QUALITY ASSESSMENT USING METEO-CERT:

THE METEOSWISS CLASSIFICATION PROCEDURE FOR AUTOMATIC WEATHER STATIONS

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FOREWORD

To be inserted.

(Prof. B. Calpini)
President
Commission for Instruments and Methods of Observation

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SUMMARY

In 2004, the Swiss National Meteorological and Climatological Service (MeteoSwiss) started to build its automatic observation network SwissMetNet. This state-of-the-art network meets the highest WMO requirements. For budget reasons it was limited to about 150 fully equipped automatic weather stations (AWSs) plus additional 100 automatic rain gauges. Based on the gap analysis of the Rolling Review of Requirements process (WMO, 2015) it became clear that both internal and external clients were in need of more observation data in order to generate better predictions in the field of nowcasting, warnings and hydrology. Therefore, in 2008 MeteoSwiss started to systematically integrate AWS from networks of other public institutions (e.g. cantons or research institutes) and private weather services (e.g. MeteoGroup) into its central data storage platform, the MeteoSwiss Data Warehouse (DWH). The integration of 3rd party network data thus significantly increased the coverage of meteorological surface observations over Switzerland. Ultimately, this leads to a higher accuracy and quality in the field of warning and nowcasting.

However, integrating AWSs from other networks also brings challenges concerning the quality and uncertainty of these additional data sources. This IOM report presents MeteoSwiss' development of a neutral **Meteo**rological **Cert**ification process called *METEO-Cert*. Based on WMO principles and regulations METEO-Cert does an independent assessment of both the quality of 3rd party network data and MeteoSwiss' own observation network SwissMetNet. As a result it provides quality flags which can be added to each corresponding data set in the DWH. The hereof resulting quality information leads to a known uncertainty of the integrated AWS and is of great importance when using the data for further data processing. It can be delivered in combination with the data itself to every user within and outside MeteoSwiss.

In 2010, MeteoSwiss started implementing METEO-Cert and in 2013 mandated the Swiss Federal Institute of Metrology (METAS) as a neutral inspector to carry out the assessments at the stations' sites to ensure the neutrality of this process. Reason to outsource this process was to guarantee utmost neutrality in the quality assessment of partner stations. Since 2014, the quality information resulting of the METEO-Cert procedure is stored in the MeteoSwiss DWH and is accessible to the user. This integration of quality and uncertainty information follows the principle of the WMO Integrated Global Observing System (WIGOS) and brings a clear overall improvement in the evolution of practices (CIMO siting classification of the AWS, used instrument technology, network services, etc.) for both MeteoSwiss and private partners. As a result of METEO-Cert, about 10 % of the overall assessed stations (both public and private) have been improved based on the findings and deliver now higher quality observation data. Also due to METEO-Cert the local station managers have acquired a higher sensibility towards changes in and around the AWS which, if not addressed and solved, can lead to a higher uncertainty of the observation data. In order to monitor these improvements METEO-Cert is applied to every AWS every five years.

This IOM report maps out the principles and challenges associated with this process. It further provides background information on how METEO-Cert operates and how its future development is planned. Finally, it shows how the tool can be adapted and used by decision makers of other national meteorological and hydrological services (NMHSs) to evaluate the quality of partner networks in their country and to decide whether the data should be integrated or not.

1. INTRODUCTION

In accordance with the user driven demands analysed in the Rolling Review of Requirements process and the implementation of WIGOS (WMO, 2015) MeteoSwiss pursues the strategy to strengthen its cooperation with partners in Switzerland and in border regions of neighbouring countries. The main goal is to use synergies when developing its observation network. In addition, MeteoSwiss as the national weather service, is responsible for performing official mandates with the known reliability. The quality control of measurements is part of this duty.

The purpose of the METEO-Cert quality control procedure is twofold:

1. It ensures that WMO standards are met for both MeteoSwiss and partner stations.
2. It attributes a data quality level to the data of both MeteoSwiss and partner stations.

Through this quality labelling it is possible to compare partner stations with MeteoSwiss stations and to have a systematic acquisition of metadata regarding quality on a regular basis. Knowing the quality level, and thus the degree of representativeness of data from 3rd party networks, helps also to identify the possible areas of application of the data and its limitations.

METEO-Cert can only be applied on AWSs built for meteorology or climatology. The procedure[1] is neither applicable to stations with manual observations nor to stations focusing on other applications, such as agricultural or road meteorology. Those stations are located at special sites (e.g. within the crops or next to a highway) and do not follow the CIMO siting recommendations (WMO, 2014) for a typical climatological or a surface synoptic station.

[1] The procedure could of course be further developed to also assess other types of weather stations, but for MeteoSwiss the aim was to focus on meteorology and climatology.

2. METHODS: HOW THE PROCEDURE WAS DEVELOPPED

2.1. History

In 2008, MeteoSwiss started integrating data from 3rd party networks in order to reduce costs and to fill observation data gaps identified in the Rolling Review of Requirements process. While many clients were happy with the increased coverage of meteorological surface observations, some of them were reluctant to use the data since the quality of the sources and ultimately the uncertainty of the partner data was not known. They wanted to have systematically gained information about the data quality in order to decide if the partner data could be used for a certain application. This led, in 2010, to the development of the METEO-Cert quality assessment procedure, which is presented in this paper.

2.2. Requirements

With the integration of data from 3rd party networks, the demand for comprehensive metadata about those stations rose. The requirements of the data users were manifold:

- What is the measurement uncertainty of the instruments used by partners?
- Can their data also be used during winter? Are the instruments heated?
- What purpose was the station built for? Meteorology? Climatology?
- Where is the station? What is the surrounding vegetation? Are there obstacles nearby?
- Which stations can be used for model assimilation or verification?

So the goal of the procedure was to have an objective tool to assess stations, to assign an overall quality level or uncertainty flag to partner data, and to define the possible fields of application for each partner station.

2.3. Principle of METEO-Cert

METEO-Cert is based on the requirements for high quality measurements defined in the WMO Guide to Meteorological Instruments and Methods of Observation (the CIMO Guide), which states in Part I, Chapter 1: "The accuracy with which an observation describes the state of a selected part of the atmosphere is not the same as the uncertainty of the instrument, because the value of the observation also depends on the instrument's *exposure to the atmosphere."* and "The stated achievable uncertainties can be obtained with *good instrument* systems that are *properly operated*, but are not always obtained in practice." (WMO, 2014).

So, high quality measurement data can be obtained by means of using:

1. Automatic weather station (AWS);
2. High quality measuring instruments;
3. Selecting the optimal site and exposure;
4. Well-trained staff doing regular maintenance, inspections and calibrations.

In METEO-Cert these four points are assessed for every meteorological variable measured on the evaluated AWS. An overall assessment of a station as a whole is not done since it is quite possible that, for example an open and exposed site is suitable for measuring a variable like wind but not for precipitation. Therefore the individual meteorological variables are assessed separately.

As a result of the assessment each meteorological variable is given a quality label:

1. **Fully compliant**: All the WMO requirements defined in the CIMO Guide are fulfilled. High quality station with lowest possible uncertainty.
2. **Compliant**: Most WMO requirements fulfilled. Intermediate but still acceptable uncertainty for certain fields of application, such as nowcasting and warning.
3. **Not compliant**: Some important WMO requirements are not fulfilled. Be aware of the limitations and use data with caution since the uncertainty is not known.

For simplicity, MeteoSwiss has decided to use a very easy to understand labelling method with only three levels. As a rule of thumb, it can be stated that meteorological variables labelled "fully compliant" can be used for climatology, since only well maintained high quality instruments on very representative sites fall within this category. Although variables that are "compliant" could still be used in meteorology (where a higher uncertainty is still tolerable), they would have to be checked in depth before being used in a climatological study. Meteorological variables that are "not compliant" do have a very high or even unknown uncertainty and the use of such data should be analyzed case by case.

It is important to understand the limitations of the quality label: the procedure's focus is an inspection on site! A variable that is labelled "not compliant" can still deliver high quality measurement data. For example, in high alpine regions, MeteoSwiss has installed many thermometers at 6 m above rock instead of 2 m above grass, due to the snow height in winter. The meteorological variables measured by such an instrument with a non-standard measurement height are therefore not compliant according to the CIMO Guide, but if one is aware of the possible higher uncertainty due to the special site, the data can of course be used for both meteorology and climatology (especially if one has long series of data at the same site).

2.4. Criteria and Assessment

The METEO-Cert questionnaire (a sample report is provided in Appendix) includes about 100 criteria grouped into general criterion for the AWS, and specific criteria for each meteorological variable (temperature, precipitation, wind, etc.). For each criterion there are two thresholds ("fully compliant" and "compliant") which are used for the assessment of the criteria. The criterion with the lowest quality label is used as the overall result for a meteorological variable.

The "general criteria" section of the questionnaire contains questions concerning general information about the AWS which is stored as metadata in the DWH:

- Station information: AWS name, coordinates, altitude, station type (regular or mountain station), general description and comment by inspector (WMO 2014, Part I, 1, annex 1.C)
- Inspector information: Date of inspection, name, contact information, etc.
- Operator information: Name, contact information, keeper information (if applicable), etc.

But there are two criteria valid for the whole station which are being assessed by METEO-Cert:

- Observing Cycle: What frequency does AWS measure a certain meteorological variable at?
- Transmission Interval: How often does AWS transmit the observation data to operator? For certain applications like nowcasting and warning a high sampling is important.

Since only AWSs are assessed by METEO-Cert, these two criteria are crucial: in order to be "fully compliant", stations must be able to measure and transmit data every 10 minutes; hourly transmission is still considered "compliant". Stations that measure and/or transmit daily are considered "not compliant" for all meteorological variables they measure.

2.4.1. Instruments

The METEO-Cert questionnaire is assessing instruments measuring the following meteorological variables: temperature and humidity, pressure, wind, precipitation, global radiation and sunshine duration. This set was chosen because they are all covered in the WMO/ISO Siting classification scheme (WMO 2014, Part I, 1, annex 1.B). Instruments measuring other variables such as visibility, cloud height or radioactivity, are currently not covered but could be added to METEO-Cert if the CIMO siting classification is broadened accordingly.

For each meteorological variable the questionnaire provides an extensive database with instrument names, manufacturer, resolution, information on heating, etc. The inspector chooses the correct instrument from a pulldown menu of the METEO-Cert tool developed in Microsoft Excel,

and most of the criteria concerning the instrument section are filled-out automatically. Some of the criteria within this section are:

- Operational measurement uncertainty of instrument ("accuracy" of instrument)
- Ventilation and heating.
- Is the used instrument constructed for outdoor use ("weather-proof")?
- Does the instrument also work under cold conditions (snow, icing)?
- Is the operating range compatible with extreme wind gusts?

It is important to understand that METEO-Cert does not assess the instruments individually through, for example laboratory or outdoor compliance tests, or by relying on comparative studies. This is due to the fact that results of comparative studies do not always apply to the weather conditions in Switzerland and they usually do not include all instruments available on the market (for instance, new instruments are missing). Instead, the procedure relies on the information provided by the manufacturer and compares those values with the operational measurement uncertainties defined in the CIMO Guide (WMO, 2014) and in CIMO's sustained performance classification (Leroy, 2013). This has the advantage that the comparison is neutral (operator does not assess his own and/or 3rd party instruments) and that new instruments can be included in METEO-Cert without having to assess them first. However, this approach also has its limitations since the results of METEO-Cert rely on untested information provided by the manufacturer.

Table 1. Operational measurement uncertainty requirements in METEO-Cert

Meteorological variable	Fully compliant (Annex 1.E in WMO-No. 8)	Compliant Class C in Leroy (2013)
Temperature	0.2 K	1 K
Humidity	3 %	10 %
Pressure	0.15 hPa	1 hPa
Wind speed	10 %	15 %
Wind direction	5°	10°
Precipitation	5 %	10 %
Radiation	2 %	10 %
Sunshine	2 %	10 %

Table 2. Requirements concerning ventilation and heating

Meteorological variable	Ventilation (active)	Heating
Temperature & Humidity	Required	Required
Pressure	-	-
Wind speed & direction	-	Required for mountain stations*
Precipitation	-	Required for mountain stations*
Radiation & Sunshine	Mountain stations require means to ensure glass dome is kept free (ventilation and/or heating)*	

* Regular stations can still reach "compliant" if criteria is not met. Mountain stations (see section 2.5) missing the criteria are always labelled "not compliant".

2.4.2. Siting and exposure

A high quality instrument does not automatically guarantee reliable measurements if the chosen measurement site is not representative or the exposure to the environment is not adequate. Therefore METEO-Cert uses different criteria to ensure that the recommendations listed in the CIMO Guide are followed correctly. Those criteria are:

1. Measurement height;
2. CIMO Siting Classification;
3. Correct exposure of the instrument.

The CIMO Guide lists measurements heights for every meteorological variable in the according chapters (WMO, 2014). If a height range (e.g. for precipitation from 0.5 m to 1.5 m; WMO 2014, Part I, 6, 6.1.4) is given, then METEO-Cert uses the value typical for Switzerland (such as for precipitation where 1.5 m is used). Check Table 3 for an overview of the acceptable measurement heights. As explained in section 2.5, METEO-Cert does distinguish between regular and mountain stations.

Table 3. Measurement height thresholds used in METEO-Cert

Meteorological variable	Regular stations (Elevation below 1000 m)	Mountain stations (Elevation over 1000 m)
Temperature/Humidity	2 m (±10 %)	Max. 3 m
Pressure	Exact instrument height must be known by operator with an uncertainty of ±1 m (±5 m for "compliant")	
Wind	10 m in flat open land. Higher in rougher terrain (rule of thumb: 10m above the "mean" roughness of terrain)*	
Precipitation	1.5 m (±10 %)	Max. 3 m

* Refer to METEO-Cert manual (Fisler and Kube, 2015) for details about how wind measurement height is assessed depending on terrain roughness using the Davenport classification.

The CIMO siting classification for surface observing stations on land (WMO, 2014, Part I, 1, appendix 1.B) is an WMO/ISO standard (ISO 19289, 2015) and the most widely accepted reference to characterize environmental conditions and to rate a site's representativeness for measuring a certain meteorological variable. Therefore METEO-Cert relies heavily on this classification system. One of the main points when doing an inspection is to evaluate the site class for every measured meteorological variable. Class 1 and 2 are considered "fully compliant" for a regular station and class 3 is still "compliant". Class 4 and 5 are rated as "not compliant" in METEO-Cert. Mountain stations, due to the complex terrain in high altitude regions, are labelled "fully compliant" up to CIMO siting class 3, and "compliant" for class 4.

On site, the inspector has to evaluate further if the instrument is *correctly exposed* to the environment. This yes/no question does contain a certain amount of ambiguity but the METEO-Cert manual (Fisler and Kube, 2015) provides a useful guideline for each meteorological variable, indicating what is meant by *correct*. Such as:

- Temperature and humidity: instrument is free standing (at least 2 m radius) and not attached to a wall. Housing is white and intact.
- Pressure: instrument is exposed to open air and housing of instrument is intact.
- Wind: mast is straight and is strong enough to withhold extreme wind gusts.
- Precipitation: Mast is straight (if not, tipping-bucket gauges can show measurement bias), instrument is not installed on a roof and is not sheltered by close objects or instruments.
- Radiation and sunshine duration: Instrument is levelled, free standing and housing intact.

2.4.3. Station supervision

Instruments should be calibrated, checked regularly by means of control measurements and replaced if expected uncertainty is no longer achieved. In addition, measuring instruments should be subjected to an automatic data control and, ideally, set to run redundantly (parallel measurement). This reduces maintenance work as faulty instruments are automatically tracked.

In METEO-Cert the following five criteria are involved in the assessment of a station supervision:

1. *Calibration or replacement*: calibration must be carried at defined intervals (e.g. every few years) in an accredited laboratory. In case on site replacement is an issue, in situ calibration can also be considered.
2. *Control*: Control measurements are carried out by the operator at the station once a year.
3. *Maintenance*: Instruments must be checked and cleaned regularly by a keeper. A list of expected tasks carried out by the keeper are described for every meteorological variable in the METEO-Cert manual (Fisler and Kube, 2015).
4. *Parallel measurement:* A second instrument is operated at the observation station and provides a redundant set of data.
5. *Data quality control*: Plausibility of measurement data is continuously validated. Outliers, measurement errors etc. should be reported to the operator automatically and lead to appropriate maintenance work.

Table 4. METEO-Cert station supervision concept overview

	Maintenance	Control	Calibration
Frequency	Weekly or several times a year	Annually	Every few years
Location	At station	At station	In laboratory
Personnel	Keeper	Operator	Accredited laboratory
Task	Visual check, clean instruments, cut grass and report problems	Control measurements, open instruments, test, adjust and replace	Calibration in laboratory
Defect/Problem	Report to operator	Repair on site or replace	Replace if calibration not possible
Accepted alternative	Automatic data control	Parallel measurement	Regular replacement

The CIMO Guide does not list any exact number of weeks or years for tasks like maintenance, control measurements or calibrations. Instead it lists general recommendations such as in Part I, Chapter 1: "…instruments should be maintained regularly so that the quality of observations does not deteriorate …". And also the Manual on the WMO Integrated Global Observing System (WMO, 2015) is very unspecific when it comes to maintenance, inspections and calibration: "Members shall determine the frequency and timing (schedule) of the preventive maintenance taking into account the type of observing system, environmental and climate conditions of the observing site and platform, and the instrumentation installed".

Therefore, the thresholds used for the five "station supervision" criteria were determined empirically based on both the expertise of MeteoSwiss and discussions with operators of 3rd party networks. Needless to say that these five criteria were the most controversially discussed points while developing METEO-Cert. Especially private operators of 3rd party networks do not have the budgets nor the staff to fulfil all of them. Furthermore, it has to be stated that for most applications like nowcasting or warning there is no need for highly calibrated instruments (some of the cheaper instruments used in meteorology do not even offer the possibility to be calibrated). As a result of many discussions with staff of both MeteoSwiss and partner stations, METEO-Cert

does not expect from the operator to fulfil all five criteria. Instead the following thresholds were defined:

1. **Fully compliant**: At least three "station supervision" criteria are met.
2. **Compliant**: Two criteria are met.
3. **Not compliant**: One or none of the "station supervision" criteria are met.

2.4.4. Post-Analysis: Data Availability and Timeliness

When integrating data from 3rd party networks, it is important to check if the promised downtime and transmission intervals are met. Therefore the post-analysis part of METEO-Cert examines one year of data and does assess if the following criteria do meet the requirements:

- Timeliness: How fast are the data delivered to the client? Often same as transmission interval, but in some cases the 3rd party networks process data slowly, which results in higher delivery times and therefore higher timeliness values.
- Data Availability: Completeness of the data set measured by an AWS. Observation data should be available as complete as possible and instrument failures kept to a minimum.

These two criteria are also used in the Observing Systems Capability Analysis and Review Tool (OSCAR, see http://oscar.wmo.int) and thus using RRR an NMHS can define its needs and compare those gaps with a partners capabilities. The Manual on the WIGOS (WMO, 2015) recommends: "Members should address the requirements for timeliness (...) which result from the RRR process and in accordance with the details provided by other sections as appropriate". The Guide to the Global Observing System (WMO, 2010) recommends: "Effective real-time quality control monitoring (...) should include checks of (...) completeness and timeliness of the collection of observational data" and "The point at which a decline from 100 % becomes sufficient to render the system no longer cost-effective might depend somewhat upon the circumstances of its use; in general, however, the aim is to achieve a data availability of more than 90 % for successful operational systems. For Regional Basic Synoptic Stations, a data availability of at least 95 % appears to be indispensable for daily routine work."

But METEO-Cert is using specific thresholds, which meet the needs of MeteoSwiss (see Table 5). They have been taken from the MeteoSwiss measurement concept (Häberli et al., 2008) and they are also used in MeteoSwiss' own observation network "SwissMetNet". Other NMHSs might use other thresholds and therefore adapt the procedure accordingly. Its recommended to use a one-year-dataset to calculate the 3rd party networks timeliness and data availability values.

For METEO-Cert the post-analysis examination of one year of data is done only once within every assessment cycle (for example every five years). But within MeteoSwiss the check if data availability and timeliness rates are met by both partner and MeteoSwiss stations has been implemented as a reoccurring process. The verification of the values listed in Table 5 is now done continuously (for example every month) and if the goals are not met, some measures are defined in order to address and fix the problem that caused the dropping rates.

Table 5. Timeliness and data availability thresholds (as define by MeteoSwiss)

	Generic	Specific for METEO-Cert (Häberli et al., 2008)
Timeliness	OSCAR/Requirements lists user requirements for nowcasting goal at 5-15min and threshold at 60-120min.	**Fully compliant**: ≤ 20 min **Compliant**: ≤ 90 min **Not compliant**: > 90 min
Data Availability	≥ 95 % for RBSN ≥ 90 % for operational systems	**Fully compliant**: ≥ 96 % **Compliant**: ≥ 80 % **Not compliant**: < 80 %

2.5. Adaptations for Switzerland

Nearly all the METEO-Cert criteria, presented in detail in the previous section, are taken from the CIMO Guide (WMO, 2014). Although the CIMO Guide is a reference document accepted worldwide, it sometimes defines ranges (such as for measurement height) and provides recommendations which are not applicable in every country. Therefore for METEO-Cert some adaptations for Switzerland had to be introduced. Those adaptations were made based on the expertise and the authority of MeteoSwiss as a NMHS. All the adaptations are listed in Table 6.

Furthermore, in order to cope with the extreme conditions of high altitude environments, the concept of *mountain stations* has been introduced into METEO-Cert. All stations with an elevation above 1000 m are called *mountain stations* and they have different thresholds for some criteria than *regular stations*. On the one hand, an instrument heating must be more powerful for a mountain station than for a regular station (non-heated instruments are always labelled "not compliant" at mountain stations). On the other hand, it is very hard to find locations that correspond to CIMO siting classification, and therefore less strict thresholds apply for this criteria. Furthermore, depending on the expected maximum snow height, instruments at mountain stations can be installed higher than those on regular stations. The elevation threshold of 1000 m has already been used in the SwissMetNet project as a rule of thumb for deciding whether rain gauges should be installed at 1.5 m or 2 m, due to expected snow heights.

Table 6. Comparison of respective thresholds as defined in the CIMO Guide and adaptation for Switzerland as implemented in METEO-Cert

	Generic (as defined in CIMO Guide)	Specific for Switzerland (as defined in METEO-Cert)
Measurement height	The CIMO Guide does allow heights of 0.5 m to 1.5 m for rain gauges, and 1.2 m to 2 m for thermometers. But it also states to keep instrument: "above the maximum expected depth of snow cover…" (WMO, 2014).	Set to 1.5 m for rain gauges (Sevruk, 1985) and 2 m for thermometers on regular stations (MeteoSwiss, 2016). Up to 3 m for mountain stations. See Table 3 for more details!
Heating and/or ventilation	Optional: "In some localities it may be desirable…"; (WMO, 2014, Part I, 5).	Required for most variables in order to be "fully compliant" (Müller, 1983). See Table 2
Solid precip. measurement	Optional: "Heating devices can be used…"; (WMO, 2014, Part I, 6)	Required in order to be "fully compliant" since solid precip. common all over Switzerland.
Rain gauge collector size	The range of 200-500 mm^2 is "most convenient" (WMO, 2014, Part I, 6).	200 mm^2 (According to Gutermann, 1974 the Swiss standard since the Hellmann gauge was introduced)
Extreme wind gusts	3 s wind gusts with no max, that an instrument be able to measure, defined. (WMO, 2014, Part I, 5)	1 s gusts with max 180 km/h (discussed in Ceppi, 2008)
Threshold for sunshine	>120 W/m^2 (WMO, 2014, Part I, 8)	>200 W/m^2 (Müller, 1989) For historical reasons different than WMO recommendation
Coordinate system used	World Geodetic System 1984 with Long./Lat. (WGS 84)	Swiss coordinate system used (CH1903)

2.6. METEO-Cert classification procedure and tool

The classification procedure or METEO-Cert focuses on an on-site inspection and on the objective recording of the criteria listed in the METEO-Cert questionnaire. It is important that inspectors have meteorological knowledge and that they are able to apply appropriately the CIMO siting classification and distinguish different instrument types.

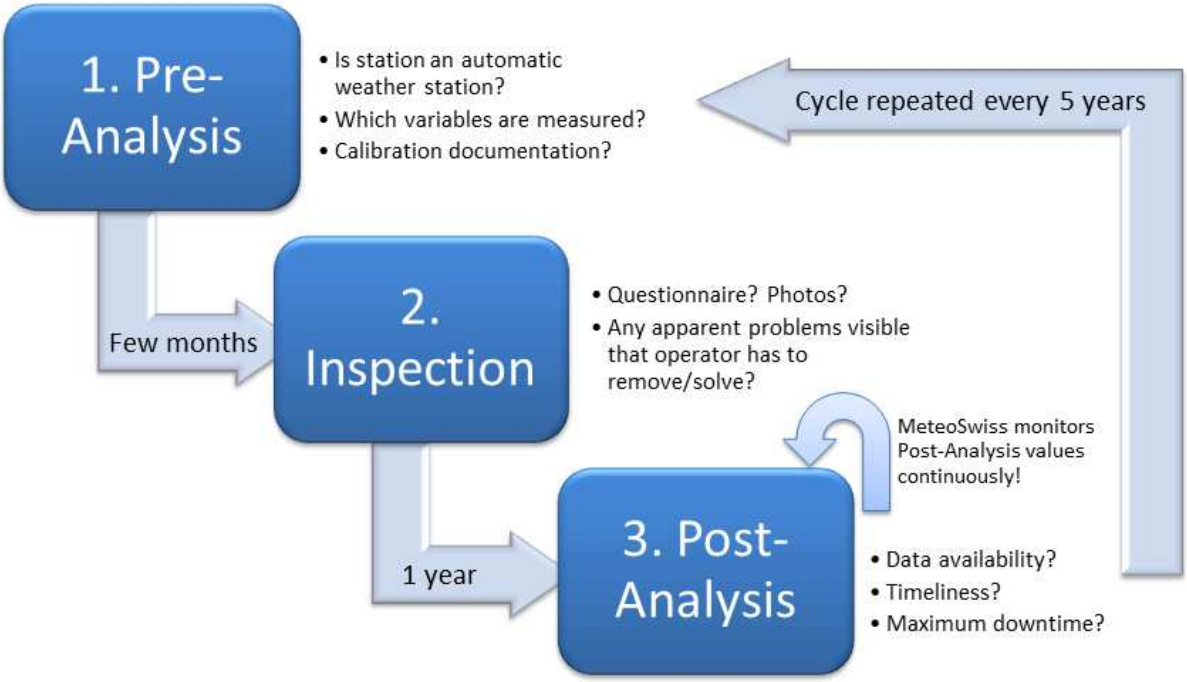

Figure 1. The classification procedure of METEO-Cert

The three main steps of METEO-Cert are:

1. Each inspection is preceded by a pre-analysis of the AWS (Step 1 in Figure 1). During this pre-analysis the operator (usually the station owner, see Glossary for details) provides basic metadata information like lists of installed instruments, measured meteorological variables, map/coordinates, station history etc. The inspector determines if the station meets the basic requirements to be certified and requests calibration certificates of the instruments (if available).
2. The second step is the inspection and it should be carried out every five years in line with recommendations of the CIMO Guide (WMO, 2014, Part I, 1). At the inspection the questionnaire is filled out, metadata about the visit are collected (who visited the station and when) and pictures of the AWS, as well as of the instruments, are taken.
3. For step 3, the post-analysis procedure, it is necessary to have at least one year of data to be able to evaluate if the requirements for data availability and timeliness are met. These values can already be calculated by the operator at the time of the site inspection, if the AWS has been in operation for at least one year.

The METEO-Cert tool has been developed in Microsoft Excel. An interactive questionnaire with pulldown menus guides the inspector through the process and makes sure that only valid values are entered into the questionnaire. The assessment of the criteria and the overall results are calculated directly by the tool when filling out the questionnaire. An example is shown in Figure 2, where the blue part is filled out by the inspector, the colour code to the right shows the assessment of the criteria, while the red text on the top of middle column represents the overall

assessment for the meteorological variable. An example of a full report written by METAS is provided in the Appendix.

Precipitation	Fully Compliant	
Sensor	Lambrecht: 1518 H3	
Is instrument designed to work under snow and hail conditions?	Yes	2
Is instrument heating site-appropriate?	Yes	2
Is instrument based on tipping-gauge pricinple?	Yes	
Accuracy [%]	2%	2
Collector size	200 mm2	2
Measurement height	1.5 m	2
Is the sensor correctly exposed?	Yes	2
CIMO Siting Classification	1	2
Is the instrument on a roof?	No	2
Station supervision [points]	7	2
Frequency of calibration in lab or replacement? [years]	5 years	2
Frequency of comparison measurements or controls on site by op	24 months	1
Frequency of maintenance by Keeper? [week]	2 weeks	2
Is there a parallel measurement with a second instrument?	No	0
Is there automatic data control or monitoring?	Yes	2
Post-Analysis: Data availability [%]	100.0%	2
Post-Analysis: Timeliness [min]	3.2 min	2

Figure 2. Example of the METEO-Cert questionnaire

In total, about 100 criteria per station, or around 20 criteria per meteorological variable are assessed. The overall result for a meteorological variable is defined by the lowest result of one criteria (with the exception of *station supervision*, see section 2.4.3). If for example a rain gauge is mounted on a roof, or mounted on a 5 m pole, then the variable "precipitation" of this station is considered "not compliant", even if it is a well maintained high quality instrument. Or, if a temperature sensor is located next to a large parking lot (e.g. CIMO Siting Class 4 or 5) it will always be labelled "not compliant", independently of the used instrument, the type of supervision or the data transmission rate. On the other hand, an instrument not reaching the CIMO operational measurement uncertainty requirements (see Table 1) will never be labelled "fully compliant", even if mounted on the most representative site at 2 m above grass.

3. RESULTS

The application of the METEO-Cert procedure is carried out by a third party organization in order to guarantee a neutral assessment. In Switzerland the inspections are conducted by METAS, which is responsible for national standards, primary and secondary calibrations, and quality control duties. For this study, 806 instruments were analyzed (Table 7).

Table 7. Number of instruments inspected by METAS (2013 – 2016)

Operator	2013	2014	2015	2016	*Total*
MeteoSwiss	101	149	184	156	*590*
Partner	90	102	22	2	*216*
Overall assessed instruments:					***806***

3.1. Instruments

As expected, all of the assessed instruments were built for outdoor use. One from a national weather service can expect that, but when it comes to partner stations it is reassuring to see that without exception, all used instruments are built for meteorological use. When it comes to the measurement uncertainty of the instruments, there is a difference between MeteoSwiss and partner stations (see Figure 3). MeteoSwiss uses, with one exception, only instruments that are fully compliant with the CIMO Guide's recommended operational measurement uncertainties (WMO, 2014, Part I, 1, annex 1.E).

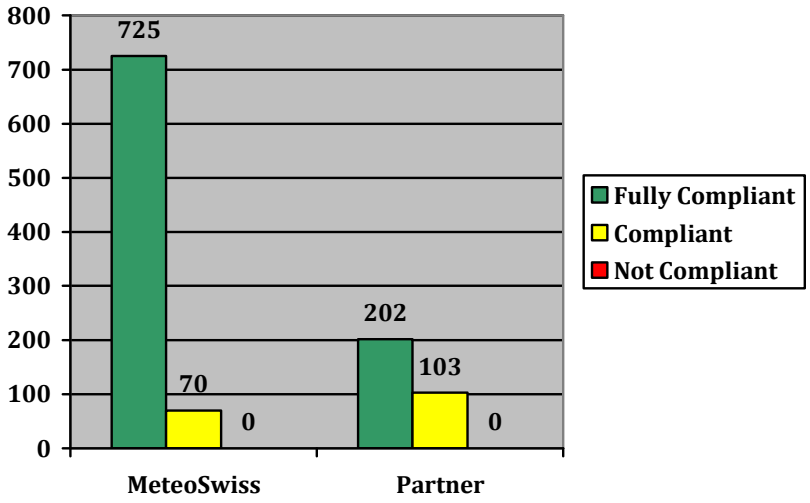

Figure 3. Measurement uncertainty criteria for MeteoSwiss and partner instruments

The only exception is the SPN1 Sunshine Pyranometer, by Delta-T Devices, with an operational measurement uncertainty of 5 % instead of the recommended 2 %. The SPN1 is used to measure global radiation and sunshine duration on some new stations, that were built for meteorology and warning purposes. On the other hand, the MeteoSwiss network consists of many high quality radiation stations that are part of the National (Swiss) and the Regional Basic Climatological Network (NBCN and RBCN, respectively), the Swiss Alpine Climate Radiation Monitoring (SACRaM) and part of the international Baseline Surface Radiation Network (BSRN). BSRN is the global baseline monitoring network for monitoring radiation fluxes at the Earth's surface.

Partner stations on the other hand show that around one third of the used instruments do not follow the uncertainty recommendations of the CIMO Guide. This is mostly due to the use of Davis Vantage Pro2 (see Figure 5) or similar "all-in-one" weather stations by private operators. The reason is that the intended measurement purpose of those private operator networks does not lie in the field of climatology. This means that for those partners there is no motivation to follow the strict recommendations of the CIMO Guide, achievable only by using expensive high quality instruments. Using less expensive instruments, which are still compliant to applications in meteorology and warnings, allows private operators to maintain a dense station network at lower costs. As long as the end-user of the data is aware of its limitation, there are no objections against this strategy.

A closer look at "fully compliant" partner instruments shows that many Swiss cantons use the same (Lambrecht and Ott) rain gauges as MeteoSwiss for their hydrological station network. The data of those stations are therefore comparable to the MeteoSwiss data and climatologists at MeteoSwiss have also started to use partner stations operated by cantons in their studies, in the last few years. This was one of the findings of the METEO-Cert inspections that led to a higher density of meteorological data in the MeteoSwiss DWH at lower costs. A list of those stations can be found in (Kube, et al., 2016, annex A).

The use of ventilation and heating, a criterion assessed for all meteorological variables except pressure (Figure 4), shows that there is an even clearer distinction between MeteoSwiss and partner instruments. MeteoSwiss uses only instruments that are ventilated and heated in order to ensure accurate measurements both during hot summer days, and cold, snowy winter days.

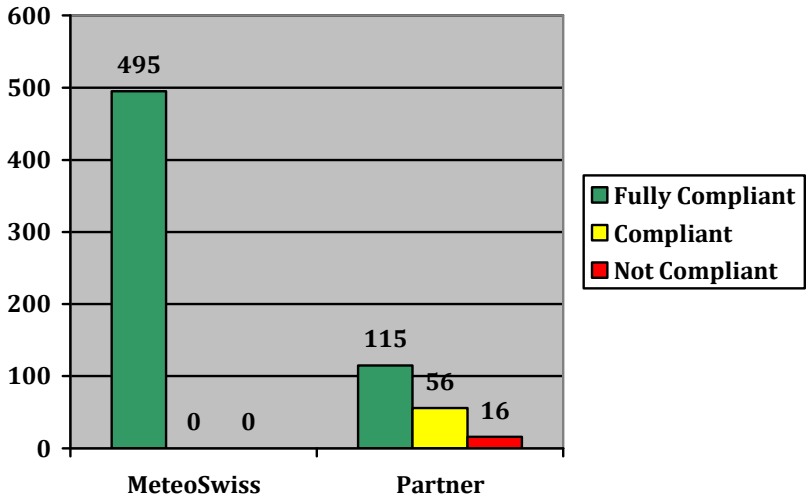

Figure 4. Heating/Ventilation criteria for MeteoSwiss and partner instruments

Partners often use compact *all-in-one* weather stations that are not ventilated and where only the rain gauge is heated. Furthermore heating is usually not available on solar powered partner stations because the high energy consumption of such instruments cannot be satisfied by a solar panel (for examples see Figure 5). For mountain stations the lack of heating is not compliant according to the CIMO Guide, since their correct operation in winter cannot be guaranteed. This is the case for 16 partner instruments measuring either global radiation or wind. For 56 instruments mounted on regular stations the missing heating leads to the label "compliant". All the other 115 partner instruments do offer satisfying ventilation or heating and are therefore "fully compliant".

Figure 5. Examples of non-heated partner stations. From left to right: tipping bucket rain gauge in Bercher (Canton of Vaud), solar powered station in Nollen (Canton of Thurgau) and non-heated wind gauge in the mountain village of Juf (Private partner).

3.2. Siting and exposure

Measurement heights for temperature, wind and precipitation should be built according to the CIMO Guide recommendations (if maximum snow heights allows it) listed in Table 3. Tower stations are considered "not compliant" in most cases since they don't use standard heights for measuring wind or temperature. Those instruments (such as the wind gauge of the MeteoSwiss station PSI Würenlingen, placed on a 70-m tower as shown in Figure 7) have been mounted on a tower for a specific purpose and therefore were never intended to be fully compliant with CIMO measurement height regulations.

The results show that MeteoSwiss is measuring both temperature and rain (with the exception of some high altitude stations shown in Figure 8) on the recommended measurement heights. For wind measurements, the recommendation from the CIMO guide is to measure at 10 m above the mean roughness of the terrain. Since MeteoSwiss mostly measures at 10 m above ground, even in more urban areas with a high roughness, some of the instruments were only labelled "compliant" or even "not compliant" due to the higher measurement uncertainty (see (Fisler and Kube, 2015) for details on how uncertainty, based on measurement height and terrain roughness, was calculated). But defining the thresholds for the wind measurement heights has been and still is a heavily debated issue, so those results should be interpreted with caution.

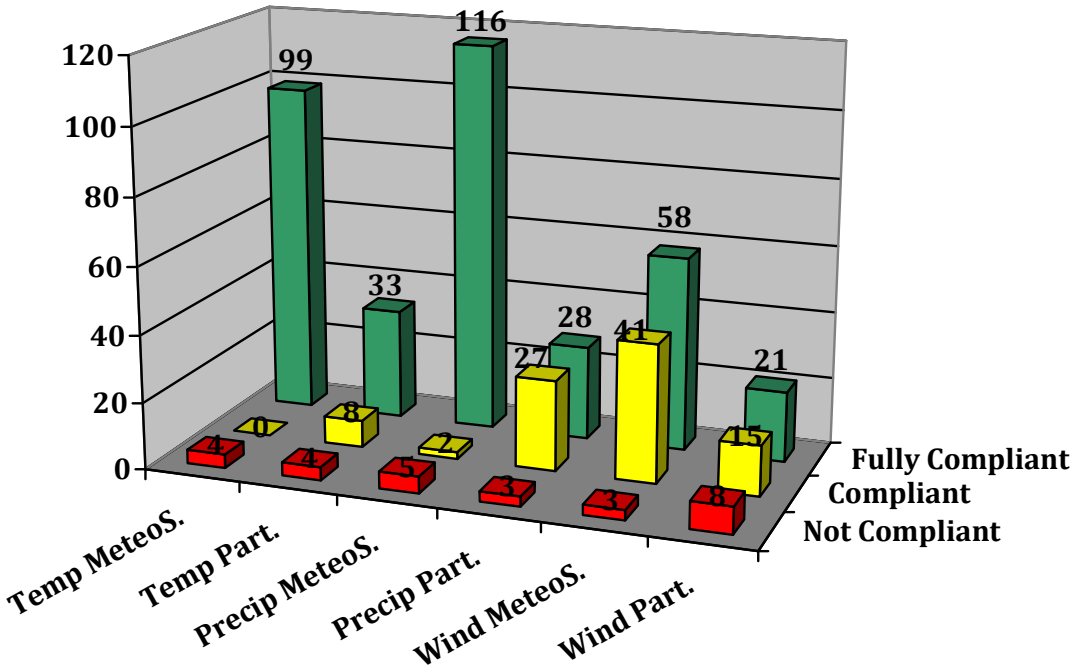

Figure 6. Measurement height compliances for temperature, precipitation and wind, for both, MeteoSwiss and partner stations

In total about 85 % of all MeteoSwiss instrument are fully compliant with CIMO's measurement height regulations and only 15 % are either compliant or not compliant. All of those cases have a specific reason why they deviate from the standard, either external factors such as expectant snow heights, or because the station was not built for climatology (e.g. tower stations).

Figure 7. Examples of "not compliant" measurement heights: the rain gauge of the Lugano station on a large roof (left), and the wind gauge of the PSI Würenlingen station at 70 m tower (right).

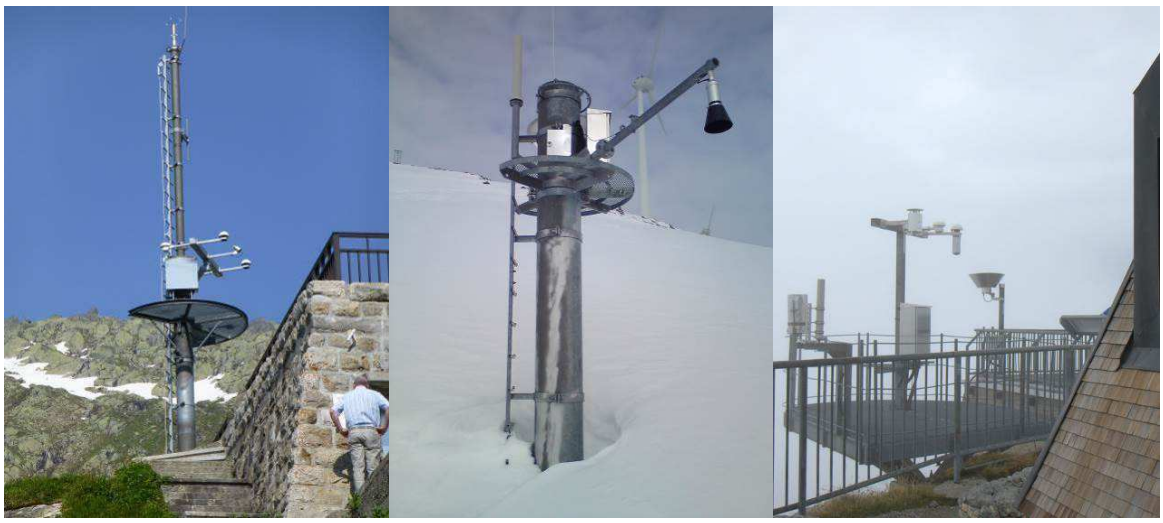

Figure 8. Examples of MeteoSwiss high altitude stations, from left to right: Grimsel, Gütsch, Säntis

In comparison, only 55 % of the partner instruments follow strictly the measurement heights recommended by the WMO. Around 35 % of the instruments are labelled "compliant" (meaning that they more or less follow the recommended heights) and 10 % of the instruments do not follow the recommendations at all and are labelled "not compliant". Based on these results, some partners have started to adjust their measurement heights and thus, in further inspections these problems might not be visible anymore. Examples can be seen in Figure 9, but for more details about the improvements done by partners based on the METEO-Cert reports refer to the chapter 4.

Figure 9. Examples of partner stations which at measurement heights have been adjusted after the findings of the METEO-Cert (from left to right: Marthalen, Schwyz and Sax)

METEO-Cert uses the CIMO Siting Classification to assess if an instrument has been placed at a site, which is representative for the measured meteorological variable. According to this

classification, 70 % of MeteoSwiss instruments are in class 1 and 2 ("fully compliant") whereas less than 40 % of the partner instruments are in these classes. On the other hand MeteoSwiss has about 15 % of "not compliant" sites (class 4 and 5, such as high altitude stations built on special sites) whereas nearly 40 % of the partner sites are class 4 and 5 and thus "not compliant".

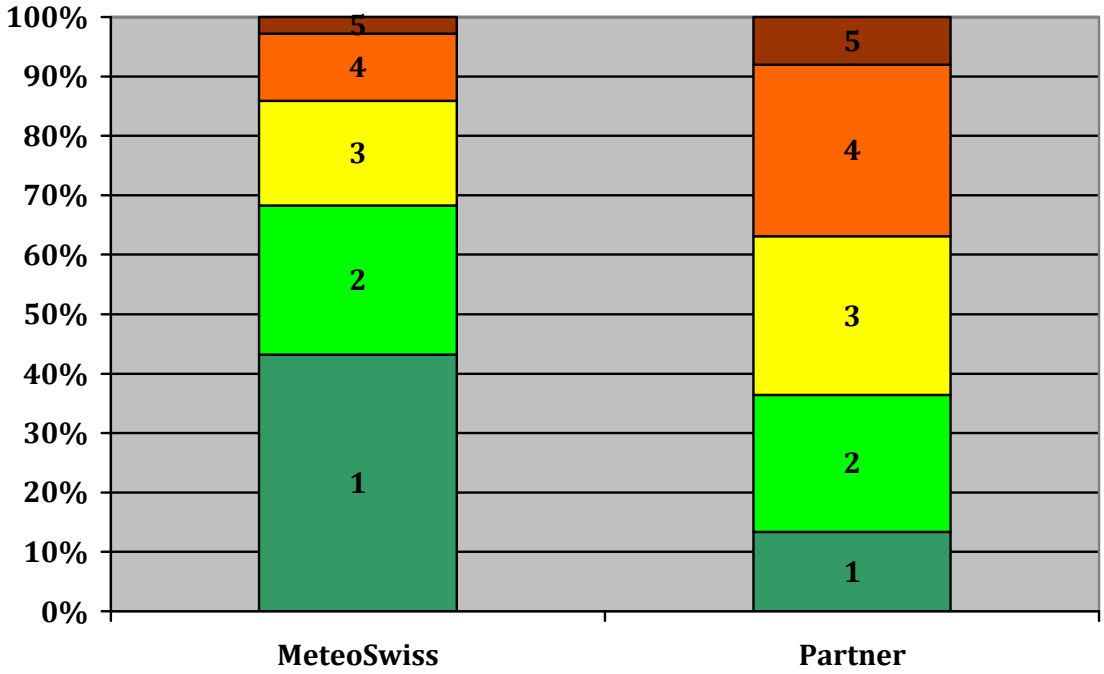

Figure 10. A relative comparison of CIMO siting classes for temperature (1), wind (2), precipitation (3), radiation (4) and sunshine duration (5). Left: MeteoSwiss stations (495 instruments), right: partner stations (187 instruments).

These results show that optimizing measurement sites and looking for sites with a lower Siting Class is the most effective action for augmenting the METEO-Cert quality label of both, MeteoSwiss and partner stations. For an interpretation of the results please see chapter 4.

Figure 11. Examples of MeteoSwiss stations: CIMO siting class 1 (Berne, left), and class 2 (Elm, right). Both stations are considered as "Fully Compliant" in METEO-Cert for temperature and humidity.

Figure 12. Examples of MeteoSwiss stations: CIMO siting Class 4 (PSI Würenlingen, left) and Class 5 (Luzern, right). Both stations are considered as "Not Compliant" for temperature and humidity, due to shading.

Figure 13. The partner station of Zernez, a former location (left) and a new location(right), after the publication of the METEO-Cert

Besides choosing a good site there is also the correct exposure which will determine if a measurement is representative or not (see METEO-Cert manual for more details about the *correct exposure*). Results show that 99.7 % of MeteoSwiss instruments and 96 % of partner instruments are correctly exposed and thus fully compliant with CIMO standards concerning exposure. Some examples of *not correctly exposed* instruments are shown in Figure 14. Luckily, the operator of those partner stations helped eliminating those shortcomings after the publication of the METEO-Cert results, and in a next inspection those stations could receive a higher quality label.

Figure 14. Examples of partners' (top) and Meteoswiss' (bottom) instruments considered as *not correctly exposed*: the rain gauge opening was blocked (top left), the thermometer was installed on a copper roof (top middle), the wind gauge was too close to a chimney (top right), wind sensor too close to lamp (bottom left), temperature sensor too close to house (bottom right).

3.3. Station supervision

Both partner and MeteoSwiss' stations are investing time and money in the maintenance of their networks. This is reflected in the results. In the case of MeteoSwiss, 580 out of the total 590 instruments show best results for station supervision. The remaining 10 instruments are mostly radiation instruments mounted on roofs or towers where the warden does not have access to clean the instrument every two weeks (for example, the radiation instruments at PSI Würenlingen station shown in Figure 7).

About two thirds of the partner stations show results that are "fully compliant" and one third is "compliant". Those instruments are mainly low quality stations which cannot be calibrated and thus fail with this criterion.

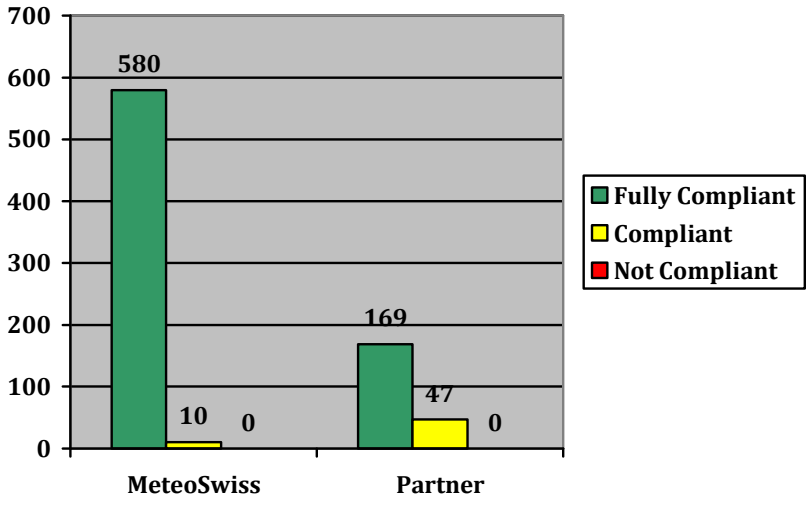

Figure 15. Station supervision results for MeteoSwiss' and partner instruments

3.4. Post-Analysis: Data Availability and Timeliness

In order to assess data availability METEO-Cert analyzes one year of ten minute data and ranks the results as "fully compliant" if 96 % of the values are available, and as "compliant" if at least 80 % of the values of a measured meteorological variable like temperature or precipitation are available. MeteoSwiss tries to operate within these boundaries and repair defect instruments as fast as possible. Therefore nearly all variables measured by MeteoSwiss are "fully compliant" in respect to this criterion (mostly showing data availability rates of over 99 %). The five cases labelled "compliant" (Figure 16) were caused by instruments which had longer repair cycles due to restricted access of these stations. Their data availability ranged between 92 % and 95.9 %.

Also the partner stations show very satisfying data availability rates and thus in 181 cases instruments got the label "fully compliant" (Figure 16). Most of the 22 cases labelled "compliant" are rain or wind gauges, instruments that are typically more affected by harsh environmental conditions and prone to malfunction. The six cases rated "not compliant" are all meteorological variables measured by a partner station in a remote mountain village in the southern part of Switzerland. The communication network is very weak, data transmission rate is around 50% and therefore all six meteorological variables measured at the station are labelled "not compliant" in respect to the "data availability" criteria.

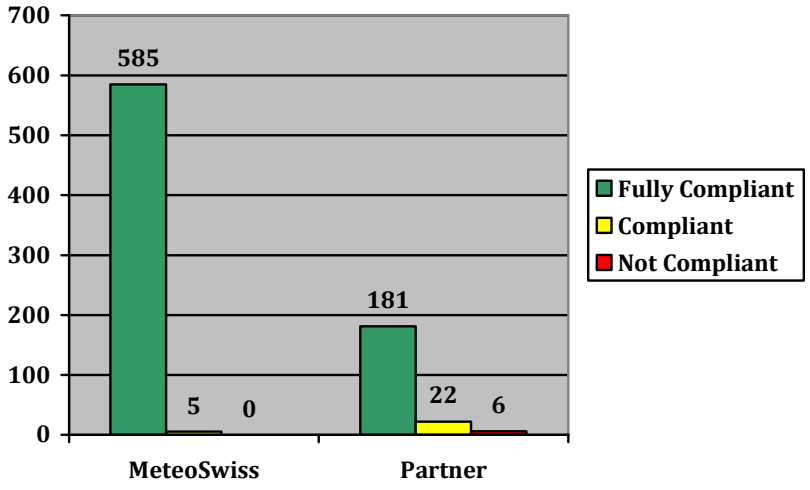

Figure 16. Data availability (the completeness of the data delivery over one year)

Timeliness does not seem to be an issue for both MeteoSwiss' and partner stations. MeteoSwiss' stations are within the defined thresholds, most measured meteorological variables exceeding those thresholds by far with a data delivery time of 2-4 minutes. Partner stations are also "fully compliant" in most cases, with the exception of certain cantons that, for budget reasons, have a defined data delivery time of one hour. As data delivery costs of mobile networks drop, it is expected that all partner station will operate in a ten minute delivery mode, soon.

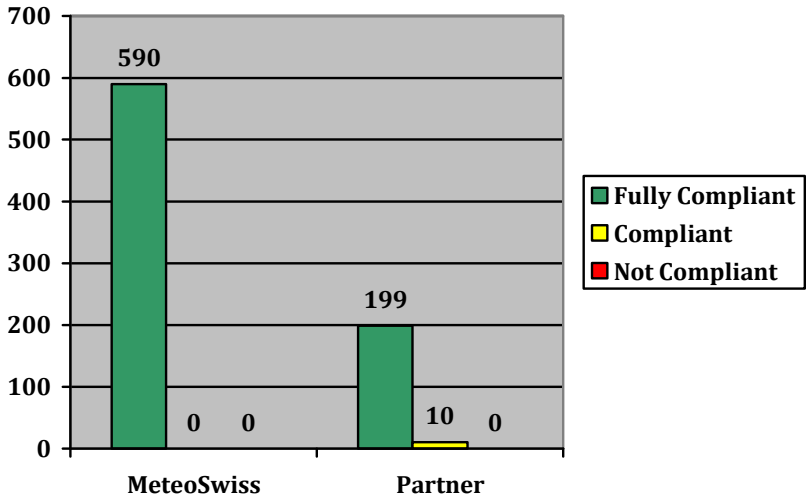

Figure 17. Timeliness results (how fast the data are delivered to the client)

3.5. Overall results

In total two thirds of the assessed instruments are operated by MeteoSwiss and one third by both private or public partners such as cantons or national institutions (Table 7). The overall assessment shows satisfying results for MeteoSwiss, whereas partner stations show some room for improvement, especially when it comes to the stations siting. This is certainly due to the fact that MeteoSwiss, as the NMHS of Switzerland and member of WMO, needs to comply with WMO

regulations, whereas partners do not have this obligation. On the other hand, private partners often have other constraints or requirements set by their customers (e.g. budget, placement, etc.) which they need to comply with.

About 70 % of the assessed MeteoSwiss' instruments are fully compliant with the WMO regulations for climate use (Figure 18). Nearly 25 % of the instruments fall within the category "compliant", meaning that they comply with most of the WMO regulations. About half of those instruments are radiation and sunshine duration sensors, which do not reach the operational measurement uncertainty limit set by the CIMO guide. This instrument has been chosen for budget reasons. They measure both radiation and sunshine duration in one instrument. In addition, they are cheaper and require less maintenance than similar instruments. But, as discussed in section 3.1, MeteoSwiss also has high quality radiation stations that are part of the international Baseline Surface Radiation Network (BSRN) or the Regional National Basic Climatological Network (RBCN). The other half of the instruments labelled "compliant" are set up in a location with CIMO siting class of 3 (or 4 at a mountain station). The siting is also responsible for ranking the remaining 5 % of the instruments as "not compliant", making this criterion the most important for the MeteoSwiss' stations when it comes to future improvements of their SwissMetNet network.

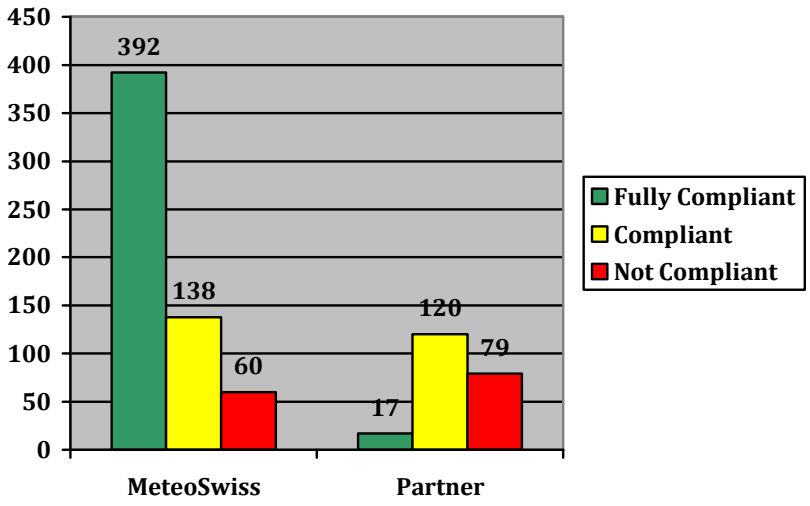

Figure 18. Overall results for MeteoSwiss and partner stations.

Only 7 % partner instruments were labelled "fully compliant". These are mainly partner stations equipped with higher quality instruments of the Thies company, used throughout Switzerland at important locations. When looking at this *poor* result, it has to be kept in mind that most partner stations are not aimed at climatology and thus the chosen instrument, site or supervision will never be fully compliant with all the WMO regulations. Nevertheless, the label "compliant" should be reached when using the data of an instrument for meteorology and nowcasting.

Most of the assessed partner stations use lower quality instrument built for nowcasting. Due to their lower accuracy (Operational measurement uncertainty class C, according to Table 1) they cannot be "fully compliant". This mainly explains why more than a half of the partner instruments (56 %) are assessed as "compliant". No improvement in their rating is possible as long as this instrument is used. But within this class there are 10 high quality rain gauges mounted at representatives sites that could reach the label "fully compliant" if the operator (mostly cantons) would increase the transmission rate to real-time data delivery. This is not done by those

institutions for budget reasons. But all of them have the option to switch to real-time data delivery when severe weather conditions are forecasted.

The remaining 37 % of the partner instruments were assessed as “not compliant” due to the following reasons (sometimes in combination):

- Poor CIMO Siting Class (52x);
- Lack of heating at mountain stations (16x);
- Measurement height not in accordance with WMO regulations (15x);
- Low data availability due to unstable mobile communication network (6x).

A closer look at these stations shows that the vast majority has been setup in private gardens or on rooftops. Thus the stations are often surrounded by obstacles and do not measure at standard heights, which could potentially influence the measurement. Furthermore, some compact weather stations do not offer a heating for every instrument. This can be problematic, for example for wind measurements in mountainous environment. Another problem with some *all-in-one* weather stations is that it is not possible to adjust the measurement heights of the sensors individually. In some cases the rain gauge is built on top of the temperature sensor and therefore, the operator has to choose if the temperature measurement should be done at 2 m or the top of the rain gauge should be placed at 1.5 m. Being “fully compliant” for both sensors will never be possible.

4. DISCUSSION

During the last six years MeteoSwiss has developed and implemented a quality control procedure for automatic weather stations called METEO-Cert. Since then, the procedure has been producing meaningful and useful results for both MeteoSwiss and its partners. The Swiss Federal Institute of Metrology METAS, being responsible for the inspections at the weather stations, has confirmed the objectiveness and applicability of METEO-Cert. Since 2015, METAS has been accredited by the Swiss Accreditation Service for their application of the METEO-Cert procedure (SAS, 2015) based on ISO/IEC 17020. The main challenges when creating and implementing METEO-Cert were:

- Criteria: What are the criteria that influence the uncertainty of a measurement on a weather station?
- Objectiveness: Can a criteria be recorded or measured in an objective way by the person doing the assessment?
- Rating: What are the thresholds for each criteria and how should they be weighted for the overall result of a variable?
- Inspector: Who will conduct the assessment? What are the requirements in order to be accredited as an inspector?

Most of the criteria (operational measurement uncertainty, measurement height, etc.) and their acceptable thresholds were found in the CIMO Guide (WMO, 2014). There were also criteria which were described in a more general, non-measurable way, such as "regular maintenance and calibration is needed". After many discussions with both the MeteoSwiss' and partner staff all the criteria concerning maintenance and calibration were defined in a clear and objective way summarized in section 2.4.3. Other challenges were the adaptations of the CIMO guide that had to be made due to special regulations in Switzerland or for historic reasons. These are summarized and explained in section 2.5.

Another challenge encountered during the implementation of the procedure was the changing inspectors due to changes in the METAS staff. Even though the criteria are as objective as possible, there will always remain some ambiguity when assessing a CIMO siting class or the roughness of a terrain. Also the way the questionnaire (Figure 2) was filled out was not always consistent. As a result, the questionnaire was enriched with pulldown-menus and some other improvements of the tool were implemented in order to prevent faulty reports. To address the problem of new METAS staff each new inspector has now to make their first three station visits with an experienced METAS inspector and a MeteoSwiss expert, in order to make sure that the METEO-Cert procedure is applied in a consistent way.

Every year, since 2013, the latest certification results are analyzed with the station maintenance teams of both, MeteoSwiss and partner networks. Especially the meteorological variables of stations which are "not compliant" are reviewed and possible improvements are discussed with the operator. As a result of this process, about 20 % of partner stations have been improved using one of the following measures:

- Adjusting measurement heights (mostly wind sensors);
- Relocating the station or removing of obstacles (e.g. trees) leading to a more representative CIMO siting class;
- Adding heating systems (especially for rain gauges);
- Switching to real-time data transmission.

Together with some minor improvements on MeteoSwiss' stations, it can be stated that with the help of METEO-Cert around 10 % of the assessed stations have been improved.

When looking at the "not compliant" MeteoSwiss' stations (as shown in the previous chapter, a reason for that are higher CIMO siting classes) it has to be kept in mind that MeteoSwiss usually builds stations in flat and open areas mostly dominated by agricultural land. Having a contract with the landowner for at least 30 years, ensures stable conditions around the station. Nevertheless, both trees and agglomerations are growing and agricultural land is converted into

residential area. Stations once built in sites with a CIMO siting class 1 or 2 can be reclassified into siting class 3 or 4. In some examples MeteoSwiss aimed at better locations to build their SwissMetNet stations, but did not receive the construction permit by the local authorities and had to remain at the original location. Other stations were built on specific sites such as nuclear power plants (for example PSI Würenlingen shown in Figure 7) or airports, fulfilling a particular purpose and not having climatology as a primary focus. Thus surrounding (cooling) towers or concrete areas influencing wind or temperature measurements were accepted when choosing the location.

There are also the mountain stations such as Säntis, Gütsch or Grimsel, which due to their high altitude terrain and extreme snow heights in winter will never achieve a requirement of "2 m above grass" (Siting Class 1 for temperature measurement as recommended in the CIMO Guide). This shows the limits of the labelling. In order to address this problem, in 2017 METEO-Cert will be adapted in such a way that high altitude stations (which will be called "alpine stations") will accept measurement heights of up to 6 m. Other changes for high altitude stations are planned for 2017 and will hopefully lead to more meaningful results for these special sites. But even if the method does have certain limitations for high altitude stations, the METEO-Cert results offer important metadata to clients when using the data of these stations.

Also, a still ongoing discussion is on how to publish the detailed results of METEO-Cert. In a first step a condensed summary is published in the MeteoSwiss App and on the website for most meteorological variables labelled "Not Compliant". For example, the two cases presented in Figure 7 led to a comment about the PSI Würenlingen station, "Wind measurement on exposed site on a tower 70 m above ground" (Figure 19), and another comment about the special siting of the Lugano station. These comments are easily comprehensible by the audience of the app, and experts working with, for example wind speed, are aware of the limitations when using the data of the PSI Würenlingen station.

In a second step, it is planned to publish the detailed METEO-Cert results on the MeteoSwiss website, including exact instrument types, CIMO siting classes for every meteorological variable, measurement heights, etc. A good example of how this could be achieved can be seen on the station metadata files (*fiche de poste*) of the MeteoFrance open data website (http://donneespubliques.meteofrance.fr). MeteoFrance publishes CIMO siting classes including remarks on nearby obstacles, terrain roughness, measurement heights, instrument types, etc., for every station of their network.

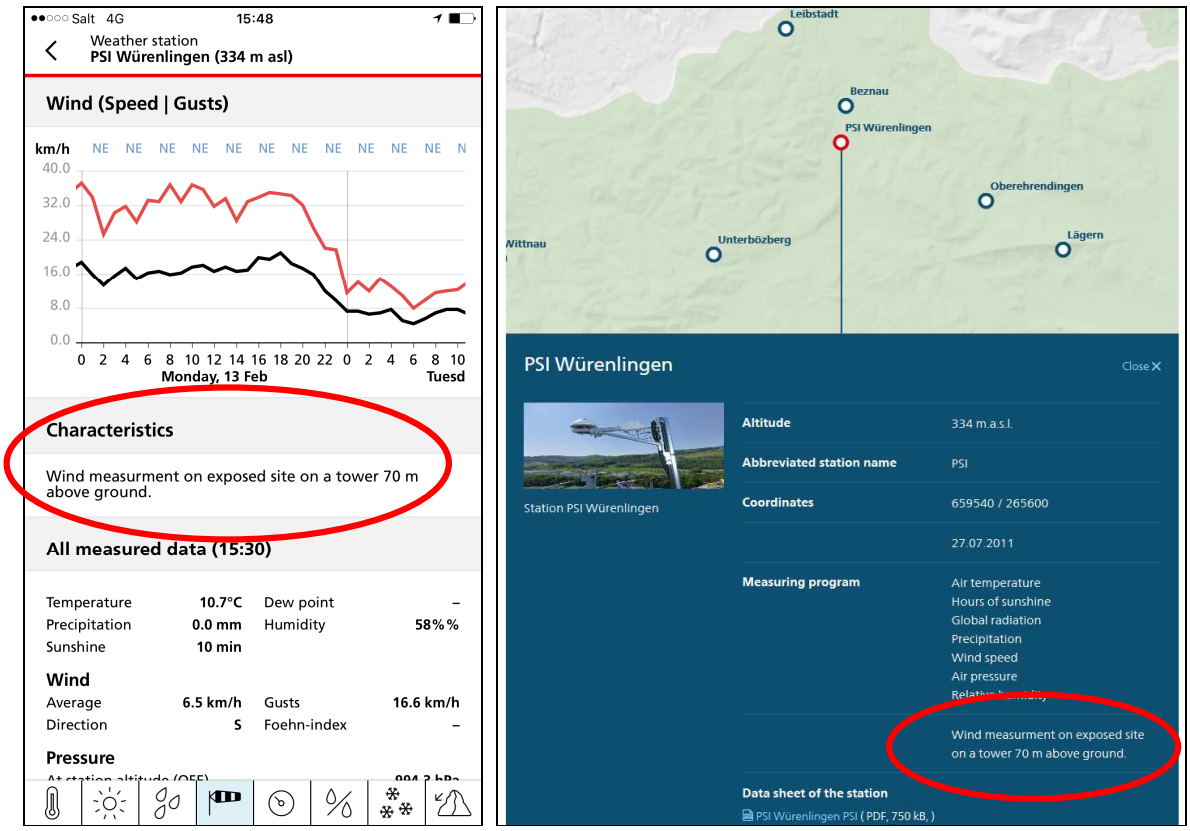

Figure 19. A view of the PSI Würenlingen station in the MeteoSwiss App (left) and on the website (right). Comments on tower wind measurement are circled in red.

5. CONCLUSION

The METEO-Cert results for the period from 2013 to 2016, lead to following conclusions:

- Deficiencies become visible and improvements can be made to both, the SwissMetNet and partner stations, in order to be "fully compliant". Those improvements, discussed in yearly workshops with the operators, can even lead to relocating a station.
- Operators of weather stations (such as maintenance staff) have become more sensible to quality issues related to nearby obstacles, measurement heights, station supervision and other criteria assessed in the METEO-Cert procedure, which can have an effect on the uncertainty of the measurement data.
- METEO-Cert provides an objective decision tool when it comes to the question of integrating an existing partner station, instead of building a new station at a given location in order to reduce costs (assuming that integrating a partner station is cheaper than building a new station).
- METEO-Cert provides profound information (via metadata collected through METEO-Cert) about how the data can be applied in meteorological and climatological applications.
- Although having been developed for Switzerland, the procedure could easily be adapted for other weather services if required.

Currently a bit more than two third of the fully equipped MeteoSwiss AWSs have been assessed by METAS. The remaining stations will be assessed in 2017 and 2018. Further work and research after that period will have to be done in order to define the exact impacts and consequences that METEO-Cert results have on the operation of a weather station network. One consequence could be that stations which are part of WMO's Regional Basic Climatological Network (RBCN) or Centennial Observing Stations network must get the "fully compliant" label.

One of the findings from 2013-2016 period was that METEO-Cert, in many cases, does not deliver meaningful results for high altitude stations. In order to address this problem, in 2017 the concept of "alpine stations" was introduced for stations at elevations above 1800 m. This is a third station type next to the already existing regular stations (<1000 m) and mountain stations (>1000 m). Alpine stations will allow measurements on roofs or measurement heights up to 6 m (due to extreme snow heights) and will not require grass cover on the measurement sites if it is not representative for the region. Further studies will show if these improvements lead to more meaningful results for high altitude stations.

Another change for 2017 is that wind siting classes will be captured in eight geographic directions. This will allow to be more flexible when assessing the representativeness of a site for wind measurements. For example, stations in alpine valleys have sometimes high siting classes due to obstacles near the stations. But these obstacles were not in the main wind directions of the valley and thus not influencing the wind measurement. Nevertheless, the label "Not Compliant" for wind was given to this type of station, which does not reflect the reality adequately.

As a possible outlook for further development, it can be said that the procedure itself is flexible enough to be adapted for other national weather services. The adaptation for Switzerland presented in section 2.5 could easily be changed in order to comply with the requirements set by other operators of weather stations, or by a foreign government. Furthermore, the METEO-Cert report contains an extensive list of more than 300 instruments used worldwide, which is crucial when making inspections at stations outside of Switzerland.

Last but not least, the methodology can also be adapted in such a way that it is compliant with other standards and important regulations, such as those for aeronautic, road or agricultural meteorology. This could be done either by developing new criteria, or by adapting the thresholds for the existing criteria.

6. ACKNOWLEDGMENT

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Since 2013, we have also received a lot of support from METAS, the Swiss Federal Institute of Metrology. Thanks go to Gulian Couvreur for his patience and continued support while implementing the procedure and working on the details of the reports and the certificates.

Last but not least we are grateful for the trust and confidence that our superior Bertrand Calpini had in this work and for the support throughout the last years. It was also Bertrand Calpini who originally had the vision not only to integrate 3rd party networks at MeteoSwiss, but also to create a tool for assessing their quality.

7. GLOSSARY

- AWSs: Automatic Weather Stations
- BSRN: Baseline Surface Radiation Network
- DWH: Data Ware House
- GUM: Guide to the Expression of Uncertainty in Measurement
- Inspector: A neutral body (such as METAS) conducting the METEO-Cert inspections.
- Keeper: In general the landowner (such as farmer) or a person living close to the AWS responsible for cutting grass, cleaning the instruments every few weeks and for contacting the operator in case of visible defects and malfunctioning of the AWS.
- Manufacturer: Company producing meteorological instruments.
- METAS: Federal Institute of Metrology Switzerland (www.metas.ch)
- METEO-Cert: Quality assessment procedure for AWSs developed by MeteoSwiss
- Mountain stations: AWSs above 1000 m. Can be exposed to extreme cold and to extreme snow heights.
- NBCN: National Basic Climatological Network
- NMHS: National Meteorological and Hydrological Service
- Operator: Person or body responsible for running an AWS and for fixing and replacing instruments in case of failure. Usually the operator is also owner of the AWS but in certain cases the owner can mandate e.g. an engineering company to run an AWS network.
- OSCAR: Observing Systems Capability Analysis and Review Tool
- RBCN: Regional Basic Climatological Network
- Regular stations: AWSs below 1000 m, usually not exposed to extreme snow heights.
- RRR: Rolling Review of Requirements
- SACRaM: Swiss Alpine Climate Radiation Monitoring
- SwissMetNet: MeteoSwiss' surface observation station network
- WIGOS: WMO Integrated Global Observing System

8. REFERENCES

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9. APPENDIX: SAMPLE REPORT OF SWISSMETNET STATION PLAFFEIEN

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Institute of Metrology METAS
Conformity Evaluation Body METAS-Cert

Title	Report
Weather Station Inspection Report	**2015-12-02-342**
Author(s) **Hans Peter BACH**	Date 18 December 2015
Addressees MeteoSchweiz: Luca MODOLO MeteoSwiss: Joël FISLER METAS-Cert: Certification commission	Enclosure(s) Annex I: Pictures of the weather station Annex II: Inspection report

Summary

Assessment to verify the meeting of the requirements of

MeteoSwiss Acceptance Procedure for Automatic Weather Measuring Stations version 3.1.

by

the Conformity Evaluation Body METAS-Cert

under the scope of

Inspection of Automatic Weather Measuring Stations

Date(s) of the inspection

2 December 2015

Station code / Station name

PLF / Swiss Met Net: Plaffeien, PLF

Coordinates

586808 / 177400

at

Station SMN Planfayon
1716 Planfayon

Keeper

Rolan & CLAUDIA

Operator

MeteoSchweiz
Ch. de l'Aérologie
1530 Payerne
Switzerland

Conclusion

Based on this inspection, a classification of the Automatic Weather Measuring Station is possible.

Signature Certification Commission

SMN_PLAFFEIEN_2015-12-02-342_Def.docx / 18 December 2015 / Baha / MS-Ref. 6030.47F05_EN, V 1.5 1/11

2015-12-02-342

1 Introduction

The Automatic Weather Measuring Station was inspected by METAS-Cert according to the MeteoSwiss Acceptance Procedure for Automatic Weather Measuring Stations version 3.1.

1.1 List of participants

1.1.1 Keeper

Mr. Rolan & CLAUDIA

1.1.2 Assessor(s) (METAS-Cert)

Hans Peter BACH Scientific collaborator

1.2 Generalities

During the inspection, the station keeper was not present but could be contacted before the inspection.

2 Observations

The automatic weather station (T, RH, p, Wind, Precipitation, Radiation, Sunshine duration, Radioactriity, Snow hight, Ground temperature) is located on the top of a hill with a wide beautiful view and is surrounded from lawn fields. The next tree or forest is about 100 m from station. There are no buildings and no streets near the station.

3 Results

Temperature and Humidity	Fully Compliant
Pressure	Fully Compliant
Wind	Compliant
Precipitation	Fully Compliant
Radiation	Compliant
Sunshine duration	Compliant

Conformity Evaluation Body METAS-Cert
For the inspection

Hans Peter BACH

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Institute of Metrology METAS
Conformity Evaluation Body METAS-Cert

Appendix I : Pictures of the Automatic Weather Measuring Station

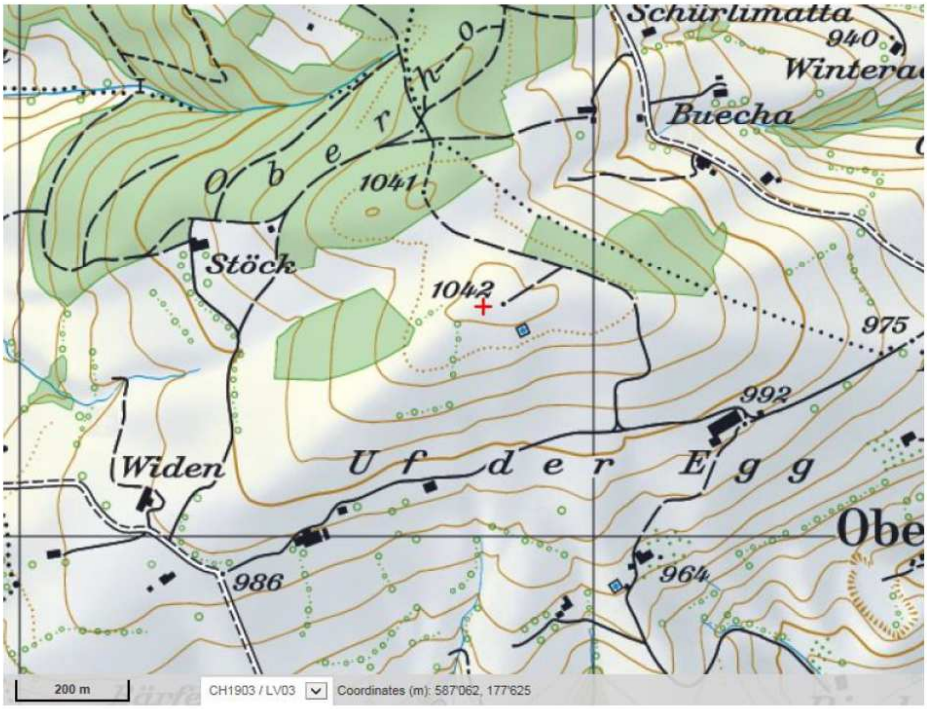

Figure 1 – Map

N E S W N

Figure 2 – 360° View

Figure 3 – 4 Directions (N – E – S – W)

Figure 4 – Global view of the station

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Figure 5 – Temperature and Humidity

Figure 6 - Pressure

Figure 7 – Wind

Figure 8 – Precipitation

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Figure 9 – Radiation and Sunshine duration

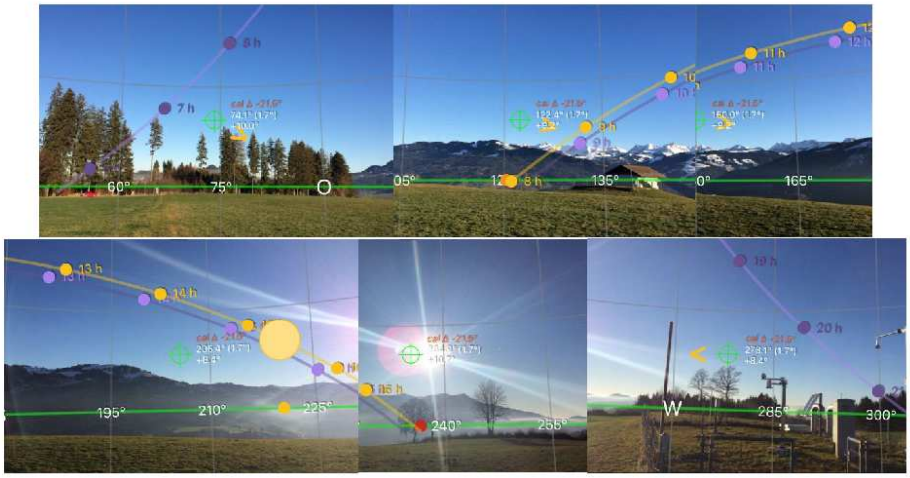

Figure 10 – Sun Positions

Non-assessed instruments

Figure 11 – Radioactivity

Figure 12 – Snow height

Figure 13 – Snow height: Lawn should be cute some times

Figure 14 – Ground temperature

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Appendix II: Inspection report

METEO-Cert Questionnaire (v 3.1)		Class
	Show Location on Map	
Information on the station and site		
Station name Select Station	Plaffeien	
Shortname	PLF	
Swiss Coordinates X	586808	
Swiss Coordinates Y	177400	
Altitude above sea level	1042 m	
Site category (regular lowland vs. mountain site)	Mountain	
Tower station?	No	
Site description	A / Height (30-100 m above valley)	
Station information changed? (Status-Info, not stored in DWH!)	No	
Station and/or keeper address (Status-Info, not stored in DWH!)	Station SMN Planfayon, 1716 Planfayon	
Audit on site		
Date of audit	02.12.2015	
Name of auditor	Hans Peter Bach	
Email of auditor	HansPeter.Bach@metas.ch	
Picture of each instrument taken?	Yes	
Picture of the surrounding taken?	Yes	
Automation details		
Does the station have automatic instruments?	Yes	2
Observing Cycle (Frequency of measurement) [time]	00:10:00	2
Transmission Interval [time]	00:10:00	2
Is data stored locally in case of communication interruption?	Yes	
Operator and AWS details		
Operator organziation/company ("owner" of AWS)	MeteoSchweiz	
Operator Department		
Name (Operator contact person)	Modolo	
Surname	Luca	
Address	e l'Aérologie, CP 316, 1530 Payerne, Switzerland	
Phone	026 662 63 00	
Mobile	079 793 33 20	
Email	csnat@meteoswiss.ch	
URL (of AWS or operator)	www.meteoschweiz.ch	
Does AWS have a Keeper? (if yes fill out address below)	Yes	
Keeper Organziation/Company		
Keeper name	Rolan & Claudia	
Keeper surname	Puerro	
Keeper phone	026 419 10 79	
Keeper mobile		
Keeper email		
Station history available?	No	
Is there public access to the AWS?	Yes	
Is the AWS protected again lightning strike?	Yes	

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Information about the installed instruments		
Temperature and Humidity	Fully Compliant	
Sensor	Meteolabor: ThyganVTP6	
Is the sensor correctly ventilated?	Yes	2
Is the sensor protected and weather-proof?	Yes	2
Accuracy of instrument at 20C	0.15 K	2
Accuracy of relative humidity instrument	**0.10%**	2
Measurement height	2.0 m	2
Is the sensor correctly exposed?	Yes	2
CIMO Siting Classification	1	2
Station supervision [points]	8	2
Frequency of calibration in lab or replacement? [years]	5 years	2
Frequency of comparison measurements or controls on site by op	24 months	2
Frequency of maintenance by Keeper? [week]	2 weeks	2
Is there a parallel measurement with a second instrument?	No	0
Is there automatic data control or monitoring?	Yes	2
Post-Analysis: Data availability [%]	**100.0%**	2
Post-Analysis: Timeliness [min]	3.2 min	2
Comments		
Pressure	Fully Compliant	
Sensor	Vaisala: PTB220 (Class A)	
Is the sensor protected and weather-proof?	Yes	2
Accuracy of instrument at 20 °C	0.15 hPa	2
Altitude of pressure sensor [m]	1042.0 m	
Accuracy of measurement altitude [cm]	10 cm	2
Is the sensor correctly exposed?	Yes	2
Station supervision [points]	4	2
Frequency of calibration in lab or replacement? [years]	5 years	1
Frequency of comparison measurements or controls on site by op	24 months	1
Is there a parallel measurement with a second instrument?	No	0
Is there automatic data control or monitoring?	Yes	2
Post-Analysis: Data availability [%]	**100.0%**	2
Post-Analysis: Timeliness [min]	3.2 min	2
Comments		

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Wind	Compliant	
Sensor	Lambrecht: 14512	
Accuracy of wind speed instrument [%]	**2%**	2
Accuracy of wind direction instrument [°]	3.6 °	2
Is instrument heating site-appropriate?	Yes	2
Does the sensor measure up to 180km/h?	Yes	2
Is the sensor correctly exposed?	Yes	2
Error dependent on roughness and measurement height	**18%**	1
Measurement height (from ground)	10.0 m	
Wind class according to Davenport	6	
CIMO Siting Classification	2	2
Station supervision [points]	7	2
Frequency of calibration in lab or replacement? [years]	5 years	2
Frequency of comparison measurements or controls on site by op	24 months	1
Frequency of maintenance by Keeper? [week]	2 weeks	2
Is there a parallel measurement with a second instrument?	No	0
Is there automatic data control or monitoring?	Yes	2
Post-Analysis: Data availability [%]	**100.0%**	2
Post-Analysis: Timeliness [min]	3.2 min	2
Comments		
Precipitation	Fully Compliant	
Sensor	Lambrecht: 1518 H3	
Is instrument designed to work under snow and hail conditions?	Yes	2
Is instrument heating site-appropriate?	Yes	2
Is instrument based on tipping-gauge pricinple?	Yes	
Accuracy [%]	**2%**	2
Collector size	200 mm2	2
Measurement height	1.5 m	2
Is the sensor correctly exposed?	Yes	2
CIMO Siting Classification	1	2
Is the instrument on a roof?	No	2
Station supervision [points]	7	2
Frequency of calibration in lab or replacement? [years]	5 years	2
Frequency of comparison measurements or controls on site by op	24 months	1
Frequency of maintenance by Keeper? [week]	2 weeks	2
Is there a parallel measurement with a second instrument?	No	0
Is there automatic data control or monitoring?	Yes	2
Post-Analysis: Data availability [%]	**100.0%**	2
Post-Analysis: Timeliness [min]	3.2 min	2
Comments		

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Radiation	Compliant	
Sensor	Delta-T Device: SPN1	
Measurement Principle	Pyranometer	
Are there means to ensure the glass dome is kept free?	Yes	2
Accuracy [%]	**5%**	1
Is the sensor levelled?	Yes	2
Is the sensor correctly exposed?	Yes	2
CIMO Siting Classification	2	2
Station supervision [points]	4	2
Frequency of calibration in lab or replacement? [years]	5 years	0
Frequency of maintenance by Keeper? [week]	2 weeks	2
Is there a parallel measurement with a second instrument?	No	0
Is there automatic data control or monitoring?	Yes	2
Post-Analysis: Data availability [%]	**100.0%**	2
Post-Analysis: Timeliness [min]	3.2 min	2
Comments		
Sunshine duration	Compliant	
Sensor	Delta-T Device: SPN1	
Are there means to ensure the glass dome is kept free?	Yes	2
Accuracy [%]	**5%**	1
Is the sensor levelled and correctly adjusted?	Yes	2
Is the sensor correctly exposed?	Yes	2
CIMO Siting Classification	4	1
Station supervision [points]	4	2
Frequency of calibration in lab or replacement? [years]	5 years	0
Frequency of maintenance by Keeper? [week]	2 weeks	2
Is there a parallel measurement with a second instrument?	No	0
Is there automatic data control or monitoring?	Yes	2
Post-Analysis: Data availability [%]	**100.0%**	2
Post-Analysis: Timeliness [min]	3.2 min	2
Comments	Forest in the sun path in a distance from about 200 m from station	