SPECIFICATION AND EVALUATION OF PRESENT WEATHER SENSORS

Wiel Wauben, Karin Tukker, Steven Knoop, Corné Oudshoorn

Royal Netherlands Meteorological Institute (KNMI)

P.O. Box 201, 3730 AE De Bilt, The Netherlands

email: Wiel.Wauben@knmi.nl

ABSTRACT

The Royal Netherlands Meteorological Institute (KNMI) uses the Vaisala FD12P present weather sensor for the automated determination of visibility and of the type, intensity and duration of precipitation in its national meteorological observation network. Replacement of the FD12P is required in the near future due to discontinuation of support for this sensor by the manufacturer. For this purpose, KNMI issued an European Tender for the acquisition and maintenance of new present weather sensors.

The Tender consisted of mandatory requirements and desirable features. The mandatory requirements had to be met in order that the offered solution could be accepted. The desirable features received a score and determined the ranking of the accepted offers. The requirements were categorized into functional requirements and quality; maintainability (including reliability, software, support and maintenance), implementation (including technical and hardware requirements, training and documentation) and costs (purchase and maintenance, thus total cost of ownership over a period of 10 years).

As part of the Tender evaluation a period of nearly 1 year was reserved for laboratory and field tests of the three highest scoring offers. During this evaluation there were two formal moments of interaction with each Tenderer of a selected PWS individually. The first moment was a meeting at KNMI to verify the correct installation, configuration, operation and usage of the PWS. The second moment, halfway the field evaluation, the Tenderer was given the results of their PWS and had the opportunity to make changes, upgrades or replacement of the PWS or setup when the results were considered not to be as expected.

The paper gives details of the requirements for the present weather sensor and results of the evaluation will be presented and discussed. The evaluation was challenging since verification in laboratory conditions was not possible and a field reference was generally not available.

1. INTRODUCTION

KNMI employs the Vaisala FD12P Present Weather Sensor (PWS) in the national meteorological observation network since 1997. The FD12P is an optical forward scatter sensor that is capable of measuring visibility (Meteorological Optical Range, MOR). For aeronautical applications the PWS is equipped with a LM21 background luminance sensor so that the aeronautical visibility and Runway Visual Range (RVR) can be determined. In addition, the FD12P uses the information obtained with a precipitation detector and a temperature sensor to determine the type and intensity of precipitation. Since November 2002 all synoptic and climatological observations of KNMI are performed fully automatically (Wauben, 2002), where the FD12P is used for the automated determination of MOR and present and past weather. More recently the aeronautical observations have been automated with the exception of Amsterdam Airport Schiphol. In this case, the FD12P provides the aeronautical visibility, Runway Visual Range (RVR) and present and recent weather. In all situations the instantaneous 1-minute averaged MOR, background luminance and precipitation intensity and -type of the FD12P are used. KNMI algorithms convert the sensor information into information that is reported to the users. The FD12P is used by KNMI in the Netherlands at automated weather stations, at civil airports and military airbases, on platforms in the North Sea and also at civil airports in the Caribbean Netherlands for the fully automated generation of synoptic, climatological and aeronautical reports. Although the FD12P sensor serves KNMI well, there have been issues related to the calibration of the MOR (Bloemink, 2006) and the reduction of MOR due to flying insects (Wauben, 2012). The discrimination of precipitation type by the FD12P also remains an area with room for improvement (De Haij and Wauben, 2010; Wauben, 2014).

KNMI employs approximately 75 FD12P sensors. The FD12P is out of production since the middle of 2010 and the manufacturer support of the sensor will end in 2019. Hence, KNMI needs a successor of the FD12P. As a preparation for the European Tender KNMI selected and purchased several PWSs in 2015 in order to get experience with these sensors and to provide input for the upcoming specification and evaluation that will be part of an European Tender procedure. First results of the field evaluation of sensors for precipitation type discrimination for the period February 2016 to July 2016 have been given in Wauben et al. (2016). In this paper the requirements for the PWS and results of the evaluation are presented and discussed. The evaluation of PWSs is challenging since verification in laboratory conditions is not possible and a field reference is generally not available. Evaluations by other institutes, although very useful, often concern conditions that not comparable to those in The Netherlands, where for example solid or mixed precipitation around 0 °C is crucial. Also these test did not include all PWSs and the (most recent) versions that are of interest for KNMI.

2. REQUEST FOR PROPOSALS AND REQUIREMENTS FOR PWS

The Request for Proposals (RfP) of an European Tender gives the requirements and desirables for the acquisition of PWSs and the procedure. In this section some details of the requirements and procedure are presented. The selection is based on issues that are specifically relevant for PWSs or that where otherwise considered noteworthy mentioning.

The specifications and requirements were based on Tender documents published by KNMI over the past years for various meteorological sensors or systems. Examples and information obtained from other meteorological institutes was also used. Input from technical and maintenance staff, users, and experts, both general and for the specific sensor under consideration, was taken into account. A careful reconsideration of requirements previously used was made, for example the “default’ requirement for 1 year warranty was changed into 2 years.

An external party advised and assisted KNMI during the Tender procedure. There is flexibility in how to setup the procedure, but it needs to be transparent and objective. The requirements must be relevant and clearly stated and the verification method and assignment of scores must by unambiguous. One can have either many detailed or a few general requirements to ensure that the offered product is fit for purpose. The first typically covers all ins and outs the latter gives the operating conditions and the usage of the product.

2.1. General

The RfP concerned the acquisition of PWSs by KNMI, and included the costs for third line maintenance. The Tenderer with an offer that had the best price-quality ratio and met the minimum requirements was be awarded the contract. The total cost of ownership (TCO) over a 10 years period was considered for that purpose. The contract will be awarded for a period of 10 years with an option for unilateral prolongation by purchaser, under the same conditions, for another 5 years.

The time schedule for the PWS Tender that KNMI followed started on March 7, 2017 with publication of the Tender and was planned to end in June 2018 with a contract conclusion. A period of nearly one year was reserved for the evaluation test as evaluation of the PWSs involved a field test in all meteorological conditions. The schedule was met in practice although the evaluation test started one month later than planned. The provisional award was issued in June 2017. The contract has not been signed yet due to holidays, but is currently being finalised. Preparations for the implementation phase are ongoing.

Score and weights

The RfP contained mandatory requirements and desirable features. The mandatory requirements (shall) had to be met in order that the offered solution could be accepted. The desirable features (should) received a score on a scale from 0 to 10. The value judgement of the KNMI evaluation team determined to what degree the requirements associated to each desirable features were met. Each desirable feature had a weight depending on its importance. The scores were multiplied by the corresponding weighting factor to determine the weighted score for each item. Adding these weighted scores together provided the score for a desirable feature category.

The requirements were categorized into: (i) functional requirements and quality; (ii) maintainability (including reliability, software, support and maintenance); (iii) implementation (including technical and hardware requirements, training and documentation); and (iv) costs (purchase and maintenance, thus TCO over a period of 10 years). Each of these categories had a weighting factor that in combination with the score for the desirable feature category determined the ranking of the accepted offers. The weighting factors for the desirable feature categories used for the PWS are given below. The largest weight was given to the quality of the PWS and maintainability. Note that maintainability includes quality (how can quality be assured/maintained) and costs (through reliability and maintenance).

Desirable feature assessment category	Weighting factor
Functional requirements and quality	35%
Maintainability	30%
Implementation	10%
Costs	25%

One mandatory requirement was associated with the desirable features, namely that the average score for the desirable feature assessment categories had to be at least 7.

The three Tenderers with the highest scores and meeting all mandatory requirements were selected to enter the evaluation phase.

Substantiation of mandatory requirements and desirable features

The response of the Tenderer to the requirements shall be brief and to the point. When a substantiation is requested, Tenderer must provide documentation or information that substantiates that a requirement is met. References to documents are allowed, but a reference to the relevant section, paragraph or page must be explicitly given and the documents must be attached to the Tender. The level of substantiations is evaluated and taken into account when determining the score.

Offered PWS must be suitable for the intended purpose

The intended purpose of the PWS is described (see Introduction). The FD12P and its successor shall meet the WMO (2014) and ICAO (2018) requirements for visibility and weather and shall be traceable to a standard for visibility (MOR and background luminance). The PWS shall be suitable for unattended 24*7 operation for conditions in the Netherlands and the Caribbean Netherlands. The successor is expected at least to match, but preferably to exceed the performance of the FD12P in terms of quality of the sensor information and maintenance intervals.

Tenderer should substantiate why the offered PWS is considered to be suitable for the intended purpose of KNMI and the advantages of the offered PWS compared to other solutions. The offered solution will be examined on the completeness, level of detail and clearness of the substantiation.

PWS or separate visibility and precipitation sensors

KNMI is looking for a replacement of the FD12P PWS. The replacement can either be: (i) another PWS that measures the above mentioned quantities; or (ii) separate sensors for MOR and background luminance, and for precipitation type and intensity. The first sensor is called a visibility sensor, the second sensor is called a precipitation sensor, when combined in one sensor it is called a Present Weather Sensor (PWS).

Requirements that need to take separate visibility and precipitation sensors into account are included for implementation/installation and TCO.

2.2. Functional requirements

WMO and ICAO requirements

Mandatory requirements are specified for visibility (MOR, aeronautical VIS and Runway Visual Range) and background luminance. Tenderer shall substantiate that these requirements are met. The substantiation shall include the measurement uncertainty including for example long and short term stability, linearity, hysteresis, repeatability, temperature dependency, calibration and lens contamination according to the "Guide to the Expression of Uncertainty in Measurement" (GUM, JCGM_100_2008).

The mandatory requirement concerning precipitation type is that Tenderer shall substantiate that each precipitation type the PWS can report has been verified during field evaluations, for example against certified human observers using WMO and ICAO reporting practices. Concerning precipitation intensity there is only a WMO requirement for precipitation detection, as the FD12P is currently only used for that purpose.

Additional requirements are: the range of MOR shall be at least 10 m to 50 km (at least the FD12P range); and the precipitation types the PWS can report shall include at least drizzle, rain, snow, ice pellets (sleet) and hail (the most common and essential types). The number of precipitation types the PWS reports, the best quality of the measurements and the level of substantiation is a desirable feature (with the highest weight).

The desirable feature to obtain the best PWS for MOR is: Tenderer should specify the range and should specify and substantiate the measurement uncertainty of the MOR reported by the PWS. The offered solution will be examined on the largest range, the best quality of the measurements and the level of substantiation. In case a reference is used in this substantiation, the traceability of this reference to a standard should be described. Similar desirable features are given for background luminance and precipitation intensity.

The quality of the PWS is also specified through: The mutual agreement between the MOR reported by any 2 identical units of the offered PWS shall be within the WMO and ICAO requirements for the entire MOR range. Tenderer shall substantiate that this requirement is met. A similar requirement is given for background luminance and it is given as a desirable feature for precipitation type and intensity.

Environmental requirements

The visibility reported by the PWS can be affected by flying insects. The desirable feature to evaluate the PWS is: Tenderer should substantiate that the design of the PWS is such that the effect of flying insects on the measured and reported visibility is within acceptable limits. The effect of flying insects on the measurements should be specified and substantiated. When available, field experiences should be included. The offered solution will be examined on the completeness, level of detail and clearness of the substantiation, the smallest impact of flying insects in the measurements, and the availability of field experiences. This feature (with second highest weight) is accompanied with the mandatory requirement: Tenderer shall agree to develop, by request of KNMI, preventive measures or a filtering algorithm when flying insects prove to affect the visibility significantly during the evaluation test. This development shall be finalized and completed within 1 year after award of the contract and is within the offered price. KNMI will provide access to its test site and share data of its reference sensors to facilitate this development.

Additional requirements are given for disturbances or contamination caused by insects/spiders, spray and salt after evaporation of spray, (blowing) precipitation, dust, pollen, exhausts near runways or other environmental factors; sunlight or other light sources, such as runway/traffic lights or lights from passing aircraft/cars; surface conditions such as grass, dirt, sand, rock and water and includes the state of the grass covered ground, the state of the sea and the presence of snow on the ground.

2.3. Maintainability

Calibrators

For visibility and background luminance calibrators are required that allow verification, adjustment and calibration of the MOR and background luminance reported by the PWS. The calibrators shall be traceable to a standard reference.

The requirement for precipitation type is a calibrator(s) that allows verification, adjustment and calibration of the physical quantities from which the precipitation type is derived by the PWS and ensure that the precipitation type reported by each PWS is reproducible.

For precipitation intensity and the other quantities a desirable feature is used for weighting the score: Tenderer should substantiate the verification, adjustment and calibration of the precipitation intensity reported by the PWS or the quantities from which the precipitation intensity is derived by the

PWS with a calibrator. The offered solution will be examined on the completeness of the verification and calibration procedure, the quality of the measurements and the level of substantiation.

Quality information

Tenderer should substantiate how the PWS reports quality information about the reported precipitation types. For example a probability distribution that detected precipitation is of a particular type. The offered solution will be examined on the level of detail of the quality information.

Future developments

Tenderer should substantiate whether new firmware releases are expected in the next few years that will lead to improvements of the PWS. The offered solution will be examined on the potential for future enhancements.

The PWS should make “raw” sensor data available. The “raw” data should be such that it can be used to verify the calibration of the PWS. Raw sensor data is for example information on particle size, falling velocity, shape, water content as well as the information from which visibility and background luminance is derived. The availability of “raw” sensor data should be substantiated. The format of the raw data should be disclosed to KNMI. The offered solution will be examined on the amount, level and type of raw sensor data.

Tenderer should substantiate the possibility to reprocess archived “raw” sensor data offline by either Tenderer or KNMI in order to optimize the algorithms that derive the meteorological quantities. The offered solution will be examined on the completeness and level of facilitating the optimization of algorithms.

Performance

Tenderer should specify and substantiate the Mean Time Between Failure (MTBF) of the PWS. Tenderer should provide actual numbers of the MTBF that are supported by operational experiences. A comprehensive description of the method used to determine the MTBF should be included. The offered solution will be examined on the largest MTBF and the level of substantiation. Similar desirable features are given for the calibration and maintenance intervals.

Mandatories are given with minimum requirements for MTBF (at least 27 months, based on normal environmental conditions and continuous 24/7 operation); calibration interval (at least 1 year) and maintenance interval (at least 6 months for PWS at rural site in the Netherlands).

2.4. Implementation

Data telegram

The measured quantities of the PWS shall be reported and updated every minute or more frequently with an output averaging time of 1 minute or less. The measured quantities of the PWS should be reported and updated every 12 seconds with an output averaging time of 12 seconds. The reporting, update and output averaging time between 1 minute and 12 seconds will be examined.

The measured quantities reported by the PWS shall contain the current values and the quantities shall be consistent, i.e. determined during the same update cycle.

Service port and switch

The PWS should be equipped with a second interface for data and service communication that is using and conforming to a common protocol (for example serial, network, USB).

The PWS should be equipped with a service switch which disregards the measurements or activates a unique status when turned on. Measures against accidental triggering of the switch should be taken. The service switch shall be used by non-qualified staff from third parties for example during cleaning activities.

Size, weight and colour

The weight and dimensions of the PWS and its enclosure should be specified by Tenderer. The offered solution will be examined on ease of transportation by car and helicopter and installation by one person.

The color of the PWS and mast shall be according to requirements for airports see for example: Certification Specifications and Guidance Material for Aerodromes Design page CHAPTER Q — VISUAL AIDS FOR DENOTING OBSTACLES (CS-ADR-DSN-Issue 2). Specifically, the PWS shall be traffic red (RAL 3020), the mast shall be traffic red (RAL 3020) and traffic white (RAL 9016).

Installation and separate visibility and precipitation sensors

Tenderer should specify the requirements of the PWS concerning the installation site and its vicinity. The offered solution will be examined on the least restrictions or demands regarding the location.

The design of the PWS and the PWS setup shall be such that the cleaning, maintenance and replacement of the PWS can be performed by one person and without the use of a ladder.

Some requirements are included to ensure that the sensor interface used by KNMI can handle the individual visibility and precipitation sensors and that the offered solution can be accommodated on the existing measurement positions without the need for additional infrastructure that makes the evaluation complicated due to costly and site specific changes at airports and North Sea platforms.

- It shall be possible to connect the visibility sensor, the optional background luminance sensor and the precipitation sensor to one sensor interface equipped with two serial interfaces either RS422 or RS485.
- It shall be possible either: (i) to mount the PWS on the existing frangible mast of the FD12P by using an adapter and/or shortening of the mast and/or suitable mounting materials; or (ii) Tenderer shall include frangible masts in the offer.
- In case the offer consists of separate sensors for visibility and precipitation, it shall be possible to mount the visibility and the precipitation sensor on the same mast without causing interference of a reduction of sensor performance.

2.5. Total cost of ownership

Tenderer should specify the TCO for a period of 10 years.

The offer shall be based on a total number of 89 PWSs of which 62 shall be equipped with a background luminance sensor or a total number of 89 visibility sensors of which 62 are equipped with a background luminance sensors and 81 precipitation sensors. These numbers include the spares.

The offer shall include the costs of: (i) a duplicate set of the calibrators and tools needed by KNMI to perform the calibration of the PWS and the verification protocol; (ii) the mounting materials, the mast or changes to the existing mast and the adapter that are needed for the installation of the PWS; (iii) the items on the recommended spare parts list; (iv) the costs (with annual indexation) of support and maintenance (parts required for first and second line maintenance by KNMI and all required third line maintenance after shipment to manufacturer) for the period of validity of the contract, with a minimum of 10 years; (v) training and training materials; (vi) any optional/additional parts/tools that are recommended or required according to the Tenderer. The offer shall include a breakdown of the costs given in this section specifying the costs of additional parts/tools/sensors during the period of validity of the contract. The breakdown shall include the hourly tariff of support and maintenance staff.

In the calculation of the TCO a corrective maintenance event was assigned a cost of € 1000 and preventive maintenance was charged by € 150 per hour, either for first line maintenance on site or second line maintenance at KNMI. For third line maintenance by the contractor a cost of € 1000 was assigned to each event. Material costs were included as well. Thus typical costs for KNMI staff and facilities are used to calculate the TCO.

The RfP concerns the acquisition of PWSs by KNMI, and includes the costs for third line maintenance. A fixed price is preferred by KNMI as it contributes to determining the best offer and because assigning incidental, additional funds is problematic.

3. EVALUATION OF PRESENT WEATHER SENSORS

3.1. Requirements for evaluation test

Background and selection

The purpose of the evaluation test was to verify as far as possible that the mandatory requirements were met and to reassess the scores of the desirable features. During the preselection phase the evaluation was based on the information and documentation provided by the Tenderer. The final selection was based on the reassessed scores.

In order to guarantee equal opportunities we shared with all Tenderers the results of the field evaluation of sensors for precipitation type discrimination for the period February 2016 to July 2016 (Wauben et al., 2016) and also provided the results for August 2016 to mid-February 2017 (Knoop et al., 2017), that is close up to the moment of publication of the Tender.

Delivery and support

Tenderers of the selected PWSs had to make 2 units available to KNMI on loan (plus insurance and calibrators, mounting tools etc.). The PWSs and related parts had to be delivered to KNMI within one month after notification of preselection.

During the entire period of the evaluation test, support of the Tenderer was required. Enquiries had to be answered by the Tenderer within 1 working day up to the successful installation of the PWS on the test field of KNMI in De Bilt. Thereafter Tenderer had to answer enquiries within 1 week.

Test and evaluation description

The selected PWSs were submitted to a field evaluation, including laboratory tests before, during and after the field test. The field evaluation took place in De Bilt, but KNMI reserved the right to perform tests partly at other sites.

The test field of KNMI in De Bilt is equipped with a transmissometer, a precipitation gauge and air temperature and relative humidity sensors that serve as reference for visibility (MOR, up to 1500 m), precipitation intensity and air temperature and relative humidity, respectively. For visibility values above 1500 m and for precipitation type no reference is available. The selected PWSs under evaluation were compared with the FD12P, taking into account experiences of the FD12P after more than 10 years of operational use and by comparisons with human observers. Furthermore, the measurements of auxiliary sensors, webcam images and the evaluation of the meteorological situation by forecasters and data validation experts was taken into account. The results of the PWSs were examined by representatives of several user groups (observers, forecasters, technicians, R&D) and stakeholders (weather, climate, aviation). Details of the test field in De Bilt, the analysis and experiences of KNMI were given in the references attached to the Tender.

Verification moments

At two moments information was shared with selected Tenderers and they were allowed to modify/upgrade the PWSs under evaluation. First, during a meeting shortly after installation of the PWS on the test field, each Tenderer of a selected PWS could verify the correct installation, configuration, operation and usage of the PWS and the (raw) data storage. Second, halfway the evaluation, each Tenderer of a selected PWS received a report containing the results of the KNMI sensors and the selected PWS of the Tenderer only. In addition, the archived (raw) data of the selected PWS obtained during the field evaluation were made available to the Tenderer.

The reports contained results in the form of tables and figures. No interpretation, discussion or judgement of the results by KNMI was included. It was up to the Tenderer to decide whether the results of their PWS were as expected, or that results were not optimal or incorrect. In the latter case any concerns or suggestions for changes/upgrades/replacement of the PWS or setup had to be submitted to KNMI. An upgrade of a PWS under evaluation would make the previously obtained results invalid unless Tenderer could show what effect the upgrade had on the results previously obtained.

3.2. Results of the evaluation test

The 1-minute information reported by each selected PWS was compared with the output of the KNMI instruments at the test field in De Bilt. Examples of the tables and figures used to compare and evaluate the selected PWSs are given in Wauben et al. (2016). For about 5 months two units of each selected PWS were collocated at the test field in order to check their mutual agreement in a similar manner. In addition, daily plots and tables were generated in near real-time to facilitate evaluation by data validation staff and forecasters located in De Bilt. Figure 1 shows the pairs of selected PWSs under evaluation at the test field and an example of the near real-time presentation of the 1-minute data for evaluation by forecasters.

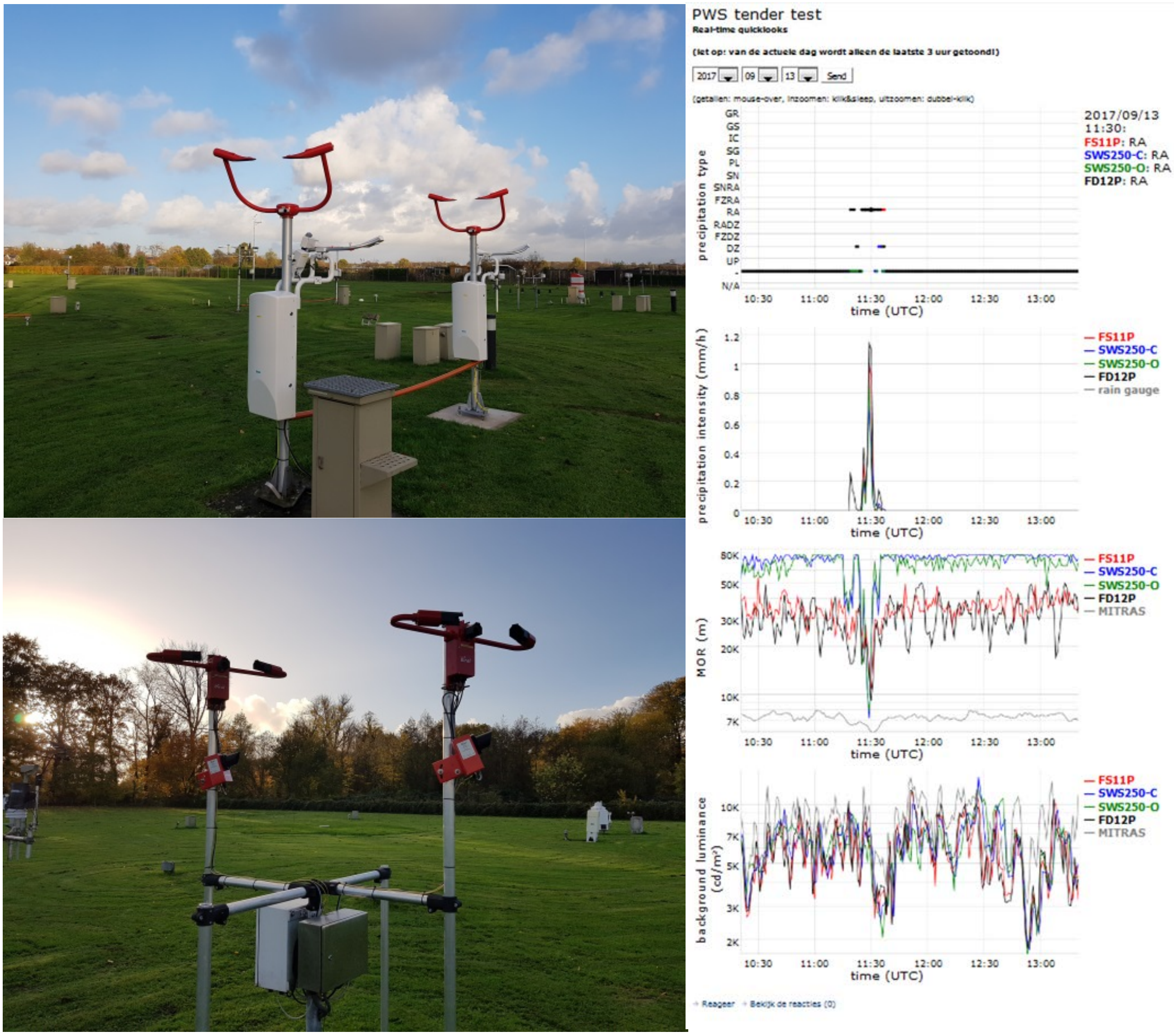
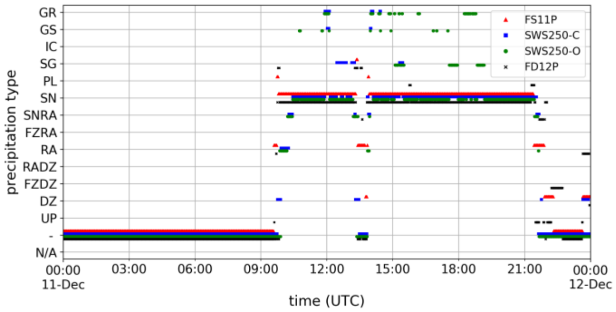


Figure 1: Overview of the setup for selected PWSs under evaluation at the test field of KNMI (left) and a screen shot of the evaluation tool for forecasters with near real-time 1-minute data (right).

Precipitation type

The 1-minute maximum precipitation type reported by each selected PWS was compared with the output of the FD12P. The relative occurrence of the 1-minute precipitation type of each PWS and the FD12P over the entire evaluation period were compared. Precipitation detection (any type), each individual precipitation type, and precipitation classes for unidentified, liquid, freezing and solid precipitation were considered. Contingency matrices containing the 1-minute precipitation type reported by each PWS versus the FD12P were generated. The agreement between the 1-minute precipitation type reported by each selected PWS and the FD12P in terms of precipitation detection, type and class were expressed in percentage correct and POD, FAR and BIAS. Results were determined by considering the 1-minute precipitation type reported by the PWS without and with the 0.02 mm/h threshold for reporting precipitation.



SWS250-O-1 / FD12P

NWS	C	P	L	ZL	LR	R	ZR	LRS	S	IP	SG	IC	SP	A	
C	313959	1644	9415	46	0	5952	2	71	104	10	102	0	0	0	331305
P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	421	90	4426	7	0	2174	0	3	13	0	34	0	0	0	7168
ZL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	1600	223	3207	7	0	15279	0	569	104	28	33	0	0	0	21050
ZR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LRS	8	42	467	0	0	1651	1	161	132	42	40	0	0	0	2544
S	103	50	17	0	0	75	0	42	1601	21	118	0	0	0	2027
IP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SG	2	61	97	1	0	983	2	133	135	27	0	0	0	0	1441
IC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SP	1	0	2	0	0	30	0	1	55	0	0	0	0	0	89
A	0	0	0	0	0	19	0	8	128	0	0	0	0	0	155
	316094	2110	17631	61	0	26163	5	988	2272	128	327	0	0	0	365779

Figure 2: Daily plot of 1-minute precipitation types reported by the PWSs and FD12P (left) and contingency matrix of the 1-minute precipitation type reported by a PWS versus FD12P (right).

The outcome of the precipitation type evaluation was:

± All PWSs had good sensitivity for detection comparable to that of the FD12P, but the default internal settings for reporting precipitation for one PWS needed to be adjusted.

+ All PWSs did not report unidentified precipitation (UP), whereas the FD12P did.

+ All PWSs did report more rain (RA) instead of drizzle (DZ) compared to the FD12P.

– One PWS reported less solid precipitation, the other PWS reported much more solid precipitation than the FD12P.

+ No PWS reported faulty snow grain (SG) during dense fog, whereas the FD12P did.

+ One PWS reported less ice pellets (IP), the other PWS reported less snow grain (SG) than the FD12P.

– One PWS reported more ice pellets (IP), the other PWS reported more snow grain (SG) than the FD12P.

± One PWS reported no hail (GR/GS), nor did the FD12P, the other PWS reported hail too often.

– No PWS including the FD12P reported hail during one of the three verified hail events that occurred during the evaluation test.

± The mutual agreement between 2 units of the same PWS was generally good, thus much better than the agreement with the FD12P, but deviations occured for all PWSs under evaluation.

Precipitation intensity

The 1-minute averaged precipitation intensity reported by each selected PWS was compared with the output of the rain gauge. The relative occurrence of the differences between the 1-minute precipitation intensity of each PWS and the gauge over the entire evaluation period were compared. Statistics on the 1-minute differences, the total precipitation amount, the number of 1-minute precipitation events, the percentage of 1-minute precipitation events where PWS and gauge agreed within the WMO limits, and the agreement of the 1-minute precipitation intensity expressed in terms of the slope of the linear regression and the correlation coefficient were considered. The 1-minute precipitation intensity of each PWS versus gauge were given as density plots. The agreement between the 1-minute precipitation intensity reported by each selected PWS and the gauge in terms of precipitation detection and intensity classes (trace, slight, moderate, heavy and violent) were expressed in POD, FAR and BIAS. Results were determined without and with the 0.02 mm/h threshold for precipitation intensity.

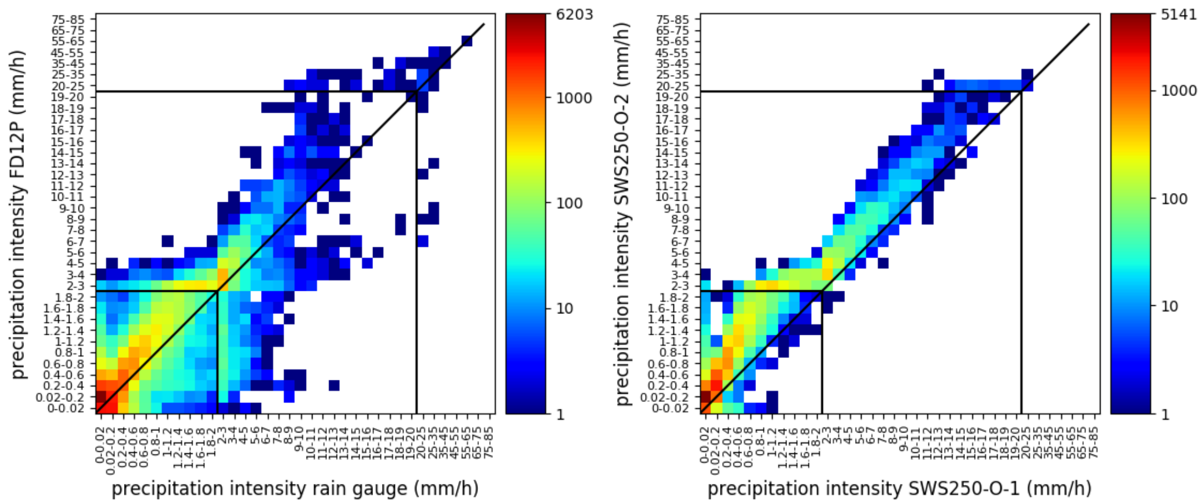


Figure 3: Density plot of 1-minute precipitation intensity reported by a PWS versus gauge (left) and mutual agreement for a PWS (right).

The outcome of the precipitation intensity evaluation was:

± All PWSs had good sensitivity for detection comparable to that of the FD12P, but the default internal settings for reporting precipitation for one PWS needed to be adjusted.

± One PWS showed better agreement for accumulation (slope), the other PWS showed less scatter (standard deviation).

+ All PWSs almost agreed within WMO limits with the gauge for precipitation accumulation, the agreement with the gauge was better than for the FD12P.

+ All PWSs did not agree within WMO limits with the gauge for precipitation intensity, but the agreement with the gauge was better than for the FD12P.

+ The mutual agreement between 2 units of the same PWS was generally good, thus much better than the agreement with the gauge. Different units of the FD12P, each using the factory calibration for precipitation amount, can show deviations up to a factor of 2.

Visibility (MOR)

The 1-minute averaged MOR reported by each selected PWS was compared with the output of the Mitras transmissometer (TMM) and the FD12P. Statistics on the differences between the 1-minute MOR of each selected PWS and the FD12P were expressed in terms of the slope of the linear regression and the correlation coefficient. The percentage of 1-minute MOR cases in which the PWS and FD12P were in agreement within the WMO limits were determined, setting MOR values above 50 km to 50 km, to facilitate the comparison with the FD12P. The 1-minute MOR values of each PWS versus FD12P were given as density plots. The agreement between the 1-minute MOR reported by each selected PWS and the FD12P in terms of fog detection and visibility classes (ICAO special criteria) were expressed in POD, FAR and BIAS. The TMM was used as reference for the WMO and ICAO agreement percentages for MOR between 0 and 1.5 km, selecting only events for which the TMM reported a MOR up to 1.5 km, and where precipitation or inhomogeneous conditions (standard deviation of the MOR in 10-minute interval more than 10%) were filtered out. The remaining 10-minute MOR values of each PWS versus TMM were included in the above comparison and were given as box plots.

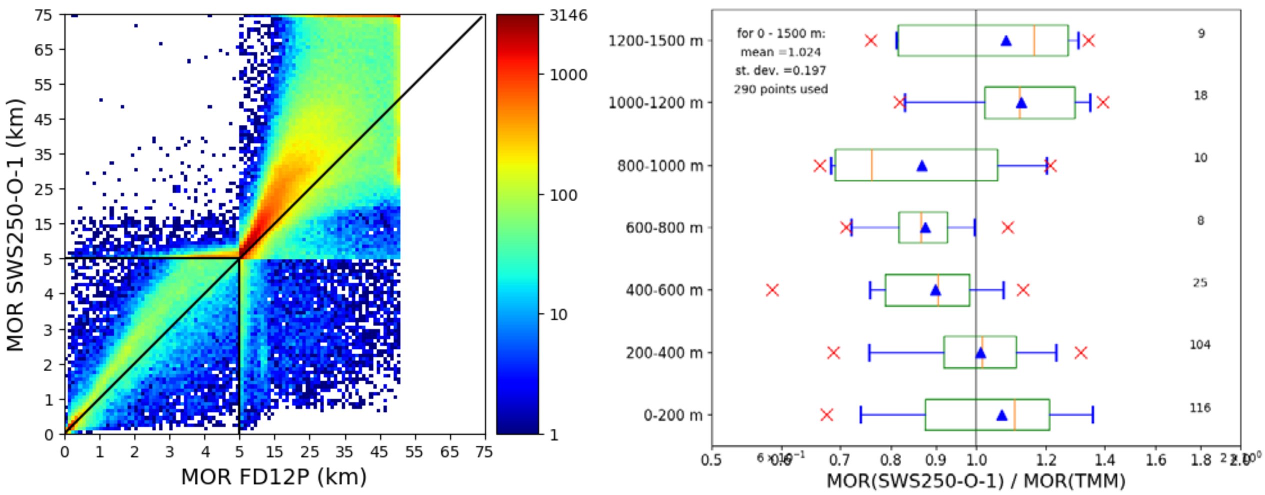


Figure 4: Density plot of 1-minute MOR reported by a PWS versus FD12P (left) and box plot for 10-minute MOR reported by a PWS versus TMM (right).

The outcome of the visibility evaluation was:

± All PWSs showed generally good agreement with the FD12P.
– All PWSs showed differences in the linearity over the 0-50 km MOR range compared to the FD12P.
± All PWSs showed similar agreement with the transmissometer as the FD12P.
± The mutual agreement between 2 units of the same PWS was generally better than the agreement with the FD12P.
– All PWSs showed differences in the linearity over the 0-50 km MOR range compared to the other unit.
– One PWS showed large scatter over the 0-50 km MOR range compared to the other unit.
± All PWSs applied filters to avoid visibility reduction due to flying insects. The suitability of the filter could, however, only be tested for mild insect events.
– The MOR of each PWS was affected by spider silk. One PWS seemed more sensitive to spider silk.

Background luminance

The 1-minute averaged background luminance reported by each selected PWS was compared with the output of the LM21 that was connected to the FD12P. Note that the minimum value, measured at night time, differs per sensor between 0 and 6 cd/m^2. To facilitate the comparison all values below 6 cd/m^2 were set to 6 cd/m^2. The frequency distribution of the 1-minute background luminance of each PWS and the LM21 over the entire evaluation period were compared. Statistics on the differences between the 1-minute background luminance of each selected PWS and the LM21 were expressed in terms of the slope of the linear regression and the correlation coefficient. The percentage of 1-minute background luminance cases in which the PWS and LM21 were in agreement within the WMO limits was given. The 1-minute background luminance values of each PWS (specifically the ratio compared to LM21) versus LM21 were given as density plots. The agreement between the 1-minute background luminance reported by each selected PWS and the LM21 in terms of background luminance classes (night, intermediate, normal and bright day) were expressed in POD, FAR and BIAS.

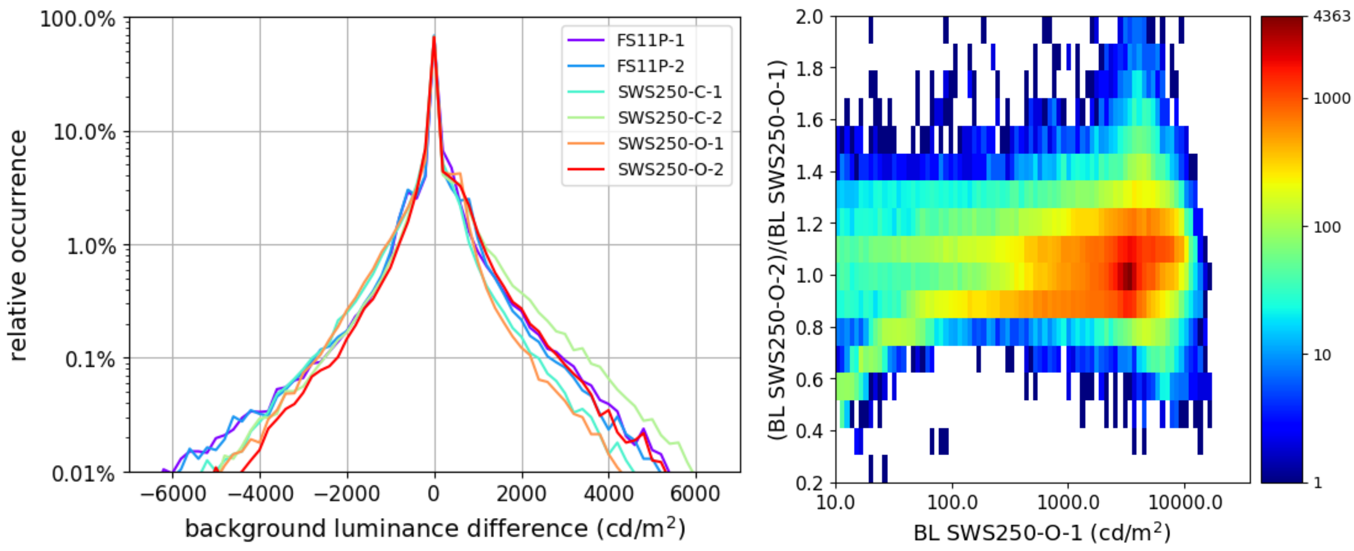


Figure 5: Relative occurrence of the difference between the 1-minute background luminance of a PWS and LM21 (left) and density plot of the relative mutual difference for a PWS as a function of the background luminance (right).

The outcome of the background luminance evaluation was:

± All PWSs showed generally good agreement with the LM21.
± All PWSs had good scores for all background luminance classes except for bright day. Deviations are probably caused by differences in the elevation (offset) and orientation of the sensor (scatter due to cloud in field of view or not).
± The mutual agreement between 2 collocated units of the same PWS was good.
– One PWS showed small differences in the linearity for the 0 to 1000 cd/m^2 range compared to the other unit.

Temperature

The 1-minute averaged temperature reported by each selected PWS has been compared with the operational temperature sensor of the AWS (at a height 1.5 m and in a radiation screen). The frequency distribution of the 1-minute temperature reported by each PWS and AWS over the entire evaluation period are compared. Statistics on the differences between the 1-minute temperature of each PWSs and the AWS are expressed in terms of the slope of the linear regression and the correlation coefficient. The percentage of 1-minute temperature cases where PWS and AWS agree within the WMO limits is given.

The outcome of the temperature evaluation was:

± As could be expected the temperature reported by a PWS cannot be used as the air temperature.
± One PWS showed overall an offset of 1.4 °C and a standard deviation of 0.9 °C, the other PWS showed an offset of –0.7 °C and a standard deviation of 1.6 °C.
± One PWS showed good mutual agreement between 2 collocated units of the same PWS, the other PWS showed larger deviations.

Laboratory tests, installation and maintenance

The laboratory tests, installation and maintenance revealed several issues for each PWSs under evaluation that were adequately resolved by the Tenderer. Examples are errors in the documentation and undocumented features, alignment and optimal collocation for the field setup. An example of an undocumented features is the fact that for each PWS the settings of the background luminance calibration can be obtained in order to monitor the need for and the changes made during a calibration.

The laboratory test, installation and maintenance did not reveal any quality issues with any PWS. It did give useful feedback on the user friendliness of the PWS and the clearness of the documentation, ease of installation and replacement and the attractiveness and sensitivity of a PWS for spiders.

Contamination of optical windows of the PWSs was not an issue, but conditions at the test field in De Bilt are mild in that respect.

4. CONCLUSIONS, OUTLOOK AND RECOMMENDATIONS

The European Tender for the acquisition of PWS by KNMI, including 3rd line maintenance, was performed using the procedure, requirements and evaluation described in the previous sections. Five offers were received from four Tenderers. Two offers did not meet all mandatory requirements, specifically the requirement for an average score for the desirable feature assessment categories of at least 7. The remaining three offers included two offers of the same PWS by different Tenderers. As there were no provisions against such a situation in the RfP both entered the evaluation phase as individual offers. Fortunately, these two offers did not prevent another offer to enter the evaluation phase, so fair play was assumed. The evaluation test showed that both offers were acceptable for KNMI, although each PWS had some issues requiring further attention. The offer that had the best price-quality ratio, based on the desirable features and their weights, was awarded the contract. The “winner” was the Biral SWS250 present weather sensor in combination with the ALS2 background luminance sensor offered by Observator Instruments.

It should be noted that not all requirements could be tested during the evaluation phase as conditions did not occur or the time available did not permit it. Some of these requirements will be addressed during the verification phase. During this phase tests will be performed to ensure that the new PWS gives satisfactory results in all conditions (North Sea and coast, near runway at airport, site prone to flying insects and spiders). In addition, acceptance, maintenance and calibration protocols will be setup and verified; implementation of the new PWS in the national meteorological observation network with associated processing of the sensor information must take place; and parallel measurements to provide to users information on the suitability of the new PWS and how to manage the transition will be performed and documented.

Some recommendations concerning requirements and evaluation are given below.

3.1. Requirements

Naturally a requirement is needed to prevent two (nearly) identical offers by different Tenderers to enter the evaluation phase in future. This was discussed during the preparation of the RfP, but mainly in the context of offers with 2 separate sensors for visibility and precipitation type. It resulted in: When the selected Tenders contain identical sensors for either visibility or precipitation, the highest scoring Tender containing a different sensor will be considered as well. This did not exclude “identical” offers submitted by different Tenderers.

Many desirable features having only a small weight, and thus little effect on the overall score, are included in the RfP. They are specifically mentioned as a framework or standards are missing and because it needs to be clear what is required, how it is evaluated and against what criteria.

Several requirements concerning temperature and humidity probes, that might be included in the PWS offer to enhance the discrimination of the precipitation type, were included in the RfP. They were considered essential as new temperature and humidity probes could be introduced in the meteorological network. However, they were not applicable as the offers did not include external probes in a radiation shield suitable for operational air temperature and relative humidity measurements.

No requirement concerning environmental friendliness of the offered PWS and/or manufacturer were included in the RfP. Only indirectly through weight, size and power consumption.

3.2. Evaluation

During the evaluation test there was no time for a test on the North Sea or at the coast. The evaluation procedure requires that all three selected PWSs must be included. No site with facilities for testing are available on the North Sea or at the coast where three PWSs could easily be accommodated. Such a test is part of the verification phase.

The alignment of optical PWSs is important. This will be handled by qualified KNMI staff during installation. However, replacement of a PWS might be done by third parties less familiar with the PWS.

Hence, KNMI proposed a change in the mounting of the PWS on the mast so the alignment needs only to be done at installation, but is kept during sensor replacement.

The evaluation test resulted in only minor changes to the scores. So the first selection, and the selected offers were of good quality. The evaluation revealed some issues that were solved, and the support of all selected Tenderers was timely and good. The evaluation serves as a starting point for the verification and implementation phase. Most importantly, the evaluation provided confidence in the selected PWS and manufacturer.

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