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High quality sustainable monitoring in cities for climatological services.

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Key strengths of a network of weather stations to get high quality measure, comparable data and to contain management costs: Climate Network® example

Generally, the set up of a weather stations network has to meet both technical and operational requirements and it has to take into account the overall cost over time.

It's a tough balance, but it can be achieved with appropriate design choices:

1. **Standardization** of the network, i.e. same station model with equal sensors, data logger, power supply, software and data transmission protocol.
2. **Digital sensor** (i.e. digital output): easily removable device, periodically replaced with a maintened and calibrated one of the same type.
3. **Data transfer in real time, near real time and batch processing.** The need for real-time data transmission can lead to important changes to network design and to individual stations. It changes the transmission model (data communication is from stations to server instead of the server's polling). It changes also the design of the power supply part and data logging of the station (necessity of power grid supply).
4. **Planning of maintenance and calibration procedures:** also on maintenance planning, standardization plays a crucial role. We can set the rotation of meteorological stations and fully exploit the economies of scale due to use same devices.
5. **Traceability chain:** depending on the number of stations and kind of sensors, it may be more affordable to perform the calibration process internally to minimize calibration cost.

1-2: Station standardization and choice of a proper digital device

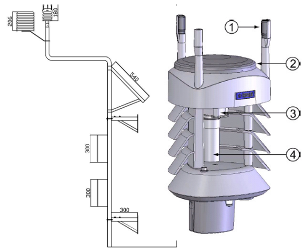
In order to get the highest level of comparability of data, we have to standardize stations using the same hardware and software components.

The choice of a particular components affect the network design, management and budget.

The first choice is between ventilated or **not ventilated device**, which leads to the choice between connecting to the power grid or **using a solar panel system.**

The second choice is between devices with or **without moving parts,** that leads to define the frequency of maintenance.

Some Climate Network meteorological stations



Weather Trasmitter Vaisala WXT520 does not include moving parts and this increases reliability.
1 = Wind transducers
2 = Precipitation sensor
3 = Pressure sensor
4 = Humidity and temperature sensors

Weather Trasmitter Vaisala WXT520 and the station plan

5: Building and maintaining the traceability chain: temperature example

Traceability is the property of a measurement result, where the result can be related to a reference through a documented unbroken chain of calibrations each contributing to the measurement uncertainty.

Metrological traceability became a mandatory requirement after the signing of the CIPM-MRA (Mutual Recognition Agreement) by the WMO (World Meteorological Organization): every meteorological measure has to be related to national or international reference standards.

Our **temperature traceability chain** starts from a Secondary Reference Platinum Resistance Thermometer (Fluke 5616), which has been calibrated together with his multimeter (Fluke Hydra 2620A) at a National Metrological Institute every 5 years. The first line standard and the multimeter are combined in a single equipment: they have been calibrated together in order to maintain a single measurement chain. The second line standards are three Resistance Thermometers (PT100 ohm in Class A according to IEC 751), used as transfer standards.

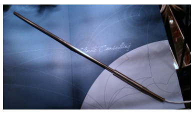
First step: calibration of the reference standard shall be performed at a National Metrological Institute

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

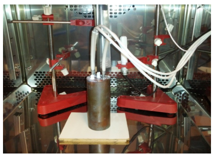
Univerza v Ljubljani Fakulteta za elektrotehniko

First line reference standard U@ 20°C 0,03°C

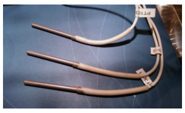
Second step: standard transfer to three Resistance Thermometers, by comparison with the primary standard



First line reference standard $U_{T=20°C}$ = 0,03°C

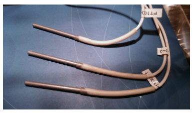


Transfer standard in a climatic chamber using a copper block comparator



Second line reference standard $U_{T=20°C}$ = 0,04°C

Third step: Weather station WXT520 calibration by comparison with three secondary standards



Second line reference standard $U_{T=20°C}$ = 0,04°C

Calibration in a climatic chamber

Weather trasmitter Vaisala WXT520
$U_{T=20°C}$ = **0,2°C**

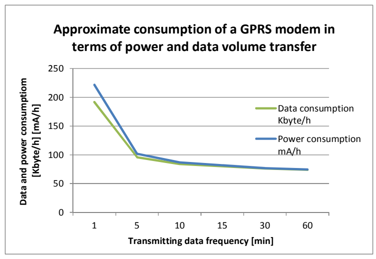
3: Data transfer: real time, near real time and batch processing

Nowadays, **real time data** are **crucial** for a lot of uses, connected to weather data. Our current challenge is the conversion of our weather station network, that transmit the acquired data once a day, into a network that transmits data in near real time. It represents a challenge in terms of overall design, energy consumption and data volume.

In a near real-time, stations send the recorded data to an IP address at **established intervals** (1 min-1 hour).

Energy consumption and **data traffic** are related to the modem activation time: the higher the transmission frequency, the greater the energy consumption and the volume of data transferred.
This happens because each data packet transmission include some redundant data, required to create the connection.

By analyzing data and power consumption (see side chart) we can **decide what type of power supply** can be used in our station: if we need to have a high frequency data transfer, from 1 to 10 min, we have to choose the power grid. Otherwise, for transmitting data frequency >10 min, we can use a solar panel system.

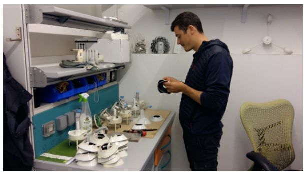


4: Planning maintenance and calibration procedures

Any operating WTX520 must be maintened and calibrated once a year: how to do it better?
We have WXT520 spares that allow us to replace up to 5 stations at the same time, according to a defined rotation scheme.
Besides, 5 more WXT520 are always ready to replace malfunctioning ones in the meantime.

Make economies of scale

Standardization has another positive effect: maintenance procedures are facilitated because the spare parts in the warehouse are the same for all stations and the individual parts can be exchanged. For example, all the solar screens of the WXTs can be exchanged and shared to facilitate the cleaning and painting operations.



Rotation of all WXT520s in calibration and maintenance

Installing a maintened and calibrated WXT520

Meanwhile another WXT520 is maintened and calibrated in laboratory

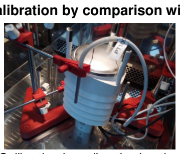
After a year the new calibrated WXT520 substitutes the old one

Calibrating the humidity sensor

Since 2016 we introduced the calibration of humidity sensor of WXT520 weather station. The traceability chain starts from a Rotronic probe HC2-S3 calibrated from a National Metrology Institute, with an uncertainty U_{RH} = 1,5% @23 °C

Weather station WXT520 calibration by comparison with reference standard

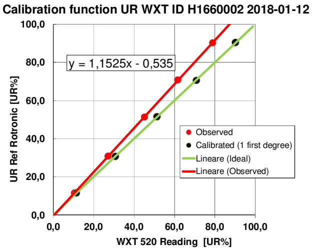
First line reference standard
U_{RH} = 1,5% @ 23°



Calibration in a climatic chamber

Weather trasmitter Vaisala WXT520
U_{RH} = **2,0% @ 23°**

Calibration function UR WXT ID H1660002 2018-01-12

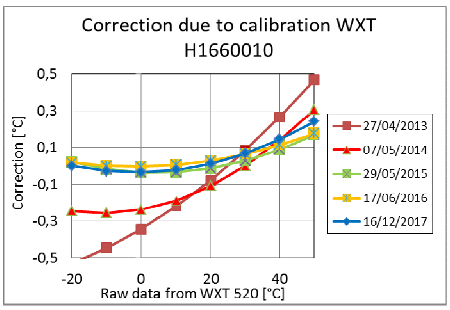


The calibration curve of the RH sensor of the WXT H1660002 has shown on the left: the behavior of the sensor has proved to be linear and for the correction curve a first degree polynomial has been chosen.
From the correction curve y = 1,152x -0,53 we deduce that the RH sensor underestimates the measurement of 15%. It means that it's impossible to detect RH values close to 100%, typical during rainy episodes.
If we apply the calibration curve to WXT raw data we obtain differences from the reference values lower than 0,3%.

This underestimation and the linear behavior of the sensor are typical of the Vaisala WXT 520. We noticed an increasing proportional underestimation with ageing: it starts from about -8% for a new WXT up to -18% for an used one (6 -7 years).

Establishing a proper calibration frequency

One of the most important questions for managing calibration is: which is the right calibration frequency in order to meet both quality of measurements and its costs?
Normally, the sensors show a drift of their characteristics over time. By analyzing the repeated calibrations of a single sensor, we can calculate the speed of this drift and establish how often we need to calibrate the device, in order to keep the drift within a predetermined value.



The drift speed also depends on the type of sensor. Generally a PT100 resistive thermometer, as recommended for example by Meteo France, can be calibrated every 5 years because its characteristics do not degrade rapidly over time.
Conversely, an electronic sensor, being more complex, could have a faster drift.
Climate Network weather stations (Vaisala WXT520) have a capacitive electronic thermometric sensor, which is calibrated annually.

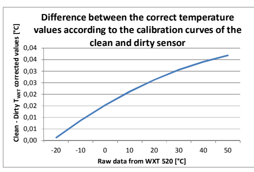
In the example on the left, we show the evolution of the calibration curves of the same temperature sensor over years.
We noticed a sensitive drift during the first two years, while in the following 3 years the characteristic curves stabilized around more contained correction values.
In this case, as evidenced by the latest calibrations, **it is possible to increase the calibration interval (i.e. 2 years), saving time and maintenance costs.**

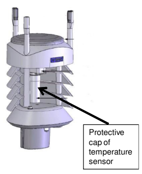
Effect of pollution and ageing of radiation screen

Does the particulate matter, deposited on the sensor, affect temperature data?
We compared calibration curves obtained by the same sensor, earlier dirty and then cleaned.

Applying the two calibration curves to the same raw data, we compared the two series of corrected values obtained: the difference between them (as shown in the side graph) are extremely restrained (less than 0,05°C).

This shows a **negligible effect of the deposition of particulate matter directly on temperature sensor.**





For this reason, we can avoid calibration for dirty sensors and perform a single calibration, after cleaning.

Does the aging of radiation screen affect temperature data?
A 5 years old device (AWS5) and a new device (AWS0) were located in the same place. Comparing their temperature values, registered at the same time, we calculated the differences.

Results showed that nighttime differences are negligible. Conversely, during daytime the differences existed and were larger at the calms (no wind), raising a instantaneous maximum of 1,63°C.
The temperature measured by the older screen is larger because of the yellowing of radiation screen with aging.

This shows a **significant effect of ageing of radiation screen.**
In order to contain this effect we started to paint the radiation screen with a glossy and UV resistant paint. For more info, see side publication.

COMPARATIVE ANALYSIS OF THE INFLUENCE OF SOLAR RADIATION SCREEN AGEING ON TEMPERATURE MEASUREMENTS*
*INTERNATIONAL JOURNAL OF CLIMATOLOGY
http://onlinelibrary.wiley.com/doi/10.1002/joc.3765