Quaderno di METEOROLOGIA APERTA N°3

GUIDE TO THE DESIGN, ENHANCEMENT, COMPLIANCE AND CERTIFICATION OF ON-SITE METEOROLOGICAL AND CLIMATOLOGICAL MONITORING STATIONS AND NETWORKS

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1. INTRODUCTION

Meteorology and climatology explore a world that is growing in terms of importance, due to its direct links with the economy, society, new technologies and the smart worlds (agriculture, environment, urban areas, energy, etc.) and due to a more general awareness of climate change.

This is encouraging people to pay more attention and be more sensitive to meteorological data, once considered purely in qualitative terms, but now subject to careful quantitative analysis. Insurance assessments on new policies, historical climatological analyses, regression analyses or re-analyses, environmental monitoring, the energy market, water management: numerous sectors make strategic and operational decisions based on meteorological triggers, which, thanks to the digital approach, are now becoming a rightfully integrated part of different and specific process segments.

When it comes to "legal meteorology®", which has an impact on contractual and legal issues, and is endowed with evidential value, this must provide even clearer, more precise and scientifically substantiated information.

Lastly, it must be considered that this great attention, which, for the moment, is limited to advanced and digital applications, is set to increasingly become the focus of social and political attention, which implies widespread critical analysis and the consequent need for sustainable and credible data.

This data is collected using a variety of technologies and sensors, among which the main role continues to be played by on-site monitoring systems, i.e.: ground-based weather stations and sensors. This publication aims to highlight how to design, build and manage these systems within a context of compliance and quality in order to provide data and datasets suitable for complex or evidential uses and to use them in meteorological matrices resulting from statistical and re-analytical processing.

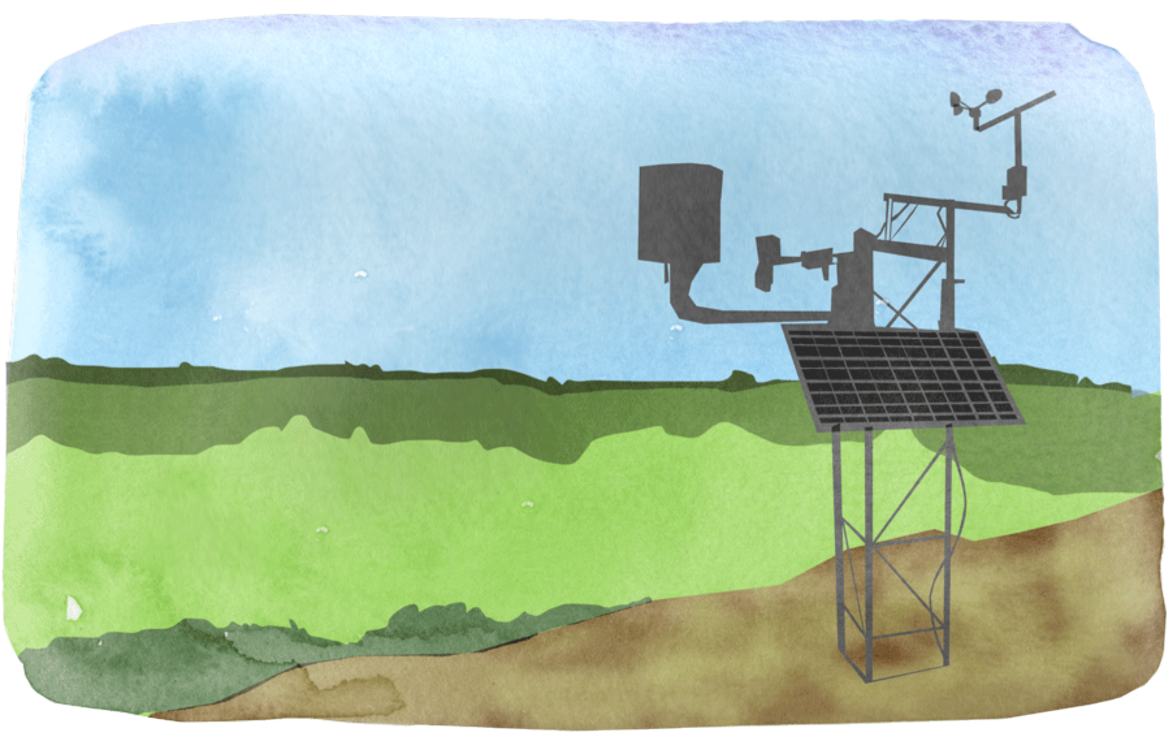

Fig. 1 On-site weather station

2. SCOPE

The construction of meteorological networks (*Fig. 1*) requires a significant commitment in terms of initial investment, management and maintenance, so it is reasonable to expect them to provide a high-quality observational base to support multiple potential uses. It has, however, been found that due to situations or problems that are sometimes easily overcome (suboptimal location of the station, lack of correct validation of the data, inadequacy of some sensors), these monitoring systems often produce data that has a limited capacity for representativeness[3] and is not suited to all applications. This is largely due to a lack of planning, or even no planning at all, when, for example, the decision is made to entrust the network supplier with the design phase, in the belief that this will reduce the costs of the project, or when the overall management of the network does not satisfy at least the basic principles of supervision required by WMO[4], sometimes merely due to inadequate knowledge of them.

First of all, monitoring networks require careful design, with the creation of a structure that meets specific technological and legislative needs, and also satisfies management and financial aspects. Where possible, and if necessary, they should be designed with a view to obtaining certification. Similarly, existing networks should be brought into line with the highest standards and optimised technologically and functionally to enhance their data and associated services. Where applicable, certification is the final stage in the process.

3. METEOROLOGICAL MONITORING SYSTEMS

3.1. THE OBSERVATION SET

The monitoring of meteorological parameters is carried out by monitoring systems, usually organised into networks of sensors and stations, using various technologies and with different characteristics and purposes. In addition to what we call on-site weather stations, a key role is played by radiosondes and remote sensors, such as satellites, radar, lightning detectors. For certain special applications, such as urban pollution, radio telescopy or airport meteorology, specific instruments such as radiometers, *sodars*, etc. are required.

It should be noted here that it is by merging information among these different families of observations that we obtain the best results in relation to knowledge of the state of the atmosphere and its evolution.

Each type of instrument undergoes its own certification process and is subject to different quality standards; with respect to this heterogeneity, we would like to specify that the document is dedicated to the implementation and certification of networks consisting of on-site stations and sensors.

3.2. ON-SITE SENSORS AND NETWORKS

Meteorological science began with on-site observations, which still form the longest and most important historical series of atmospheric knowledge available to us. Their importance has not changed over time but has actually increased. This is due to various factors: on one hand, the constant technological refinement of sensors and their performance; on the other, supplementation with data gathered from other sources, such as remote sensors (radar, satellites); and lastly, the importance acquired by on-site data in the application of new scientific methods, such as retrospective analysis or reanalysis.

Talking about ground-based meteorological networks today means moving within well-defined guidelines that are essential in the context of a global observation set, characterised by exchanges on various levels. First of all, networks must be defined on the basis of their purpose, which is used to identify their characteristics and levels of representativeness[4]. The mesoscale monitoring of major atmospheric phenomena, climatological trends, nowcasting, agri-meteorology or urban meteorology, have different requirements, so the type and distribution of sensors, the timing of data acquisition and validation, etc. will be different.
This diversity will produce different datasets. Of these datasets, those generated by meteorological monitoring networks compliant with WMO guidelines have access to advanced levels of processing, while the others have no or little access to such processing. This does not, however, mean that they are unable to fulfil the purpose for which they were created.

3.3. MARINE WEATHER OBSERVATIONS

Among special applications, considerable significance is held by marine weather observations (*Fig. 2*), due to the fact that meteorological data is of particular importance in that context. Observations at sea are used for:

- continuous monitoring of marine weather conditions in support of operational activities;
- immediate and precise feedback and verification of forecast information;
- collection of data for the elaboration of climatological studies and climatic characterisation of the area;
- preparing post-event investigations, including those of a technical-scientific or legal-administrative nature.

This is a sector characterised by distinct techniques and precautions, starting with the specificity of the parameters to be measured (wave motion, currents and visibility, in addition to the usual parameters), the sensors to be used, the material they are made of and their location.

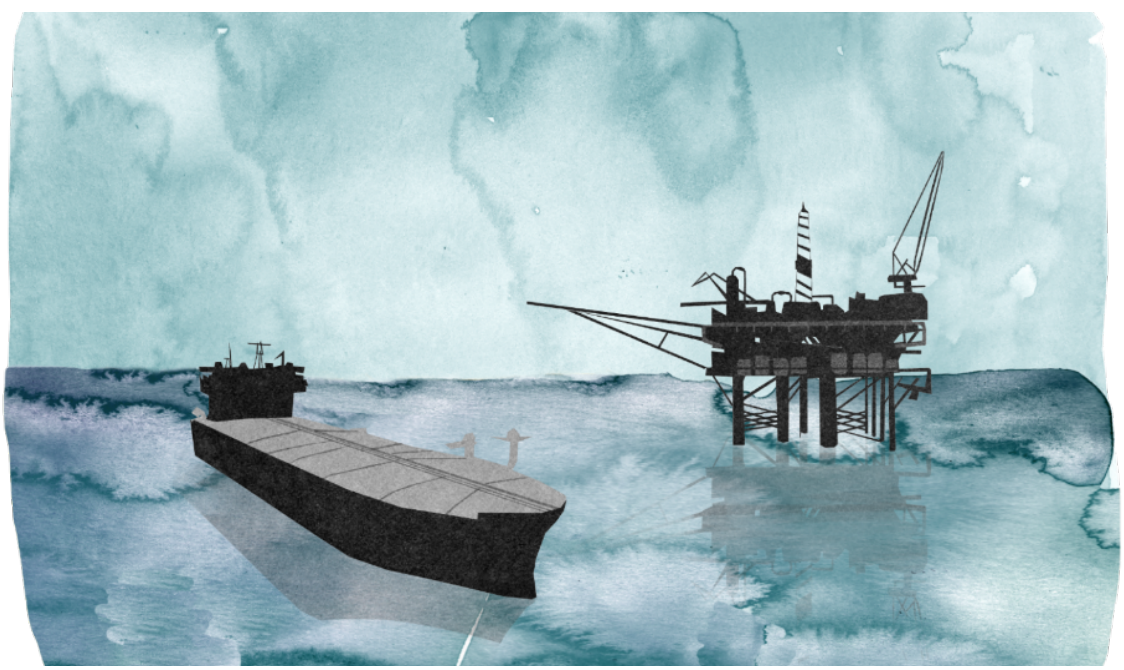

Fig. 2 Marine weather monitoring

3.4. VIRTUAL STATIONS

The considerable development of meteorological observations and the technological support of digital technology have made it possible to include atmospheric data in many decision-making and operational processes that require a high level of spatiotemporal detail. Applications of this kind can be supported by a network with representativeness guaranteed by a high quality standard, meaning that it is compliant and certified. In this context, the growing use of DSS (Decision Support Systems) in agriculture is worth mentioning. To reduce the impact and cost of crop treatments, farmers need specific meteorological data for the area in where they operate. A well-distributed network is capable of supporting and feed another, more detailed network of virtual stations with its own data (*Fig. 3*). It is possible to obtain data relating to each point throughout the territory, even in the absence of the station in that point, not using mere geo-statistical interpolation, but through meteorological reanalysis, i.e.: modelling the statistical-climatological parameters that determine the particular spatial distribution of the values of the meteorological variable of interest.

Fig. 3 The set of observations provides a basis for the creation of data grids using re-analysis

4. GENERAL PRINCIPLES

4.1. GUIDELINES, COMPLIANCE AND CERTIFICATION

The purpose of this publication is to provide clear and operational instructions for the creation or enhancement of an efficient monitoring system, made up of stations that detect meteorological variables through quality processes, compliant with WMO standards, producing adequate, sustainable data that can be shared. The aims are achieved by performing the following operations:

- analysis of the WMO guidelines in relation to the purpose and aims of the network;
- application of the WMO regulations suitable for the design of new networks or for enhancing the design of existing networks;

- verification and application of other necessary levels of standardisation or certification (particularly for electrical components);
- quality certification related to compliance with WMO standards; certification cannot be obtained for all types of networks as some, while being functional for the purpose for which they are built and used, are objectively unable to meet certain general conditions.

4.2. WMO STANDARD

The WMO is the UN technical agency which coordinates meteorology, climatology and operational hydrology for our entire planet. One of its missions is to promote the standardisation of meteorological measurements. This topic is defined in the "*Guide to Instruments and Methods of Observation*" WMO-No.8 – 2018, Vol. 1 "*Measurement of Meteorological Variables";* the document is also known as *CIMO*[5] *Guide* (WMO, 2018).
In short, the WMO defines the four criteria necessary to obtain high-quality measurements:

- use automatic weather stations;
- use high-quality sensors;
- install the sensors in suitable sites, well-exposed and at a correct height from the ground;
- guarantee a high standard of supervision (maintenance, inspection and calibration of sensors).

On that basis, a certain level of compliance is assigned to each individual sensor:

- **fully compliant**: all WMO requirements are met; high-quality sensor with the lowest possible uncertainty; can be used for both meteorological and climatological purposes;
- **compliant:** most WMO requirements are met; intermediate but acceptable uncertainty; can be used for meteorological purposes and in all kinds of operational applications (enabling DSS for the management of water resources, mitigation of flooding, agriculture, etc.);
- **non-compliant**: some important WMO requirements are not met; very high or unknown uncertainty, to be used with caution, unsuitable for numerous applications.

It is emphasised, once again, that, as meteorological data is collected for specific purposes, compliance is necessary for certain applications, e.g.: in evidential, insurance, contractual and general meteorological contexts, or where data has to be fed into other and different compliant or certified networks. However, there are applications where the required criteria can rarely be achieved due, for example, to the difficulty of installing the sensors in suitable sites. This is the case for agri-meteorology or urban meteorology, for the applications of which the sensors are installed on or near buildings, or on fields in which work is carried out. This data retains an operational value and fulfils the role for which it was collected (support for the management of irrigation and crop protection treatments, urban pollution mitigation choices, etc.); obtaining generalisable data is not possible, but the data supplied is certainly highly representative of the specific characteristics of a limited area and therefore useful for the purpose.

4.3. OTHER RELEVANT STANDARDS

In addition to the WMO guidelines, there are two other specific standards applicable to weather stations and networks:

- ISO 19289, 2015 "*Air quality - Meteorology - Siting classifications for surface observing stations on land*" which fully encompasses "*Siting Classifications for Surface Observing Stations on Land*" (WMO-No. 8, 2018), Volume I, Chapter 1, Annex 1D, looked at further on in this publication;

- UNI EN 17277:2020 "Hydrometry - Measurement requirements and classification of rainfall intensity measuring instruments", which considers the precipitation parameter and defines the procedures and instruments for carrying out laboratory and field tests, under stationary conditions, for the purposes of calibration, verification and metrological confirmation of the measuring instruments, going so far as to classify rain gauges on the basis of their performance in the laboratory.

The correct implementation of the monitoring network cannot be achieved without complying with the CE marking directives, i.e.: the set of practices that are mandatory for all products governed by an EU directive, with particular regard to:

- Machinery Directive 2006/42/EC: defining the essential health and safety requirements that machinery must meet during its design, manufacture and operation, before release onto the market;
- Low Voltage Directive 2014/35/EU: regulating safety related to the use of electrical equipment intended for use at a rated voltage between 50 and 1000 V in alternate current and between 75 and 1500 V in direct current;
- Electromagnetic Compatibility Directive 2014/30/EU: concerning electrical and electronic equipment which may create electromagnetic disturbances or the operation of which may be affected by disturbances generated by other sources of electromagnetic disturbance.

Compliance with these directives is the responsibility of the manufacturer of the network and the person who installs it, but it is advisable for the designer to require compliance with all these regulations in the specifications. It is important to emphasise the importance of earthing all installations, i.e. of a system designed to bring the metal components of the weather station to the electrical potential of the ground (Legislative Decree no. 81/2008, Ministerial Decree no. 37 of 22 January 2008, CEI 64-8/4), protecting people and animals from the risk of electrocution; the absence of this installation jeopardises maintenance work, which the contractor may refuse to carry out due to a lack of safety.

5. SENSOR AND SITE CHARACTERISTICS

5.1. HIGH-QUALITY AUTOMATIC SENSORS

The meteorological market is offering increasingly advanced and functional meteorological sensor solutions. It is clear that this family does not include the old manual stations, which required the collection of the recorded tapes and their subsequent digitisation; these are instruments that have played an important role in the history of weather stations and have collected a considerable amount of data, but which are now largely obsolete. The sensors must be chosen on the basis of a careful verification of the characteristics that are obligatorily indicated in the technical data sheets, and of a balance between investment and management costs and the resources that are available or may become available thanks to the use of data from the network. For example, it is necessary to ensure that the sensors are suitable for use in the open field and that their range of operation is compatible with the climatic possibilities of the site, and which is also characterised by an operational measurement uncertainty within the limits indicated by the *CIMO Guide* (WMO, 2018) or the "*Sustained Performance Classification for Surface Observing Stations on Land*" (WMO, Leroy, 2013).
Table 1 shows the uncertainty limits for different meteorological variables.

Meteorological Variable	Fully compliant (Annex 1.E of WMO-N.8)	Compliant Class C (Leroy, 2013)
Temperature	0.2 °C	1°C
Humidity	3 %	10 %
Precipitation	5 %	10 %
Pressure	0.15 hPa	1 hPa
Wind intensity	10 %	15 %
Wind direction	5°	10°
Global radiation	2%	10%
Heliophany	2%	10%

Table 1 Maximum limits for operational measurement uncertainty

5.2. MEASUREMENT SITE, HEIGHT ABOVE GROUND AND SENSOR EXPOSURE

The choice of the best weather stations is not sufficient to achieve a high-quality weather network. As the value of the data measured depends largely on the exposure of the instrument to the atmosphere, correctly choosing the detection site and the location of the various sensors is absolutely essential, particularly with regard to the distance from obstacles.
All the stations in the monitoring network must therefore meet the criteria set out in the WMO guidelines, concerning:

- site classification;
- height of sensors from the ground;
- exposure of instruments.

5.2.1. Site classification

The environmental conditions of a site can influence the measurement results, so they must be carefully analysed to avoid causing bias to the data.
The most widely accepted reference for characterising environmental conditions and assessing the representativeness of a measurement site is the WMO/ISO standard (ISO 19289, 2015) "*Air quality - Meteorology - Siting classifications for surface observing stations on land*" which fully encompasses "*Siting Classifications for Surface Observing Stations on Land*", published in the CIMO Guide (WMO-No. 8, 2018), Volume I, Chapter 1, Annex 1D.
The standard envisages five classes of conformity for each different atmospheric parameter measured:

- class 1 site: fully compliant;
- class 2 site: fully compliant;
- class 3 site: compliant;
- class 4 site: non-compliant;
- class 5 site: non-compliant.

A class 1 site can be considered as a reference site, while a class 5 site suffers, for example, from obstacles that are too close and adversely affect the meteorological measurement.

In particular cases such as installations in urban areas, or in agri-meteorology, or in specific areas, like roads and airports, which are generally characterised by low compliance, it is possible to add an additional flag, "S", to classes 4 or 5 to indicate a specific environment or application (e.g.: 4S).
Figs. 4-5-6 summarise the criteria to be met for a site to be defined as class 2 and therefore fully compliant in terms of temperature and humidity, precipitation and wind respectively.

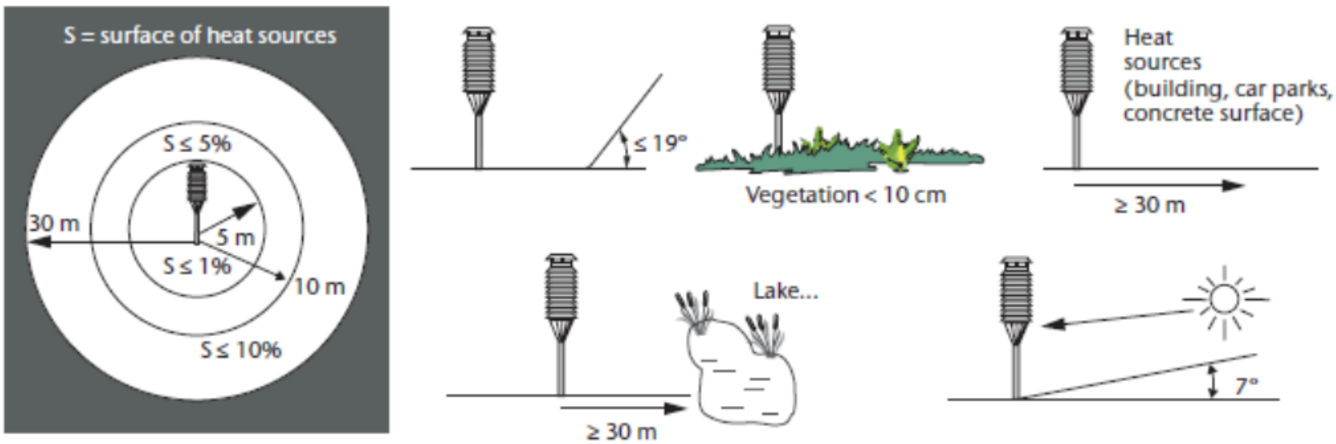

Fig. 4 Temperature and humidity, criteria for class 2 (WMO, 2018, Annex 1.D), fully compliant.

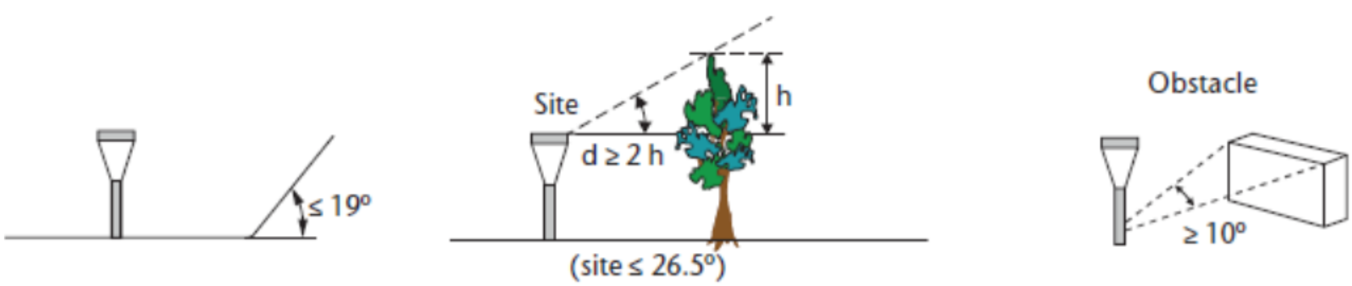

Fig. 5 Precipitation, criteria for class 2 (WMO, 2018, Annex 1.D), fully compliant

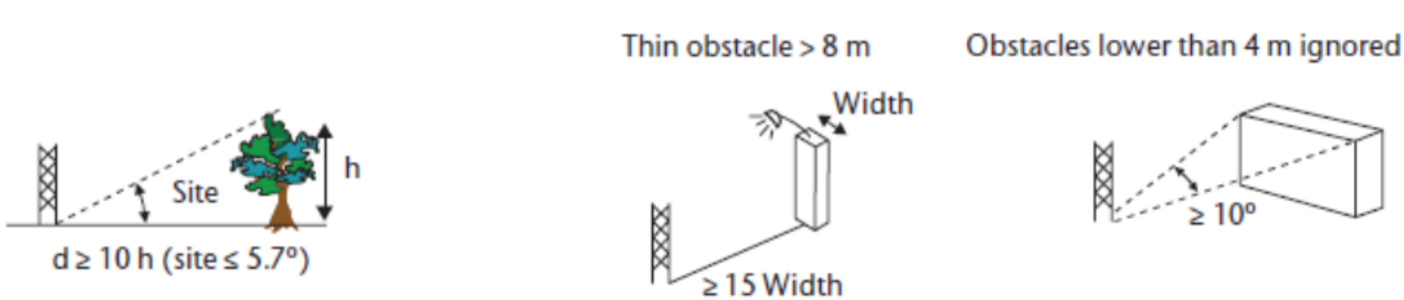

Fig. 6 Wind, criteria for class 2 (WMO, 2018, Annex 1.D), fully compliant

5.2.2. Height of sensors from the ground

The *CIMO Guide* (WMO, 2018) defines the heights from the ground at which measurements must be taken in order to be considered compliant. *Table 2* shows the most significant cases.

Meteorological Variable	Fully compliant	Compliant
Temperature and Humidity	2 m (± 10%)	1.25 – 3 m
Precipitation	1.5 m (± 10%)	0.5 – 3 m
Wind	10 m on flat, open ground	

Table 2 Height measured from the ground

5.2.3. Exposure of instruments

Fig. 7 illustrates an optimal distribution of the instruments within the weather station area, where each sensor is exposed to the environment at all times. However, the most important aspect of station installation consists in ensuring that there is no interference from existing or future obstacles in the area (hedges, trees).

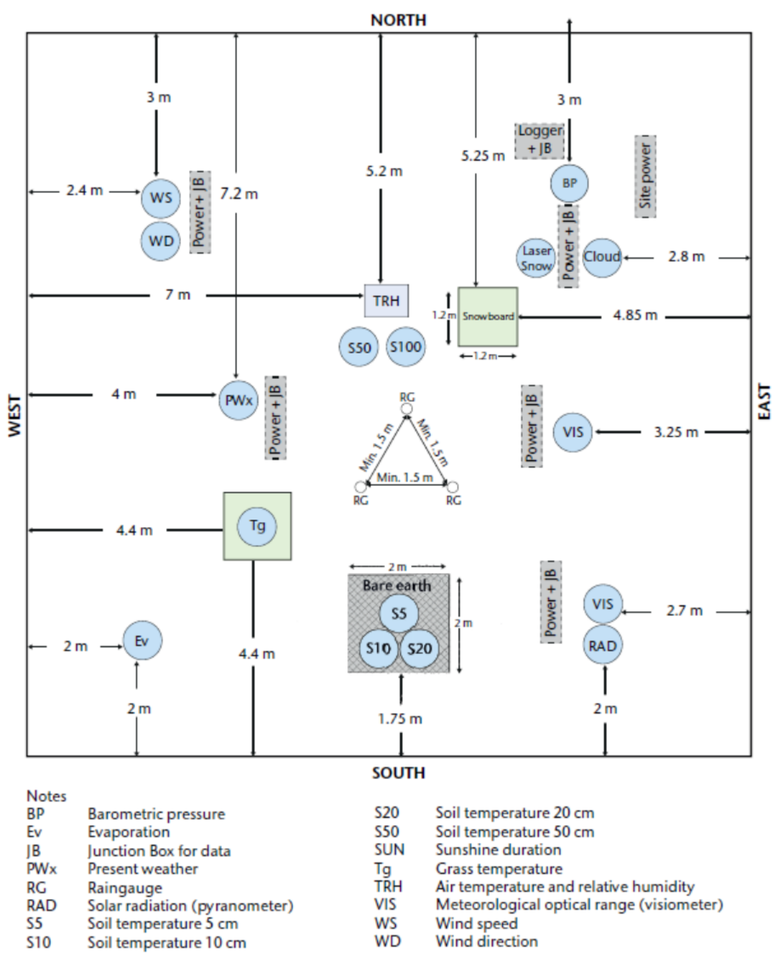

Fig. 7 Example of a weather station layout showing typical distances between the sensors and the fence - CIMO Guide (WMO, 2018)

The indications of the *CIMO Guide* (WMO, 2018) are shown below for each different sensor:

- temperature and humidity: the instrument is free from interference (within a range of at least 2 metres) and not mounted on a wall. The casing must be white and intact;
- pressure: the instrument is exposed to the open air and the casing is intact;
- wind: the pole is straight and strong enough to withstand extreme gusts;
- precipitation: the pole is straight, the instrument is not installed on a roof and is not covered by nearby objects or instruments;
- radiation and heliophany: the instrument is free from interference and in a level position, and the casing is intact.

5.3. SUPERVISION

The representativeness of the monitoring network can be guaranteed only by the proper and systematic supervision summarised by the *CIMO Guide* (WMO, 2018) in the following five points:

- calibration: carried out at regular intervals (every five years) at an accredited laboratory;
- Checking (e.g.: calibration of the rain gauge with sample measurement): carried out once a year by the station operator or a specially-appointed company;
- maintenance: the instruments must be checked and cleaned regularly by the maintenance operator;
- parallel measurement: a second instrument is used at the observation station to obtain redundant data;
- data quality control: the values measured values are validated on a daily basis; anomalous values, measurement errors, etc. are reported to the operator and lead to appropriate maintenance work.

A weather station is defined as compliant with WMO guidelines if it is continuously subjected to at least two of the activities listed.

6. DESIGNING A NEW NETWORK

The design activities involved in the creation of a compliant and certifiable monitoring network, once the purpose and the area to be monitored have been clearly defined, are described below.

6.1. ASSESSMENT OF EXISTING CONDITIONS

- Analysis of official or standardised networks (e.g.: ARPA, Civil Protection, Italian Air Force, Land Reclamation Authorities) already present in the area of interest and providing data, in order to avoid duplication;
- deliberate choice of the location of the stations based on geographical, morphological and meteo-climatic considerations, to guarantee adequate coverage of the territory (*Fig. 8*).

6.2. EXECUTIVE DESIGN

- Inspections to assess the site and choose the installation point (distances from obstacles, sources of heat, representativeness, accessibility, etc.) in compliance with WMO guidelines;
- Verification that the sites are available (on loan, rented, etc.);

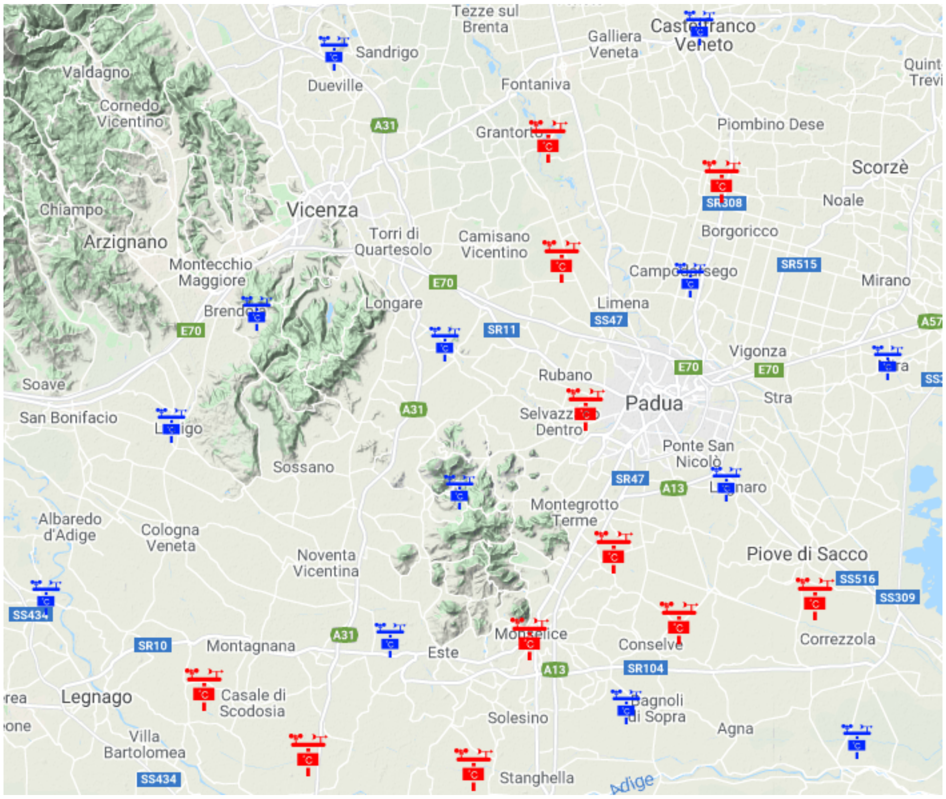

Fig. 8 Example of general plan, integration between new new station points ( ) and survey sites of other WMO-compliant networks ( )

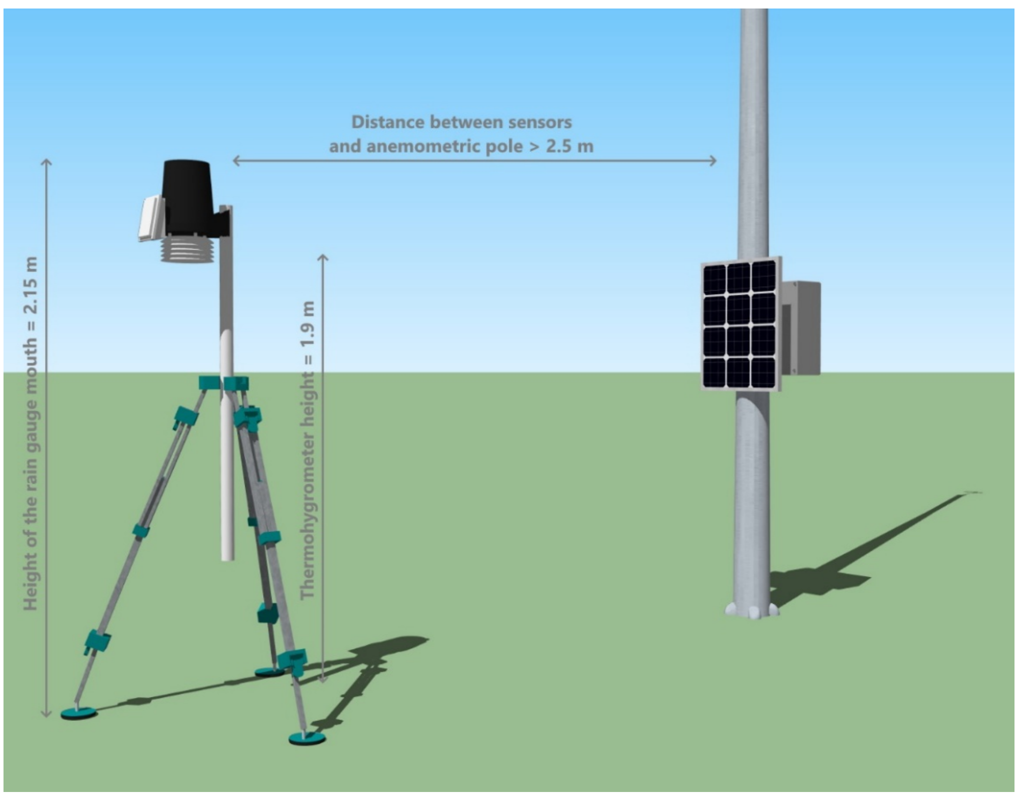

Fig. 9 Examples of indications for installation.

- choice of the stations, sensors and materials, carrying out technical (environmental operating conditions, purpose of the network, etc.) and economic assessments, in compliance with WMO guidelines (accuracy, measurement range, etc.);
- drafting of the specifications necessary for the purchase of the instruments;
- preparation of topographical and photographic annexes relating to the individual installations;
- definition of the methods used for:
  - powering the stations;
  - transmitting data;
  - supervising the stations;
  - data validation;
- technical and executive indications regarding the installation of the stations and individual sensors *(Fig. 9),* and all the supporting and accompanying elements (poles, foundations, etc.).

6.3. SUPERVISION OF WORKS AND COMMISSIONING

- Direct participation in the station installation phase *(Figs. 10a and 10b);*
- verification of the correct installation of each sensor in compliance with WMO guidelines (height from the ground, exposure, mutual distances, etc.).
- verification of supplies and invoicing;
- final technical commissioning report for each individual station, with a description of its characteristics and the site.

Fig. 10a Installation of the anemometer pole.

Fig.10b Completed installation, weather station equipped with sensors for temperature, humidity, precipitation, wind direction and intensity, leaf wetness, soil temperature and humidity.

7. ENHANCEMENT AND COMPLIANCE OF AN EXISTING NETWORK

The design activities necessary to adapt, enhance and integrate an existing network are described below.

7.1. ANALYSIS OF THE EXISTING CONDITIONS AND ASSESSMENT OF CONFORMITY

7.1.1. For existing stations

- Collection of information on the individual stations:
  - number, coordinates and type;
  - meteorological variables measured;
  - servicing status and wear;
  - frequency of measurement and transmission;
- sensor quality assessment according to WMO guidelines;
- inspection, classification of the site, assessment of the installation point (distances from obstacles, heat sources, representativeness, accessibility, etc.) *(Fig. 11)*;
- technical report for every station, consisting of:
  - general overview;
  - photographic documentation;
  - information collected before and during inspection;
  - WMO classification (fully compliant, compliant or non-compliant).

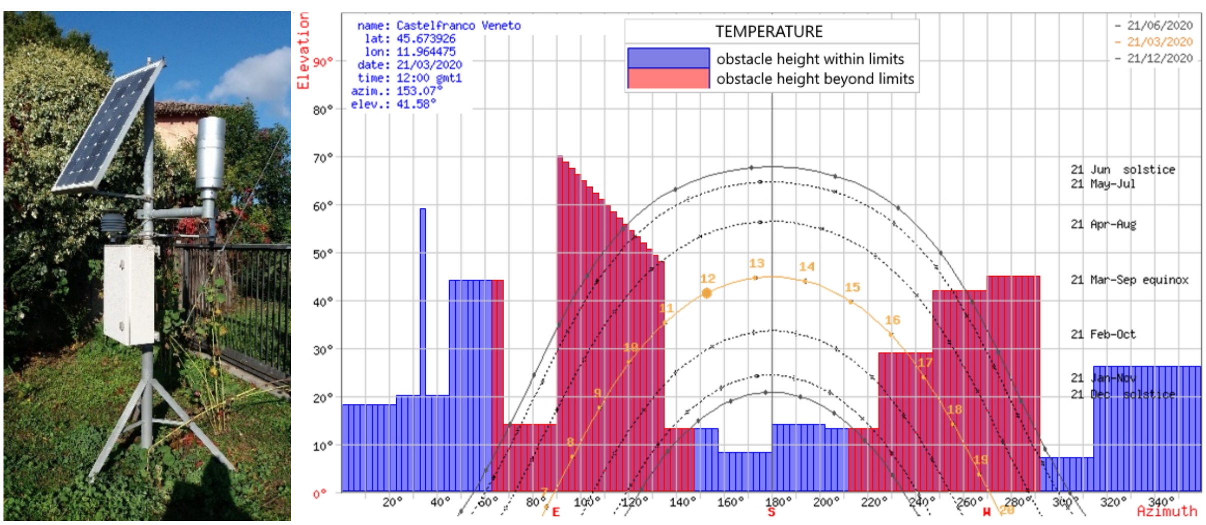

Fig. 11 Classification of the site and exposure of the sensors, diagram for the assessment of the influence of the of obstacles: elevation of the sun at different times of the year (lines) and height of obstacles (bars)

7.1.2. For enhancement and integration

- Analysis of official or standardised networks (e.g.: ARPA, Civil Protection, Italian Air Force, Land Reclamation Authorities) already present in the area of interest and providing data, in order to avoid duplication;

- deliberate choice of the sites for the relocation of some existing stations or for the installation of new ones, based on geographical, morphological and meteo-climatic considerations, to guarantee adequate coverage of the territory.

7.2. EXECUTIVE DESIGN

7.2.1. For existing stations

- Definition of the point of possible relocation of the station within the same site *(Figs.12a and 12b);*
- executive technical indications regarding work to ensure compliance.

7.2.2. For enhancement and integration

- Inspections of sites for the possible relocation of existing stations or the installation of new ones to assess the detection area and choose the installation point (distances from obstacles, sources of heat, representativeness, accessibility, etc.) in compliance with WMO guidelines;
- verification that the sites are available (on loan, rented, etc.);
- in the case of integration with new stations;
  - choice of the sensors and materials, carrying out technical (environmental operating conditions, purpose of the network, etc.) and economic assessments, in compliance with WMO guidelines (accuracy, measurement range, etc.);
  - drafting of the specifications necessary for the purchase of the instruments;

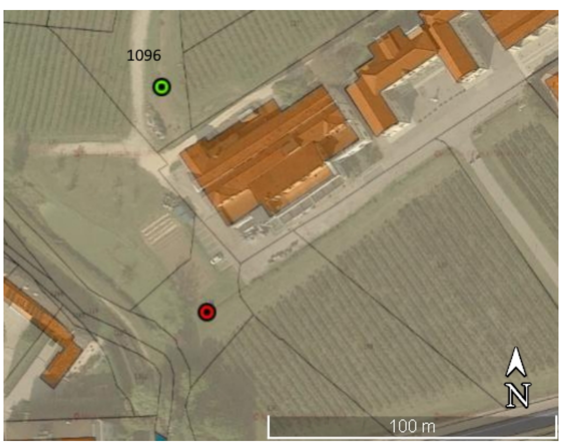

Fig. 12a Weather station, current position (●) and possibility of relocation (●).

Fig. 12b Possible relocation point of the weather station.

- preparation of topographical and photographic annexes relating to the individual installations;
- definition of the methods used for:
  - powering the stations;
  - transmitting data;
  - supervising the stations and data validation.
- technical and executive indications regarding the installation of the stations and individual sensors *(Fig. 13),* and all the supporting and accompanying elements (poles, foundations, etc.).

7.3. SUPERVISION OF WORKS AND COMMISSIONING

7.3.1. For existing stations

- Direct participation in the station installation phase;
- verification of the work to ensure compliance,
- final technical commissioning report for each individual station, with a description of its characteristics and the site.

7.3.2. For enhancement and integration

- Direct participation in the station installation phase;
- verification of supplies and invoicing (in the case of integration with new stations);
- verification of the correct installation of each sensor in compliance with WMO guidelines (height from the ground, exposure, mutual distances, etc.).
- final technical commissioning report for each individual station, with a description of its characteristics and the site (*Fig. 14*).

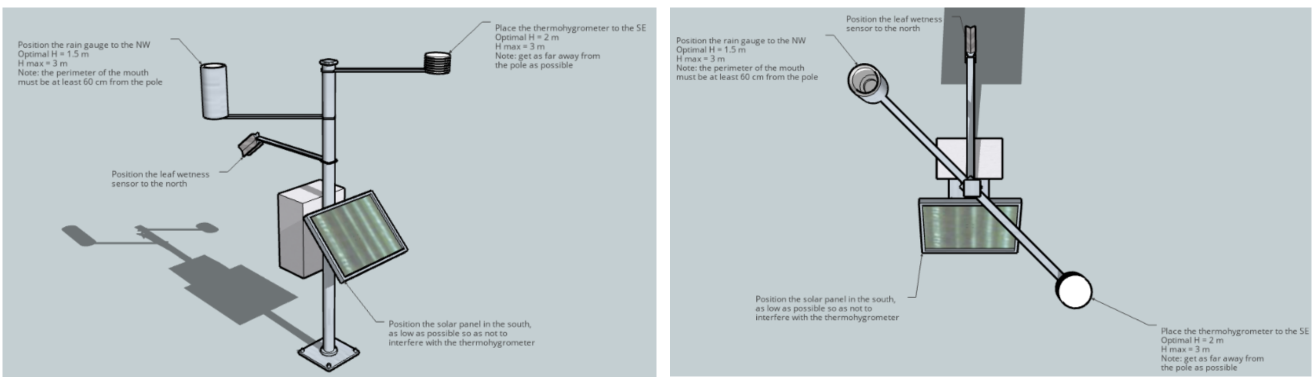

Fig. 13 Example of correct sensor exposure for a station that measures rain, temperature, humidity and leaf wetness.

Rain gauge		**Score**
Sensor (model)	t027 TP1K	
Is the sensor heated?	no	1
Is the sensor protected against the wind?	no	
Measuring principle	double tilting bucket	
Accuracy of the instrument for rain <= 5 mm (mm)	0,1	2
Accuracy of the instrument for rain > 5 mm (%)	7%	1
Collecting area (cm^2)	1000	2
Height of measurement from the ground (m)	1,3	1
Is the sensor correctly exposed?	yes	0
CIMO site classification	class 3	0
Is the instrument on a roof?	no	2
Station Supervision		0
Frequency of calibration in the laboratory or replacement (years)	never	0
Frequency of on-site check (months)	12	2
Frequency of ordinary maintenance (weeks)	4	1
Is parallel measurement carried out using a second instrument?	no	0
Is there an automatic data check?	yes	0
Post-Analysis		
Measuring frequency (min)	5	2
Transmission interval (min)	8	2
Availability of data (%)	97,2%	2
Promptness of delivery (min)	8	2
Audit Result	NON-COMPLIANT	0

Fig. 14 Excerpt from the audit record sheet, which is an integral part of the conclusive technical report.

8. CERTIFICATION

8.1. FOREWORD

A network designed, built or enhanced on the basis of the *CIMO Guide* (WMO, 2018) can be further improved with certification, which confirms its compliance with WMO standards. A certified network becomes a formidable tool, as it produces datasets that can be used in all contexts, both technical and operational, as well as in research activities and in contractual, legal or evidential contexts. A network with these characteristics can be easily integrated into other monitoring systems and, over time, can feed re-analytical processes, providing refined meteorological products.

Awareness of this need has grown considerably in recent years, both in the light of the growing importance of meteorological data in numerous processes and of the possibility of their much more intensive use, thanks to digital techniques. *Fig. 15* illustrates how, alongside the official networks (ARPA, Italian Air Force, Civil Protection, Regions, etc...), important on-site monitoring systems have developed. These are managed mainly by bodies and agencies operating directly on the territory (agricultural insurance companies, utility companies, land reclamation authorities).

Certification is issued by an independent and licensed certification body that verifies the compliance of each individual station and sensor with the WMO's "*Guide to Instruments and Methods of Observation*" (WMO-No.8, 2018) *and to the ISO standard* "*Air quality - Meteorology - Siting classifications for surface observing stations on land*" (ISO 19289, 2015).

After collecting all the information necessary for pre-analysis (coordinates, model, sensors, data sheets, data recorded by the stations, network supervision method and frequency, etc.), the certification body proceeds with inspection to classify the site and verify the correct exposure of the sensors. Lastly, after carefully analysing the data recorded by the station for at least a year, in order to ascertain the minimum requirements of completeness and promptness of delivery, it issues, where appropriate, the certificate of conformity, which requires renewal every five years.

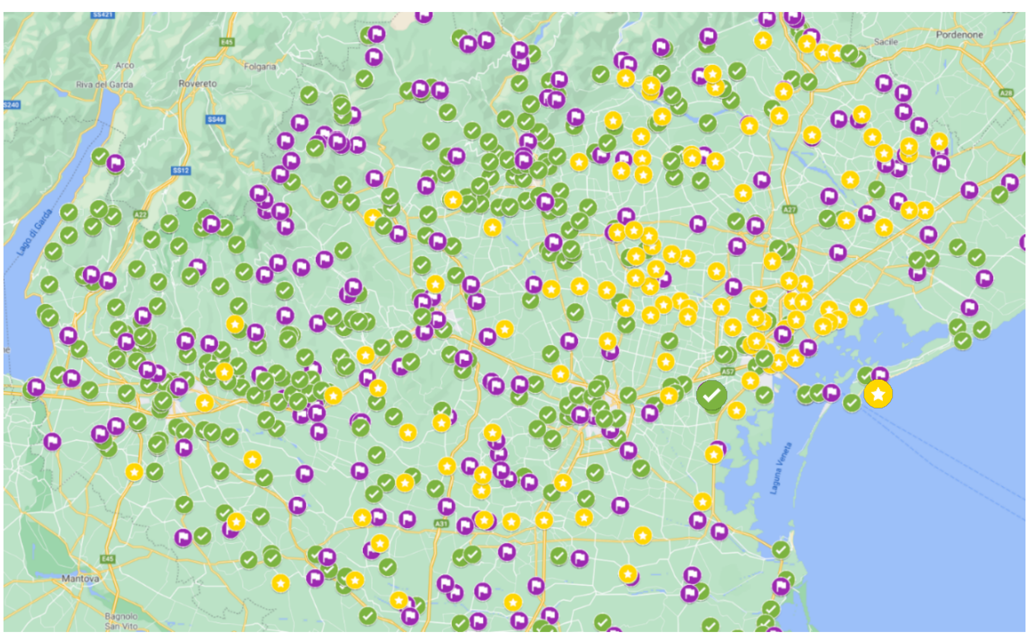

Fig. 15 Official ( ), compliant ( ) and certified ( ) weather stations

8.2. THE CERTIFICATION PROCESS

This process begins with the design and construction of the monitoring network, or with its adaptation, and ends with the certification of the weather stations. The main phases are outlined in Fig.16 for new networks and in Fig.17 for enhanced networks. The activities envisaged and the interaction with the certification body can be managed by internal staff or through a specialised consultant.

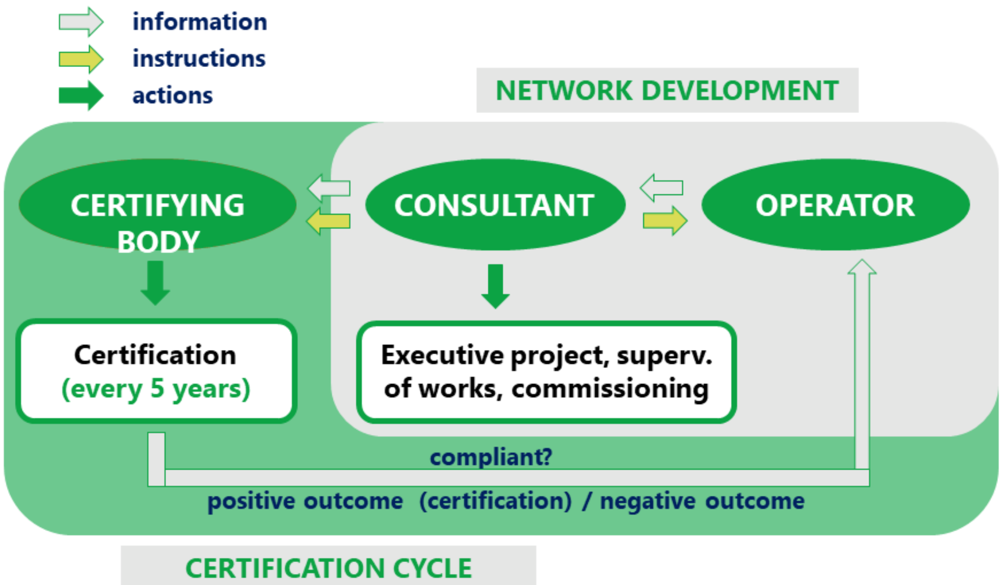

Fig.16 Certification cycle for new monitoring network: flow chart

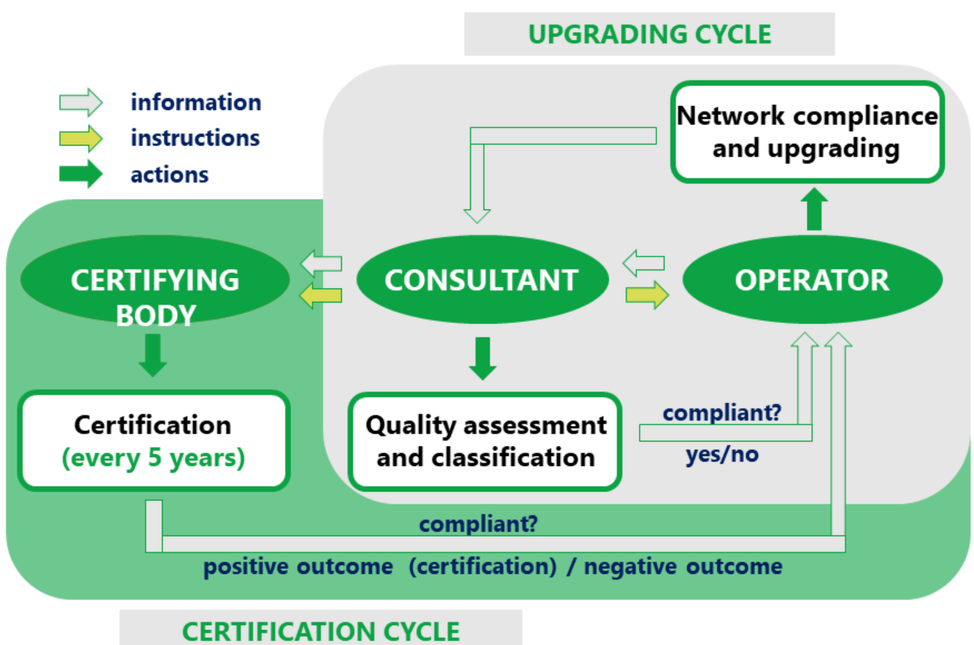

Fig. 17 Certification cycle for existing monitoring network: flowchart

8.3. THE CERTIFICATION CYCLE

During its assessment activities, the certification body refers to the procedures and criteria defined in the operational manual which incorporates the WMO guidelines.
The certification cycle, outlined in *Fig. 18*, begins with a pre-analysis carried out by the business consultant and shared with the certification body. The certification body then inspects the various stations with the assistance of the consultant, who will answer any questions and provide additional information, or acknowledge indications and advice. At the end of the on-site inspection, it will be possible to certify whether or not the weather station complies with the WMO guidelines.
If, at the time of the pre-analysis, the station has been in operation for less than a year, the outcome of the certification process will be considered provisional, as it will be necessary to collect data over a period of at least one year, verify it (post-analysis) and share it with the certification body.

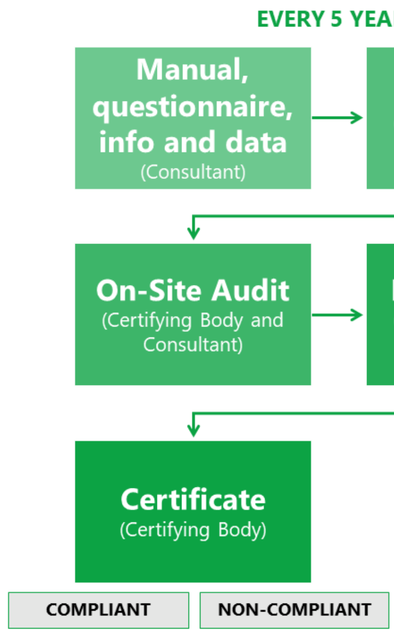

Fig. 18 Certification cycle, main elements

8.3.1. Manual

The operational manual, drafted by the consultant based on the WMO guidelines, is the reference tool for all those involved in the certification process. After describing the main steps of the procedure, the document focuses on instructions for filling in the questionnaire, providing the necessary references for a correct assessment of all the aspects to be analysed (quality of the weather station, representativeness of the site, exposure of the instruments, station supervision, etc.).

8.3.2. Questionnaire

The questionnaire, drafted by the consultant, enables the recording of all the information useful for classifying the weather station, as indicated in the manual.

8.3.3. Supply of information and data

The consultant supplies the certification body with the manual, the questionnaire, the technical specifications of the weather station and the data recorded during the last year.

8.3.4. Pre-Analysis

The certification body, assisted by the consultant, uses the data available to determine whether the station is able to meet the basic requirements for certification.

8.3.5. Site inspection

The certification body inspects the site, accompanied by the consultant. During the inspection, the certification body takes the necessary measurements, records the findings, fills in the questionnaire and photographs the station from different perspectives (overview of the site and detailed view of the instrument).

8.3.6. Post-Analysis

The consultant analyses the data supplied by each station and issues statistics concerning the completeness of the data and the promptness of reporting; the certification body verifies whether the pertinent quality thresholds are met.

8.3.7. Conformity certificate

The certification body issues each weather station visited with a certificate of compliance or non-compliance with the WMO guidelines. The certificate is valid for five years, after which the whole process must be repeated.

9. DATA CHECK AND VALIDATION

Among the five supervisory actions listed by the WMO, the daily data quality check is definitely one of the most important, as:

- it contributes to the station's compliance with the WMO guidelines;
- it enables faster detection of station malfunctions;
- it delivers high-quality data to the user.

The activity is based on the implementation of automatic algorithms and the manual procedures used to verify the data recorded. The following diagram *(Fig. 19)* illustrates the steps involved in the check, validation and alert process.
The automatic check is carried out both on raw *near real-time* data (preliminary check on hourly data) and on consolidated daily data, and concerns the following physical parameters: precipitation, temperature, humidity, wind intensity, pressure.
The algorithms used for the automatic control are based on the following analytical techniques:

- *range test*: invalidation of obviously incorrect data (values outside the range of climatic possibility);

- comparative analysis by percentiles: for every station being checked, the data of the 20 closest stations providing data is considered (also from other official and/or WMO-compliant networks). Once the 20th and 95th percentiles of the data set (20 values) have been calculated, taking into account a tolerance range consisting of the standard deviation of the data multiplied by a coefficient that varies according to season (e.g.: for rain, from a minimum of 1 in winter to a maximum of 3 in summer) to which a fixed offset is added. Values above and below these thresholds are invalidated.

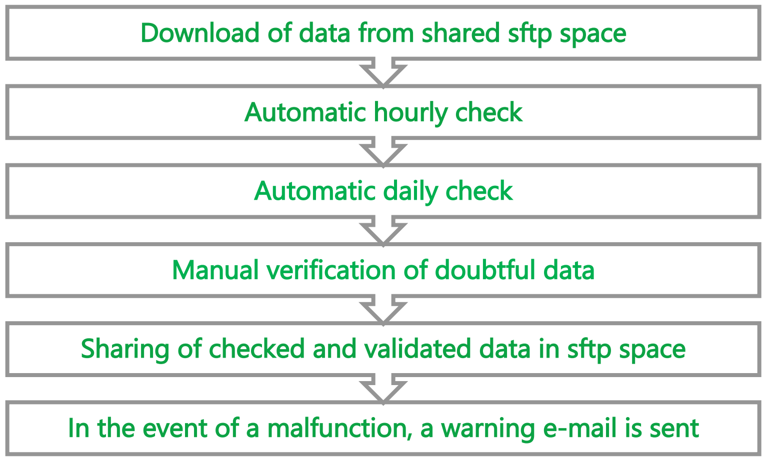

Fig. 19 Flow chart of the control, validation and alert process

The control criteria are further optimised in relation to the meteo-climatic characteristics of the site of interest. Manual check, carried out only on the daily data previously subjected to automatic check, it is carried out on a daily basis by a meteorological technician.
The system usually also has an automatic procedure for reporting sensor malfunctions.

10. NOTES

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Currently Head of the Radarmeteo Networks Service.

[3] Quaderno1_Rappresentatività_dati_meteo_IT.pdf (radarmeteo.com)

[4] WMO: *World Meteorological Organization,* UN Technical Agency tasked with global coordination of meteorology, climatology and operational hydrology.

[5]CIMO: *Commission for Instruments and Methods of Observation – WMO*

11. BIBLIOGRAPHY

- ISO 19289, 2015: *Air quality - Meteorology - Siting classifications for surface observing stations on land*. International Organization for Standardization.
- Leroy Michel, Meteo-France, 2013: *Sustained Performance Classification for Surface Observing Stations on Land*. CIMO/WMO.
- UNI EN 17277:2020: *Idrometria - Requisiti di misurazione e classificazione degli strumenti pluviometrici per la misura dell'intensità di precipitazione*
- World Meteorological Organization, 2006: *Initial guidance to obtain representative meteorological observations at urban site* (WMO/TD-No. 1250).
- World Meteorological Organization, 2010: *Guide to Agricultural Meteorological Practices* (WMO-No. 134).
- World Meteorological Organization, 2017: *Guide to the Global Observing System* (WMO-No. 488).
- World Meteorological Organization, 2017: *Quality Assessment using METEO-Cert: The MeteoSwiss Classification Procedure for Automatic Weather Stations* (IOM Report No. 126).
- World Meteorological Organization, 2018: *Guide to Instruments and Methods of Observation*, Volume I – Measurement of Meteorological Variables (WMO-No. 8).
- World Meteorological Organization, 2018: *Guide to Instruments and Methods of Observation*, Volume III – *Observing Systems* (WMO-No. 8).
- World Meteorological Organization, 2019: *Manual on the WMO Integrated Global Observing System: Annex VIII to the WMO Technical Regulations* (WMO-No. 1160).