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Assessment of the Basque Country Automatic Weather Station Network for Climate Monitoring: Quality Control, Homogenization and Siting Classification

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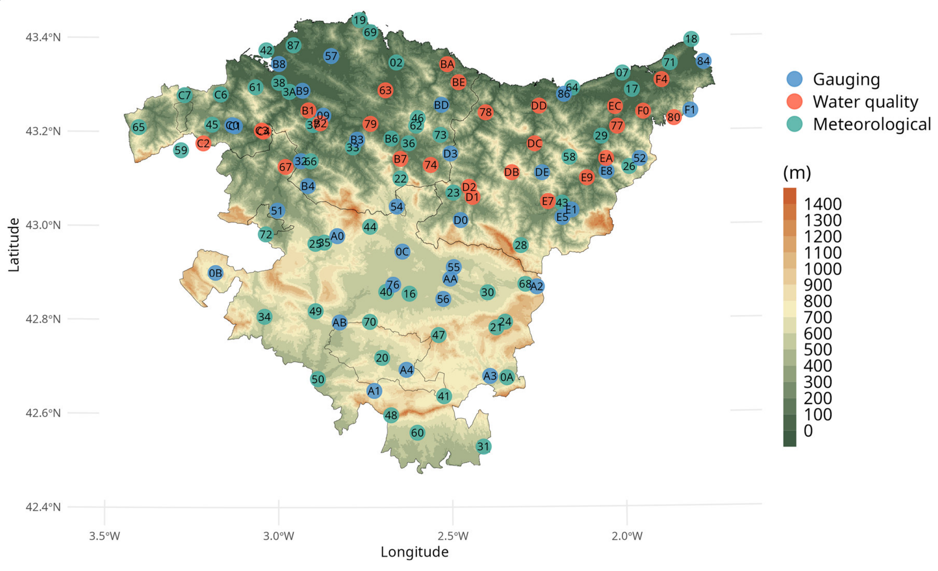
0. Introduction

The meteorological observation network of the Basque Country, managed by the Basque Meteorology Agency (Euskalmet), comprises more than 140 active Automatic Weather Stations (AWSs). The network is primarily oriented towards the real-time monitoring of extreme weather events, including floods. Consequently, many of the weather stations are installed in areas close to rivers and near obstacles, such as buildings or trees, which can substantially affect temperature measurements. These biased measurements can have a major impact on the robustness and representativeness of climate studies. The aim of this work is to characterize the Basque AWS network based on the siting classification, the quality control and homogenization.

1. Basque AWS

The Basque Country, in northern Spain, is characterized by a complex topography, with numerous valleys and mountains. There are two distinct hydrological basins: the Cantabrian basin to the north, whose rivers flow into the Cantabrian Sea, and the Mediterranean basin to the south, with rivers running to the Ebro. The Cantabrian basin is densely populated, with significant industrialization and development along the river basins. Due to these circumstances, adverse weather conditions and high-impact weather events, such as floods and flash floods, are frequent (Gaztelumendi et al., 2018). Therefore, to address the need to monitor river levels, several weather stations were installed in valley areas, close to the rivers. The stations in the network are classified into three groups: meteorological stations, which record meteorological parameters, gauging stations and water quality stations, which also include water quality parameters (Gaztelumendi et al., 2018). Currently 114 stations measure air temperature.

Fig. 1: Basque AWS network measuring air temperature. Classified by station type: gauging (blue), water quality (red) and meteorological (green). The numbers show each station identification code. Mask: MDT25-cob1 2008–2015 CC-BY 4.0 scne.es.



2. Siting Classification

The siting classification is performed following the set of recommendations by the Word Meteorological Organization (WMO) and taking advantage of the "sitingclass" package developed by Lefeuvre (2025) in R. The package calculates the exposure of weather stations and was originally built for the Norwegian weather stations maintained by the Norwegian Meteorological Institute. The original code has been modified and adapted to the specific characteristics of the Basque Country. Accordingly, some of the WMO criteria have been modified.

❑ Methodology and data

According to the WMO guidelines for stations measuring air temperature (ISO 19289:2014(E); WMO, Annex 1.D., 2024) the main sources of error are associated with unnatural surfaces, such as heat sources, reflective surfaces or water bodies, and shading by nearby obstacles. In the Basque Country, which has a very complex topography, the natural relief of the landscape will not be considered if it is more than 1 km away, as the relief is considered a natural feature of the area. The height of the vegetation in the surroundings of the station is also assessed. The siting classification is assessed based on four parameters: slope of the terrain, vegetation, surrounding land type and shade. The overall siting classification corresponds to the least favourable classification amongst the four parameters.

	Class 1	Class 2	Class 3	Class 4	Class 5
Slope	Flat, horizontal land, surrounded by an open space, slope less than ⅓ (19°)	Flat, horizontal land, surrounded by an open space, slope inclination less than ⅓ (19°)	No requirements	No requirements	No requirements
Vegetation	Ground covered with natural and low vegetation (< 10 cm) representative of the region	Ground covered with natural and low vegetation (< 10 cm) representative of the region	Ground covered with natural and low vegetation (< 25 cm) representative of the region	No requirements	No requirements
Distance to Heat Sources/Water Bodies (HS/WB)	Measurement point is situated more than 100 m from HS/WB. HS/WB occupies less than: a) 10% of a 100 m radius area b) 5% of an annulus of 10-30 m c) 1% of a 10 m radius area	Measurement point is situated more than 30 m from HS/WB. HS/WB occupies less than: a) 10% of a 30 m radius area b) 5% of an annulus of 5-10 m c) 1% of a 5 m radius area	Measurement point is situated more than 10 m from HS/WB. HS/WB occupies less than: a) 10% of a 10 m radius area b) 5% of a 5 m radius area	HS/WB occupies less than: a) 50% of a 10 m radius area b) b) 30% of a 3 m radius area	No requirements
Shade	Away from all projected shade when the sun is higher than 5°	Away from all projected shade when the sun is higher than 7°	Away from all projected shade when the sun is higher than 7°	Away from all projected shade when the sun is higher than 20°	No requirements

Table 1: Siting classification criteria for surface observing stations on land measuring air temperature. Adapated from WMO, Annex 1.D., 2024.

In addition, the temperature sensor must be situated within 1.25 to 2 m above ground level. The height should never be less than 1.25 m. Compliance with the upper limit is less strict, as the temperature gradient with respect to height decreases with height. So, only stations with a sensor at a height of 1.25 m or greater are analysed, which makes 93 stations of the Basque AWS network.
The digital terrain models, the digital surface model and orthophoto data used to generate the classification are obtained from the Spanish National Geographic Institute's download centre (Centro Nacional de Información Geográfica – CNIG), which provides the most up-to-date data for the Basque Country. Global land cover from the European Space Agency (ESA) is used as a supplementary data.

Digital Terrain Models	Definition	References
MDT02-cob2	Digital Terrain Model 2nd Coverage (2015–2021) with 2 m grid spacing.	MDT02-cob2 2015–2021 CC-BY 4.0 scne.es
MDT25-cob2	Digital Terrain Model 2nd Coverage with 25 m grid spacing.	MDT25-cob2 2015-2021 CC-BY 4.0 scne.es
Digital Surface Models	**Definition**	**References**
MDS02	Digital Surfaces Model 2nd Coverage (2015-2022) with 2 meters grid spacing.	MDS02 2015–2021 CC-BY 4.0 scne.es
MDSnEdificación2,5	Standard digital surface model of the building class corresponding to the 2nd Coverage with 2.5 m grid spacing.	MDSnEdificación2,5 2015-2021 CC-BY 4.0 scne.es
MDSnVegetación2,5	Standard digital surface model of the vegetation class corresponding to the 2nd Coverage with 2.5 m grid spacing.	MDSnVegetación2,5 2015-2021 CC-BY 4.0 scne.es
Orthophotos	**Definition**	**Reference**
Most recent PNOA orthophotos	Mosaic of the latest orthophotos of the National Plan for Aerial Orthophotography (PNOA).	PNOA 2023 CC-BY 4.0 scne.es
Land cover	**Definition**	**Reference**
ESA WorldCover 10 m 2021 v200	Global land cover map for 2021 at 10 m resolution based on Sentinel-1 and Sentinel-2 data. Generated with different algorithm versions v200. Includes 11 land cover classes.	Zanaga et al. (2022).

Table 2: Summary of data used in the study. Obtained from CNIG and ESA.

To characterize the vegetation MDSnVegetación2,5 is used, and four types of vegetation are defined based on height: grass ($h \leq 0.1$ m), crops ($0.1 \text{ m} < h \leq 0.25$ m), shrubs ($0.25 \text{ m} < h \leq 3$ m) and trees ($h > 3$ m). To identify buildings' height MDSnEdificación2,5 is used. To complete the information ESA land cover data is added. For the Basque Country 8 land cover types are present, which are merged with the local vegetation layers to generate a unified land cover map. Built-up and bare areas, which can be problematic if they are bright or reflective, are defined as heat sources. Permanent water bodies and herbaceous wetlands are classified as water bodies. This new classification allows to assess the distance from the station to heat sources and water bodies. A distance grid is generated to represent the distance of each pixel from the station. For each type of land cover, the percentages of cumulative area are calculated based on the distances defined by the WMO (3 m, 5 m, 10 m, 30 m and 100 m circles and annulus of 5–10 m and 10–30 m). For the vegetation parameter, the percentage of grass and the percentage of crops are assessed. For each predefined distance interval, the percentages of grass and crop cover are added together, and the average of all intervals is calculated to obtain a single indicator. If the indicator for grass is greater than 51 %, the site is classified as Class 1; if the combined percentage of grass and crops is greater than 51 %, it is classified as Class 3; for lower percentages it is classified as Class 4.
To compute the shade parameter the software GRASS (2025) is used. The datasets include two digital elevation models with a 2 m grid resolution (MDT02-cob2) and a 25 m grid resolution (MDT25-cob2) and a digital surface model (MDS02). The higher-resolution MDT02 model and MDS02, which includes vegetation and buildings, are evaluated within a 100 m radius, the lower-resolution MDT25 model extends to a radius of 1 km. For each dataset, the horizon angles are calculated, and for each azimuth the maximum obstruction angle from these datasets is retained. For the shade parameter, the WMO criteria are slightly modified, with Class 3 being redefined as away from all projected shade when the sun is higher than 15°. The slope is computed using the median value within a radius of 100 m based on MDT02.

❑ Results

Among the stations measuring air temperature, none are Class 1. There is only one Class 2, 9 are Class 3, 21 are Class 4 and 62 are Class 5. Most Class 5 stations do not meet the shade requirements. Since most of gauging and water quality stations –26 and 21 respectively– are situated in river basins, they are frequently shaded by nearby trees or buildings. Solely for the shade parameter 95 % of the water quality stations and 65 % of the gauging stations are Class 5. The vegetation parameter is also very demanding, with up to 80 % of stations classified as Class 4. In contrast, for the slope parameter, 85 % of stations are Class 1. The land type parameter provides a more heterogenous classification.
Selecting the stations with a more rigorous criteria (sensor height between 1.25 m and 2 m), 48 stations are selected: 31 meteorological stations, 12 gauging stations and 5 water quality stations. The siting classification results in one station as Class 2 and 9 stations as Class 3, all of them meteorological. 13 stations are classified as Class 4 and 25 as Class 5. Among the 25 Class 5 stations, 10 are gauging stations and 5 are water quality stations. This means that all water quality stations with the sensor at a suitable height are Class 5 and 83 % of the gauging stations are also Class 5.
Hence, most representative stations for air temperature measurements in the Basque AWS network are 10 Class 2 and 3 meteorological stations, whose temperature sensors are situated within 1.25 to 2 m. Unfortunately, 8 of the 10 stations are located on the Mediterranean basin and only two of the stations are situated on the Cantabrian basin.
In summary, in the Mediterranean basin the air temperature measurements are representative of a wider area, while in the Cantabrian basin most of the stations are installed in an inappropriate environment for meteorological measurements and climate-oriented studies.

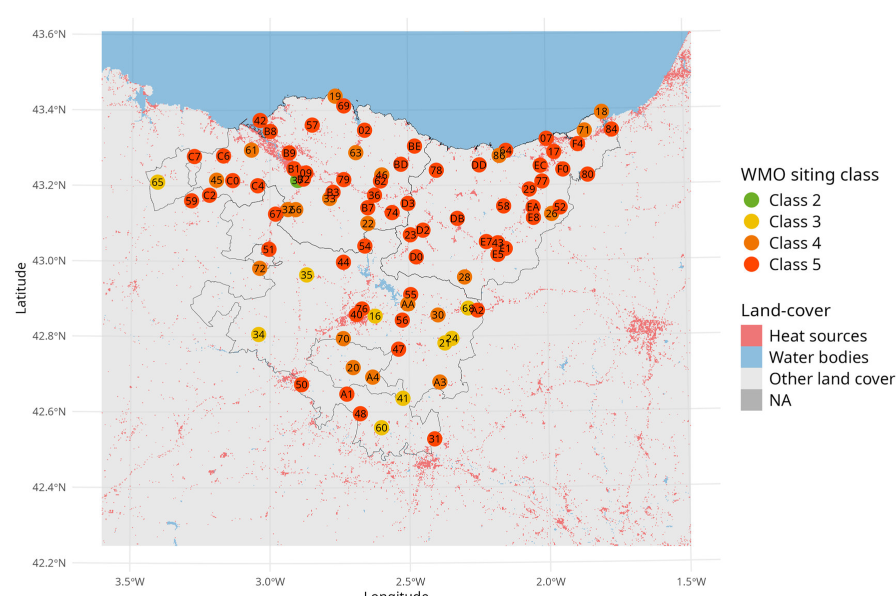


Fig. 2: Siting classification for the Basque AWS network measuring air temperature. Classifications ranging from 2 to 5 (green, yellow, orange and red respectively). Mask: ESA WorldCover 10 m 2021.

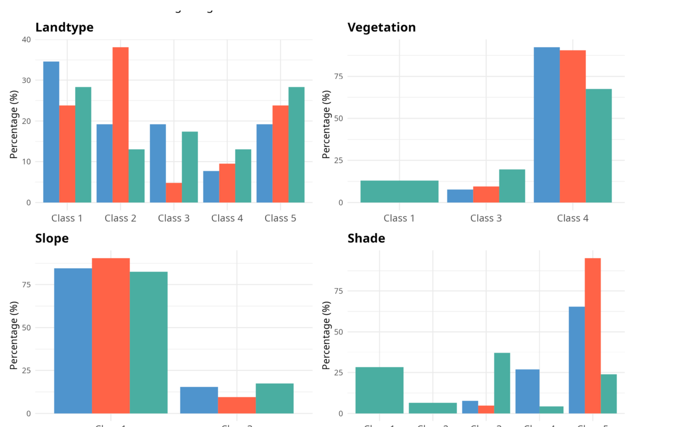


Fig. 3: Percentages of siting classifications by land type (top left), vegetation (top right), slope (bottom left) and shade (bottom right) for gauging stations (blue), water quality stations (red) and meteorological stations (green) for the Basque AWS network measuring air temperature.

3. Quality Control

The QC system in the Basque AWS network is integrated by four components: i) laboratory calibration, ii) maintenance services, iii) automated routines, and iv) manual inspection. Each component provides valuable information on the operation of the network, and their results are shared across the system to ensure the accuracy of the data. The components are subject to varying temporal parameters, ranging from the moment at which data is recorded to the analysis of its quality over time.

The main scheme of automated QC procedures is based on classification rules. Several levels of data validation have been defined, which are successively applied to meteorological variables, trying to check their consistency in different aspects: i) internal consistency, ii) pre-established limits, iii) temporal consistency, iv) internal consistency, v) spatial consistency (Hernández et al., 2012).

Time	Technical analysis
Seconds	Data checked at the AWS datalogger
Minutes	Missing data recovery Automated QC procedures
Hours	Visual inspection of raw data
Days	Trouble mails issued to maintenance service
Weeks	Visual inspection of raw and aggregate data Missing data report
Months	Supervised QC procedures Preventive or corrective maintenance
Year	Sensor calibration Instrument updating

Table 3: Timescales of QC procedures used by the Basque AWS network (based on Shafer et al., 2000).

4. Homogenization

The homogenization method has been carried out using ACMANTv4.4 software, applied to QC-daily dataset (maximum temperature TX and minimum temperature TN). The first version of homogenized data have been processed without metadata, but there is an intention to generate a second version by cross-checking the ACMANTv4.4 results with it. Regardless of their WMO SC, stations with numerous breaks in their time series or with significant breaks should be excluded from climatological analyses.

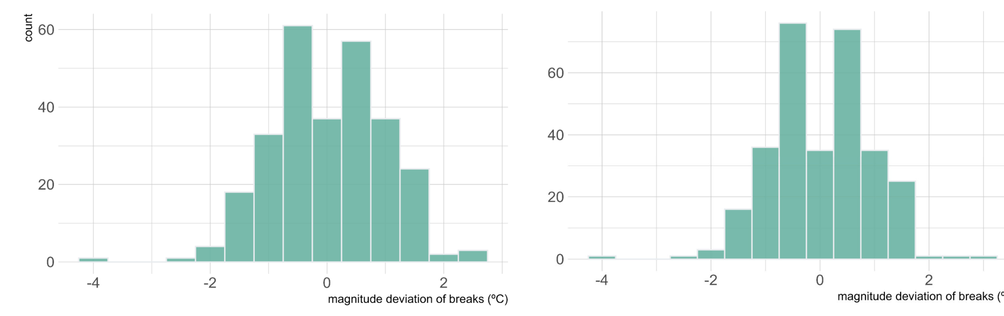


Fig. 4: magnitude deviation of breaks in TX (left) and TN (right).

N. Series with breaks		Avg. deviation magnitude (°C)		Avg. break (years)	
TX	TN	TX	TN	TX	TN
90	90	0.77	0.73	9	8.2

Table 4: Some statistics of the homogenization with ACMANTv4.4 in TX, TN and RR daily series.

5. Conclusions

This is a very relevant topic for a regional climate network such as Euskalmet, where stations were often designed for operational hydrometeorology rather than climate monitoring. A logical framework is to address the three pillars sequentially: i) WMO SC - How good is the station location?, ii) QC - Is the recorded data physically and technically valid? And iii) Homogenization - Are the long-term series climatically consistent through time? These three components are complementary, poor siting can generate biases, QC identifies erroneous values, and homogenization removes artificial discontinuities from the historical record.

The study helped the Basque Meteorology Agency identify the most representative stations for temperature measurements. Gauging and water quality stations have poorer siting classifications, largely due to the shade parameter. It should be noted that the main objective of these stations is to monitor river levels. For this reason, they require specific locations within river basins and in urban flood-prone areas. These locations are opposed to ideal sites for temperature measurement. Consequently, Class 2 or 3 sites are meteorological stations, and most of them are located on the Mediterranean basin, where the terrain is not as complex as on the Cantabrian basin and there is also less urban development. Many of the Class 4 meteorological stations are affected by vegetation, whilst Class 5 stations are affected by shade and land type. Those stations are sited in environments that are unsuitable for representative measurements. Therefore, this analysis has highlighted the need to expand the Basque AWS network to include representative temperature measurements, in particular on the Cantabrian basin.

This study opens up some interesting new avenues of research. For example, investigating the relationship between the class assigned, temperature bias and homogenization adjustments. Do Class 4–5 stations show larger warm/night-time biases? Do poorly sited stations require larger homogenization adjustments?

6. Final Remarks

As a result of the study, individual technical data sheets have been created for each station. The data sheets contain information on the station's characteristics, such as the date of installation, its elevation, the siting classification for air temperature measurements according to WMO criteria; information on the station's surroundings, including orthophotos, land cover maps, digital surface models and elevation models; as well as summary tables detailing the land type in the station's surroundings. The sheets also provide a graphical representation of the position of the sun and the maximum horizon.
Future work will focus on extending the analysis to the siting classification of stations measuring precipitation. Furthermore, recently the Spanish National Geographic Institute's download center, as of 2026, has incorporated third-generation digital elevation models with a 0.5 m grid spacing for the Basque Country. These models, combined with future high-resolution digital surface models, will enable a more precise siting classification. Likewise, the results of the algorithm must be validated against an in-situ classification of the Basque AWS network.

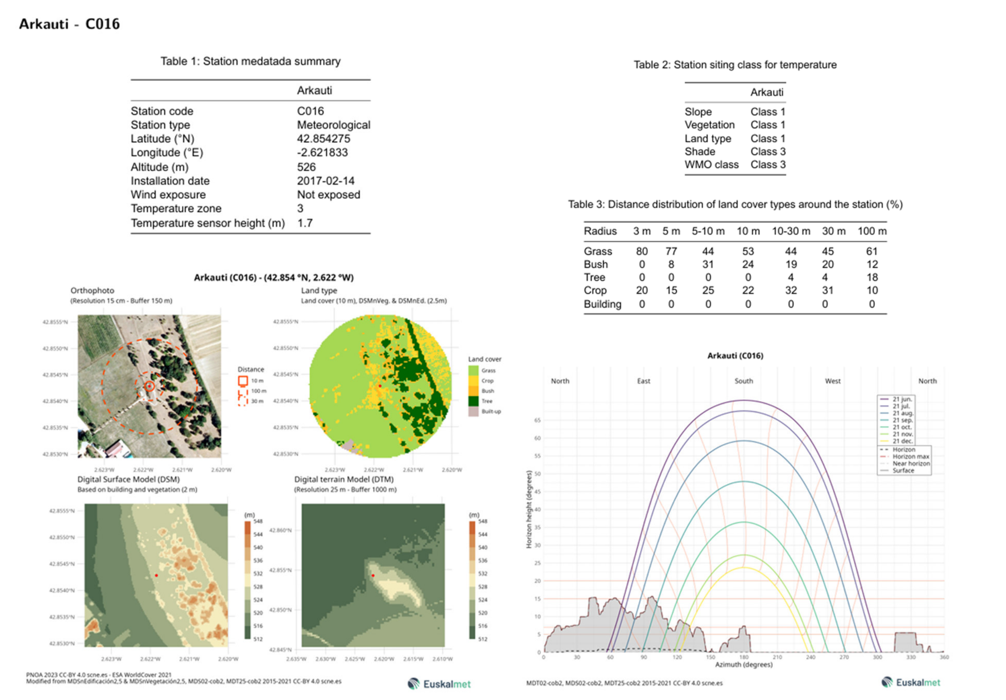


Fig. 5. technical data sheet for an AWS.

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