https://doi.org/10.18406/2316-1817v18nunico20262109 e-ISSN 2316-1817

Automation in the measurement and dissemination of agrometeorological data in Southern Triângulo Mineiro

Mateus Felipe Couto Lino[1], Euripedes Antonio de Oliveira[2], Sergio Carlos Portari Junior[3], Daniela Fernanda da Silva Fuzzo[4], João Alberto Fischer Filho[5]

[1] Universidade do Estado de Minas Gerais – Frutal. E-mail: mateus.1095828@discente.uemg.br
[2] Universidade do Estado de Minas Gerais – Frutal. E-mail: euripedesoliveiraguitarra@gmail.com
[3] Universidade do Estado de Minas Gerais – Frutal. E-mail: sergio.junior@uemg.br
[4] Universidade do Estado de Minas Gerais – Frutal. E-mail: daniela.fuzzo@uemg.br
[5] Universidade do Estado de Minas Gerais – Frutal. E-mail: joao.fischer@uemg.br

Received in: 19/12/2025
Accepted in: 22/04/2026

Abstract

Agrometeorology is the science that studies the interactions of atmospheric conditions with agricultural activities, being strategic for rural and environmental planning. The absence of local, easily accessible, and real-time meteorological data compromises management efficiency, sustainability, and crop productivity in southern Triângulo Mineiro. Thus, the objective was to develop a system to automate the collection and dissemination of agrometeorological data via the internet of things. Overall, five agrometeorological stations were installed in four municipalities and one district in the region. The system was developed in an architecture based on microservices. The analysis of information availability was evaluated by data quality assurance and quality control, whereas usability was determined by the System Usability Scale and UMUX-Lite. The platform (www.redeagromet.com.br) was published online. Data dissemination availability and punctuality were higher than 96 %, indicating efficient agrometeorological monitoring. The values obtained by the System Usability Scale (82) and UMUX-Lite (77) indicate that the platform has an accessible and easy-to-understand panel. The development of the platform filled an informational gap, providing agrometeorological data in real time via the internet of things, thus subsidizing decision-making by farmers, technicians, and researchers and strengthening the resilience of regional agriculture to climate risks.

Keywords: Climate monitoring. Internet of things. Meteorology.

Introduction

Precision agriculture is configured as a data-driven socio-technical arrangement (Carlesso, Petry, Trois, 2009) that articulates agricultural management practices with an infrastructure of sensors, communication, georeferencing, and information systems, reducing uncertainties and expanding the basis for decisions in the field. From this, the recording of agrometeorological data occupies a central position in the operationalization of activities linked to water management, climate risk assessment, and synchronization of agricultural operations (Romani *et al*., 2016).

Brazil has a heterogeneous spatial coverage of agrometeorological stations and asymmetries in access to operational data by rural producers and technicians. Thus, public web platforms structured as management information systems offer an alternative to make observational series, derived indicators, and consultation products available more easily.

Southern Triângulo Mineiro has a relevant economic expression in agribusiness, with emphasis on the production of grains, sugarcane, and fruit trees (Minas Gerais, 2023). However, it lacks accurate and accessible local weather data. This informational gap results in inappropriate decisions in agricultural activities (such as irrigation management, input application, and operation planning), causing productivity and economic losses (Alencar *et al*., 2015).

The low density of meteorological stations and the difficulties in accessing real-time data are significant limitations for the development of precision agriculture in the region (Sousa *et al*., 2015). In this sense, the Agrometeorological Network of Southern Triângulo Mineiro (RedeAgromet) is inserted as an alternative in the systematic support of agricultural activities in the region.

Internet of things (IoT) makes it possible to automate data collection by sensors and transmit them to centralized systems. The convergence of IoT, web services, and data visualization organizes flows from collection to publishing. This organization brings transparency about the quality, periodicity, and limitations of measurements (Hachimi *et al.*, 2023).

According to Puig, Rodríguez-Díaz, and Soriano (2022), low-cost platforms and open firmware enable continuous measurements and integration with control routines, such as irrigation management. In Brazil, public services offer meteorological and agrometeorological data in multiple cutouts and formats with varying levels of access.

The Meteorological Database for Teaching and Research of the National Institute of Meteorology gathers daily historical series from conventional and automatic stations. Agritempo is an Agrometeorological Monitoring System with municipal- and state-scale access to information. The Integrated Center for Agrometeorological Information of the Agronomic Institute provides state analyses and operational products with a focus on São Paulo (IAC, 2025). The National Center for Monitoring and Alerts of Natural Disasters publishes data and alerts aimed at reducing disaster risk and offers access by portal and an application programming interface (API) (CEMADEN, 2025; Ladder *et al*., 2021). These services complement national coverage and reinforce the public role of information, providing local confidence and knowledge to research and public policy (Bharwani, Williamson, Butterfield, 2025).

Regarding Southern Triângulo Mineiro, Fischer Filho *et al*. (2025) reported on RedeAgromet during its dissemination phase via social networks. The publication of bulletins and alerts indicates informational demand and adherence by the target audience, but the authors report a need to transform these data for the technical and specialized public. In view of this, despite some existing infrastructures, there is a need for public web platforms structured by the automation of the data collection and dissemination system that act as management information systems.

This research was carried out with the objective of developing and implementing a web platform via IoT to automate and share agrometeorological data in Southern Triângulo Mineiro.

Material and methods

This research in technological development was structured in three stages: data collection infrastructure implementation, software development, and information dissemination.

Study area and data collection infrastructure

The study area covers Southern Triângulo Mineiro in Minas Gerais, with agrometeorological stations installed in four municipalities and one district (Table 1). The monitored locations have an average annual rainfall from 1,400 to 1,500 mm, with rainfall concentrated from October to March. The average annual maximum temperature varies from 30 to 33°C and the average minimum temperature from 16 to 18°C, according to climatological standards 1991–2020 of the National Institute of Meteorology (INMET, 2022).

The region has a predominance of Aw climate (Koppen) and seasonal rainfall characterized by a rainy season in the summer and a dry season in the winter (Vieira *et al.*, 2024), a condition that motivates daily aggregations and gap control.

Table 1. Agromet agrometeorological stations installed in Southern Triângulo Mineiro, with their respective geographic coordinates, altitude, telemetry protocol, and data collection method.

Location	Coordinates	Altitude (m)	Telemetry	Data collection
Aparecida de Minas, district of Frutal	−20.11361; −49.23111	460.0	GSM/4 G	FTP
Frutal	−20.01889; −48.95083	519.0	GSM/4 G	FTP
Planura	−20.14963; −48.70077	450.0	GSM/4 G	API
Prata	−19.06262; −48.99600	659.3	GSM/4 G	API
São Francisco de Sales	−19.79770; −50.02290	403.6	GSM/4 G	API

Source: authors (2026).

The empirical object is a heterogeneous network of agrometeorological stations that collect and send automated data using two IoT protocols: File Transfer Protocol (FTP) and application programming interfaces (APIs).

Each agrometeorological station was equipped with sensors to monitor the climate at several intervals, including the collection of agrometeorological and operational elements (Table 2).

Temporal aggregations follow different criteria according to the physical nature of each variable. Rainfall is computed by accumulated measurements — adding the 15-minute readings to obtain the daily and monthly totals. The other variables (air temperature, relative humidity, solar radiation, wind speed, atmospheric pressure, and evapotranspiration) are summarized by the arithmetic average of their hourly and daily readings (with the additional reading of the minimum and maximum values for air temperature).

Reference evapotranspiration (ETo) — calculated by the Penman–Monteith FAO-56 method — stands out among the derived products (Allen *et al.*, 1998).

System architecture and used technologies

The system has an architecture based on microservices organized into the following layers: from edge to acquisition, cloud for ingestion and persistence, and application for APIs, visualization, and export (Table 3).

The data ingestion and processing routine uses AWS Lambda, a serverless computing service that enables the scheduling of functions, the main option due to elasticity and cost per execution. The primary database is Supabase/PostgreSQL, with <timestamptz> (a type of timestamp data with time zone), JSON, and triggers.

Table 2. Agrometeorological variables monitored by the Agromet Network stations, with their respective units of measurement and temporal collection resolutions.

Parameter	Unit of Measure	Resolution
Accumulated rainfall	mm	15 minutes/day
Air Temperature (Current, Min., Average, Max.)	°C	15 minutes/hour
Relative air humidity	%	15 minutes/hour
Global solar radiation	W/m^2	15 minutes/hour
Wind speed	m/s	15 minutes/hour
Atmospheric pressure	hPa	15 minutes/day
Evapotranspiration (Calculated)	mm	15 minutes/hour

Source: authors (2026).

Table 3. Software architecture of the RedeAgromet platform, organized by functional layers, with the used technologies and their respective purposes in the system.

Layer	Technologies	Main purpose
Acquisition/Edge	GSM/4 G stations; FTP; APIs	Collection and dissemination of station readings for ingestion.
Ingestion/ compute	AWS Lambda; EventBridge	Resilient scheduled serverless execution for extract, transform, and load (ETL) processes
Persistence	Supabase/PostgreSQL	Temporal storage with <timestamptz>, JSON, and triggers.
Authentication	Better-Auth + MySQL	Management of credentials, JWT sessions, and email confirmation.
Web application	Next.js; React; TypeScript	Implementation of APIs, rendering and routing of pages.
Visualization	Plotly.js; Recharts; Leaflet	Interactive graphics and themed maps.
Publishing/ observability	Vercel	Deploy and monitoring in the Analytics panel.
Export	CSV; XLSX; PDF	Generation of files and reports for external use.

Source: authors (2026).

The auxiliary database MySQL stores Better-Auth entities with JWT-JSON Web Token sessions (a signed token format)—and email confirmation. Frontend adopted Next.js (App Router), React, and TypeScript.

Visualizations use the Plotly and Recharts libraries. Maps employ the Leaflet library. Export is performed to CSV, XLSX, and PDF formats. Hosting takes place at Vercel, with observability in the Analytics panel.

Dissemination of information and usability evaluation

The implementation phase involved the publication of the website in its own domain. For this, domain registration, the hiring of the services of a commercial provider, and the publication and updating of the disseminated information were carried out.

The analysis of the agrometeorological data was accompanied by QA/QC (quality assurance/ quality control) measures (Faybishenko *et al*., 2022). Observed data quality control is based on the verification of ranges of physically plausible and climatologically coherent values for the region. Table 4 establishes the criteria for automatic rejection (hard-fail) and consistency alert (soft-warn) applied to each variable during the ingestion process based on international guidelines on instrumentation and agrometeorology.

Table 4. Quality control criteria (QA/QC) applied during data ingestion, with hard-fail and soft-warn thresholds per agrometeorological variable.

Agrometeorological element	Hard-fail	Soft-warn
Air temperature	[−10, 50] ºC	[−5, 45] ºC
Relative humidity	[0, 100] %	[10, 100] %
Solar radiation	[0, 1400] W/m^2	[0, 1200] W/m^2
Rainfall (15 min)	[0, 200] mm	[0, 50] mm
Wind speed	[0, 50] m/s	[0, 30] m/s
Atmospheric pressure	[800, 1100] hPa	[900, 1050] hPa

Source: Adapted from World Meteorological Organization (2018) and Allen *et al*. (1998).

In addition to the fixed hard-fail and soft-warn thresholds, historical series of the stations were used to calculate the interquartile range of each variable, enabling the identification of statistically inconsistent outliers with the local climatological behavior. Readings that exceeded 1.5x the interquartile range relative to the first and third quartiles were flagged for inspection, giving the system an additional layer of quality control sensitive to the seasonal variability of the region.

The usability evaluation followed a moderate pilot design, with an intentional sample of five participants representing the target audience. Tasks were defined in line with usage scenarios: search the daily station ETo, export series, interpret availability and punctuality, and locate operational alert. Success rate per task, completion time, observed errors, and perception were measured using the System Usability Scale (SUS) and UMUX-Lite instruments.

SUS is a standardized 10-item questionnaire that produces a score from 0 to 100, widely used as a global measure of usability (Brooke, 1996). The UMUX-Lite is a simplified version with two items that captures perceived usefulness and ease of use via a normalized score from 0 to 100, appropriate under strongly restricted application time (Lewis; Utesch; Maher, 2013).

Results and discussion

The RedeAgromet platform (www.redeagromet.com.br) offers real-time agrometeorological monitoring (Figure 1A), providing (i) visualization of meteorological parameters by a responsive interface, (ii) analysis of historical series by interactive graphs, (iii)

Figure 1. (A) Public home page of the RedeAgromet platform. **(B)** Overview of the agrometeorological monitoring system with station selection, near-real-time indicators, and interactive map of the stations.

A

B

Source: authors (2026).

access to reference evapotranspiration data (calculated by the Penman-Monteith FAO-56 method), (iv) export of data in multiple formats, and (v) geospatial consultation of the stations via a cartographic interface (Figure 1B).

The developed computational architecture can acquire, transmit, store, and process data. Muangprathub *et al*. (2019) implemented a similar system, developing a web application to manipulate crop data and field information. The authors designed a web application using large-scale IoT data that are stored and used in data analysis. In view of this, systems that use IoT to disseminate agrometeorological data are a tool to support agricultural and social management, acting as an agent of sustainable development in a region subject to climate variations.

Table 5 summarizes availability and punctuality by agrometeorological station, in which availability indicates the ratio between valid and expected observations on each day and punctuality refers to the fraction of observations received within the operational cut-off time.

For active agrometeorological stations, the average availability remained close to 96 %, with similar punctuality. The rejections by physical bands were concentrated in solar radiation readings outside the daytime period, being consistent with usual quality control rules and indicating no systematic anomalies in the other meteorological elements. RedeAgromet users need relevant information for their work. So, during the operational phase of a climate information portal, a structured QA/QC system is necessary to consolidate the credibility of the system (Swart *et al*., 2017).

In low-cost stations, Puig, Rodríguez-Díaz, and Soriano (2022) highlight the importance of QA/QC routines in observation quality. Thus, corroborating the results, Patro and Bartakke (2025), analyzing the quality of data availability from 13 automatic weather stations in the districts of Pune, Maharashtra, India, via range and consistency checks, obtained high reliability, in which the average data validity exceeded 95 % in key parameters, indicating its effectiveness for accurate meteorological monitoring.

Given the robustness of the provided data, this technological infrastructure enables scientific applications in agrometeorology, including modeling of water balances, determination of bioclimatic indices, temporal optimization of agricultural practices based on specific meteorological thresholds, and quantitative support for decision-making in sustainable agricultural management.

The usability test obtained adequate performance of the main tasks and favorable global perception (Table 6).

Table 5. Availability and daily punctuality of observations by the RedeAgromet agrometeorological station, in which availability is the ratio between valid and expected observations and punctuality the fraction received within the operational cut-off time.

Location	Availability	Punctuality
Aparecida de Minas	95.9 %	95.2 %
Frutal	96.8 %	95.9 %
Planura	96.2 %	96.0 %
Prata	96.4 %	96.0 %
São Francisco de Sales	95.7 %	95.1 %

Source: authors (2026).

Table 6. Results of the pilot usability test of the RedeAgromet platform, with success rate, median time to completion, average errors, and usability scores perceived by the SUS and UMUX-Lite methods per evaluated task.

Task	Success (%)	Median (s)	Errors (average)	SUS	UMUX-Lite
Consult ETo per station	100	28	0.2	82	77
Export daily series in CSV	100	42	0.4	82	77
Interpret availability and punctuality	80	55	0.6	82	77
Find operational alert	80	49	0.8	82	77

Source: authors (2026).

Note that the usability test was conducted on a pilot basis with an intentional sample of five participants, representing a limitation of this study. Thus, the SUS and UMUX-Lite scores should be interpreted as preliminary indicators. Future studies with broader and more diversified samples, including farmers, technicians, and researchers at different levels of familiarity with digital tools, are recommended to consolidate the evaluation of the usability of the platform.

The platform has an accessible search panel with operational indicators of availability and state of the stations, as well as exports that meet workflows in external analysis (Table 6). These scores are consistent and close to the median for software usability (a SUS score of 68) (Brooke, 2013).

However, there are residual difficulties in interpreting the availability and punctuality indicator and in locating alerts. These findings suggest reinforcement of labels and greater visual prominence in these components. Median completion times remained below one minute on all tasks, which is considered satisfactory.

The stable integration between the sensors in the field, the digital infrastructure, and the visualization system were considered robust and scalable, enabling the future expansion of the network and the development of new analytical modules, such as frost or pest- and disease-friendly conditions alerts.

Conclusions

This research implemented a web platform to disseminate agrometeorological data in real time, integrating FTP and API protocols for the automated acquisition of meteorological data from five stations in Southern Triângulo Mineiro.

The developed computational architecture showed operational efficiency in the collection, processing, and visualization of meteorological data, including the implementation of the Penman-Monteith FAO-56 algorithm to calculate e reference evapotranspiration values and export functionalities in multiple formats.

The results confirm the feasibility of the developed solution as an agrometeorological monitoring tool and its satisfactory availability and punctuality, contributing to the modernization of regional agriculture via easy access to meteorological information of scientific-quality.

RedeAgromet establishes a technological solution for democratizing access to regional agrometeorological information, providing users of the agricultural sector with fundamental data for decision-making based on scientific evidence.

Acknowledgments

To the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) and to the Programa Institucional de Apoio à Pesquisa (PAPq/UEMG) for financial support and scholarships.

References

ALENCAR, L. P.; SEDIYAMA, G. C.; MANTOVANI, E. C. Estimativa da evapotranspiração de referência (ETo padrão FAO) para Minas Gerais, na ausência de alguns dados climáticos. **Engenharia Agrícola**, v. 35, p. 39–50, 2015. DOI: https://doi.org/10.1590/1809-4430-Eng.Agric.v35n1p39-50/2015.

ALLEN, R. G.; PEREIRA, L. S.; RAES, D.; SMITH, M. **Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements.** Rome: FAO, 1998. 300 p.

BHARWANI, S.; WILLIAMSON, K.; BUTTERFIELD, R. Measuring what matters: Building impact pathways to actionable information for the weADAPT platform. **Climate Services**, v. 38, p. 100574, 2025. DOI: https://doi.org/10.1016/j.cliser.2025.100574.

BROOKE, J. SUS: a quick and dirty usability scale. In: JORDAN, P. W.; THOMAS, B.; McCLELLAND, I. L.; WEERDMEESTER, B. (org.). **Usability evaluation in industry**. London: Taylor & Francis, 1996, p. 189–194.

BROOKE, J. SUS: a retrospective. **Journal of Usability Studies**, v. 8, n. 2, p. 29–40, 2013.

CARLESSO, R.; PETRY, M. T.; TROIS, C. The use of a meteorological station network to provide crop water requirement information for irrigation management. In: LI, D.; ZHAO, C. (org.). **Computer and computing technologies in agriculture II**. Boston: Springer, 2009. p. 381–390.

CEMADEN - CENTRO NACIONAL DE MONITORAMENTO E ALERTAS DE DESASTRES NATURAIS. **Sobre o Cemaden**. Brasília: Ministério da Ciência, Tecnologia e Inovações, 2025. Disponível em: https://www.gov.br/cemaden/pt-br/paginas/sobre-o-cemaden. Acesso em: 9 out. 2025.

ESCADA, P.; COELHO, C. A.; TADDEI, R.; DESSAI, S.; CAVALCANTI, I. F.; DONATO, R.; KAYANO, M. R.; MARTINS, E. S. P. R.; MIGUEL, J. C. H.; MONTEIRO, M.; MOSCATI, M. C. Climate services in Brazil: past, present, and future perspectives. **Climate Services**, v. 24, p. 100276, 2021. DOI: https://doi.org/10.1016/j.cliser.2021.100276.

FAYBISHENKO, B.; VERSTEEG, R.; PASTORELLO, G.; DWIVEDI, D.; VARADHARAJAN, C.; AGARWAL, D. Challenging problems of quality assurance and quality control (QA/QC) of meteorological time series data. **Stochastic Environmental Research and Risk Assessment**, v. 36, n. 4, p. 1049–1062, 2022. DOI: https://doi.org/10.1007/s00477-021-02106-w.

FISCHER FILHO, J. A.; OLIVEIRA, E. A.; ASSUNÇÃO, F. J. M.; MARTINS, B. A.; FUZZO, D. F. S. RedeAgromet: compartilhando informações agrometeorológicas do Triângulo Mineiro Sul. **ELO – Diálogos em Extensão**, v. 14, p. 1–10, 2025. DOI: https://doi.org/10.21284/elo.v14i.21568.

HACHIMI, C. E.; BELAQZIZ, S.; KHABBA, S.; SEBBAR, B.; DHIBA, D.; CHEHBOUNI, A. Smart weather data management based on artificial intelligence and big data analytics for precision agriculture. **Agriculture**, v. 13, p. 95, 2023. DOI: https://doi.org/10.3390/agriculture13010095.

IAC - INSTITUTO AGRONÔMICO DE CAMPINAS. **CIIAGRO – Centro Integrado de Informações Agrometeorológicas: portal.** Campinas, 2025. Disponível em: https://www.ciiagro.org.br/. Acesso em: 9 out. 2025.

INMET – INSTITUTO NACIONAL DE METEOROLOGIA. **Normais climatológicas do**

Brasil 1991–2020. Brasília: INMET, 2022. Disponível em: https://portal.inmet.gov.br/normais. Acesso em: 9 out. 2025.

LEWIS, J. R.; UTESCH, B. S.; MAHER, D. E. UMUX-Lite: when there's no time for the SUS. In: **CHI '13 Extended Abstracts on Human Factors in Computing Systems**. New York: ACM, 2013. p. 2099–2102.

MINAS GERAIS. **Fóruns regionais**. Belo Horizonte: Agência Minas, 2017. Disponível em: http://static.agenciaminas.mg.gov.br/ckeditor_assets/attachments/3515/2017_09_21_entregas_triangulo_sul.pdf. Acesso em: 1 mar. 2023.

MUANGPRATHUB, J.; BOONNAM, N.; KAJORNKASIRAT, S.; LEKBANGPONG, N.; WANICHSOMBAT, A.; NILLAOR, P. IoT and agriculture data analysis for smart farm. **Computers and Electronics in Agriculture**, v. 156, p. 467–474, 2019. DOI: https://doi.org/10.1016/j.compag.2018.12.011.

PATRO, B. S.; BARTAKKE, P. P. Quality control (QC) and quality assurance (QA) procedures for meteorological data from automatic weather stations. In: I**nternational Conference on Range Technology (ICORT)**, 4., New York. New York: IEEE, 2025. p. 1–6.

PUIG, F.; RODRÍGUEZ-DÍAZ, J. A.; SORIANO, M. A. Development of a low-cost open-source platform for smart irrigation systems. **Agronomy**, v. 12, n. 12, p. 2909, 2022. DOI: https://doi.org/10.3390/agronomy12122909.

ROMANI, L. A. S.; BAMBINI, M. D.; COLTRI, P. P.; JUNIOR, A. L.; KOENIGKAN, L. V.; OTAVIAN, A. F.; EVANGELISTA, S. R. M.; ZULLO JÚNIOR, J.; PINTO, H. S.; ASSAD, E. D. Sistema de monitoramento agrometeorológico - Agritempo: inovação em rede apoiando políticas públicas e a tomada de decisão agrícola. **Agrometeoros**, v. 24, n. 1, p. 29–40, 2016. DOI: https://doi.org/10.31062/agrom.v24i1.24879.

SOUSA, M. M.; DRUMOND, L. C. D.; NALDI, M. C. Sistema computacional para aquisição automática e disponibilização de dados meteorológicos. **Engenharia Agrícola**, v. 35, p. 606–612, 2015. DOI: https://doi.org/10.1590/1809-4430-Eng.Agric.v35n3p606-612/2015.

SWART, R. J.; BRUIN, K.; DHENAIN, S.; DUBOIS, G.; GROOT, A.; VON DER FORST, E. Developing climate information portals with users: promises and pitfalls. **Climate Services**, v. 6, p. 12–22, 2017. DOI: https://doi.org/10.1016/j.cliser.2017.06.008.

VIEIRA, J. C. A.; ROSA, G. B.; FUZZO, D. F. S.; FISCHER FILHO, J. A. Balanço hídrico climatológico e calibração do sistema NASA Power para a região Sul do Triângulo Mineiro, Brasil. **Fronteiras: Journal of Social, Technological and Environmental Science**, v. 13, n. 4, p. 75–87, 2024. DOI: https://doi.org/10.21664/2238-8869.2024v13i4.p75-87.

WORLD METEOROLOGICAL ORGANIZATION. **Guide to meteorological instruments and methods of observation**. 7. ed. Geneva: World Meteorological Organization, 2008. 681 p. (WMO-No. 8).