting skill scores for freezing precipitation are:

	POD	FAR	CSI
01	0.36	0.0003	0.35
02	0.14	0.0004	0.13
03	0.31	0.0004	0.30
010203	0.54	0.0007	0.53

Case 2

For the three locations 01, 02 and 03, the number of cases with the different states (liquid, freezing, other) are shown below.

	ref liquid	ref freezing
01 other	25181	1256
01 liquid	70914	0
01 freezing	0	785

	ref liquid	ref freezing
02 other	9454	739
02 liquid	86641	0
02 freezing	0	1302

	ref liquid	ref freezing
03 other	7097	792
03 liquid	88998	0
03 freezing	0	1249

	ref liquid	ref freezing
010203 other	0	0
010203 liquid	96090	0
010203 freezing	5	2041

The resulting skill cores for freezing precipitation are:

	POD	FAR	CSI
01	0.38	0	0.38
02	0.64	0	0.64
03	0.61	0	0.61
010203	1.0	0.00005	1.0

Case 3

For the three locations 01, 02 and 03, the number of cases with the different states (liquid, freezing, other) are exactly the same as for case 2.

Appendix E: statistics for freezing fog

This appendix contains the statistics used to calculate the skill scores for freezing fog detection. See section 3.2 for more details.

Case 2

For the three locations 01, 02 and 03, the number of cases with the different fog states (fog, freezing fog, other) are shown below.

	ref fog	ref freezing fog
01 other	4080	2359
01 fog	14690	44
01 freezing fog	0	3850

	ref fog	ref freezing fog
02 other	3431	2069
02 fog	15310	44
02 freezing fog	29	4140

	ref fog	ref freezing fog
03 other	2336	731
03 fog	16408	99
03 freezing fog	26	5423

	ref fog	ref freezing fog
010203 other	0	0
010203 fog	18720	99
010203 freezing fog	50	6154

The resulting skill scores for the detection of freezing fog are:

	POD	FAR	CSI
01	0.62	0	0.66
02	0.66	0.0015	0.66
03	0.86	0.0014	0.86
010203	0.98	0.0027	0.98

Case 3

For the three locations 01, 02 and 03, the number of cases with the different fog states (fog, freezing fog, other) are shown below.

	ref fog	ref freezing fog
01 other	4080	2359
01 fog	14690	44
01 freezing fog	0	3850

	ref fog	ref freezing fog
02 other	3431	2069
02 fog	15339	386
02 freezing fog	0	3798

	ref fog	ref freezing fog
03 other	2336	731
03 fog	16434	150
03 freezing fog	0	5372

The resulting skill scores for the detection of freezing fog are:

	POD	FAR	CSI
01	0.62	0	0.62
02	0.61	0	0.61
03	0.86	0	0.86

In order to determine the effect of the measurement uncertainty in the air temperature (0.1 °C, see Appendix B) on these results, the previous statistics are recalculated using the maximum and minimum range for the air temperature.

T_a + 0.1 °C:

Similar calculations are performed. The resulting skill scores for the detection of freezing fog are:

Case 2

	POD	FAR	CSI
01	0.56	0	0.56
02	0.61	0	0.61
03	0.81	0	0.81
010203	0.92	0.002	0.92

Case 3

	POD	FAR	CSI
01	0.56	0	0.56
02	0.58	0	0.58
03	0.80	0	0.80

T_a – 0.1 °C:

Similar calculations are performed. The resulting skill scores for the detection of freezing fog are:

Case 2

	POD	FAR	CSI
01	0.62	0.025	0.58
02	0.67	0.023	0.62
03	0.87	0.027	0.81
010203	0.99	0.031	0.91

Case 3

	POD	FAR	CSI
01	0.62	0.025	0.58
02	0.64	0.005	0.63
03	0.87	0.018	0.83

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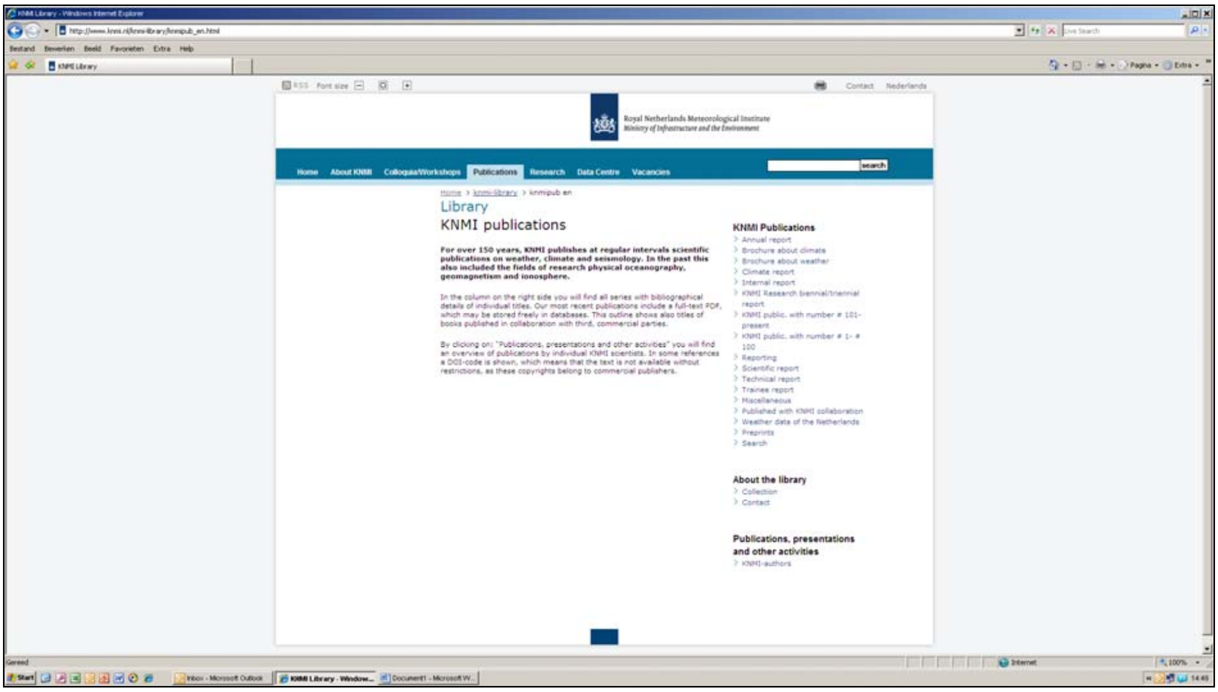

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