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Real-Time Aviation Weather Decision Support System Using Indonesian Meteorology, Climatology and Geophysics Data

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Abstract

Accurate and timely weather information is a fundamental requirement for safe aviation operations. However, conventional coded weather reports demand rapid interpretation under operational pressure, which increases the risk of delay and misinterpretation, particularly in military flight environments. This study aims to design and implement a real-time aviation weather decision support system for flight operations at Roesmin Nurjadin Air Force Base in Pekanbaru, utilizing open data provided by the Indonesian Agency for Meteorology, Climatology, and Geophysics. The research employed a development methodology consisting of needs analysis, system design, implementation, and evaluation. The system was developed in Python using scientific and visualization libraries and deployed through a web-based framework for unrestricted access. It integrates live meteorological reports, terminal forecasts, gridded weather predictions, and satellite imagery into a single interactive dashboard. The platform provides decoded weather reports, twenty-four-hour meteograms, wind roses, and trend charts, and automatically generates standardized briefing documents. Verification confirmed that decoded outputs were consistent with official meteorological data and that fallback mechanisms operated correctly. The findings demonstrate that the system accelerates situational awareness and strengthens pre-flight decision-making. Future work is recommended to evaluate usability and operational effectiveness in military and civil aviation contexts.

INTRODUCTION

Flight operations are highly sensitive to atmospheric conditions. Wind, visibility, cloud-base height, significant weather, and air pressure directly affect the safety of take-off, landing, and manoeuvring, so timely and accurate weather information is a prerequisite for sound operational decisions (Pattisina et al., 2025; Song & Ye, 2025). This sensitivity is even greater in military aviation,

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where aircrew and operations personnel at air force bases must interpret weather conditions rapidly and accurately before every training or operational sortie, because delay or misinterpretation can have immediate safety consequences (Cagnoni et al., 2026; Passarella et al., 2023).

In operational practice, aviation weather information is still frequently presented as standardized codes and manual briefing sheets that demand rapid interpretation under time pressure. Several studies have shown that transforming weather data into interactive visual dashboards enables faster and more meaningful interpretation than conventional tables or text (Bharath et al., 2024; Oktaviarini et al., 2024). A decision support system (DSS) built on actual weather data can therefore accelerate and strengthen operational decision-making.

The use of data-driven and web-based systems for high-impact, real-time weather decisions has been shown to improve both the quality and the speed of decisions, and modern civil-aviation meteorological services are increasingly moving toward intelligent, platform-based delivery (Song & Ye, 2025). Weather based decision support systems have been developed to recommend actions in response to specific conditions (Hasani & Sampurna, 2025), while the transformation of meteorological services from manual, static formats toward web-based systems has accelerated access to information (Irawan & Effiyaldi, 2021; Nugraha et al., 2022). In parallel, data-driven methods have markedly improved the prediction of hazardous low visibility events at the airport scale (Gultepe et al., 2023; Shankar & Sahana, 2023; Vorndran et al., 2023).

For operational purposes, weather conditions are reported in the standardized METAR (observation) and TAF (forecast) codes, which compress wind, visibility, significant weather, cloud, temperature, dew point, and pressure (QNH) into a single terse line (Oo et al., 2023). Although information-dense, these coded strings require manual decoding that is time-consuming and error-prone under operational pressure; automated decoding and visualization are therefore needed so that each coded element is presented as a directly actionable parameter.

The expansion of BMKG open-data services offers a strong opportunity to meet this need. The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) provides open data and Application Programming Interfaces (APIs) that deliver METAR/TAF observations, grid based forecasts, and satellite imagery in structured formats, enabling automatic, real-time updates (Sintaro & Kreckhoff, 2026). Live BMKG data can therefore serve as an authentic, integrated, and continuously updated basis for an operational decision support system.

Although these components are individually available, no web-based decision support system has yet been reported that specifically retrieves real-time weather data from the BMKG APIs METAR/TAF, forecasts, and satellite imagery and then decodes and visualizes them within a single integrated dashboard for flight-weather briefing at an air force base. This constitutes the research gap addressed here: prior work has largely treated data retrieval, decoding, and visualization separately, or has focused on predictive modelling rather than on integrated, deployable operational support. The novelty of this study lies in integrating live, multi-source BMKG open data into one publicly deployed dashboard that automatically decodes cryptic operational codes into readable parameters and standardized QAM briefing documents for a military air base a combination of data source, integration approach, and operational location not addressed in previous studies. In terms of implications, the system is expected to strengthen aviation weather information technology by accelerating situational awareness, reducing interpretation errors, and supporting safer and more efficient pre-flight decision-making, while providing a transferable model for other air bases and a foundation for further operational research. Accordingly, this study aims to develop a real-time aviation weather decision support system based on the BMKG APIs at Roesmin Nurjadin Air Force Base, following a Research and Development (R&D) approach (Waruwu, 2024).

METHODS

This study employed a Research and Development (R&D) approach, which emphasizes the systematic development of a product through needs analysis, design, implementation, and evaluation (Anidar et al., 2026; Cagnoni et al., 2026; Efendi et al., 2026; Engkizar et al., 2024, 2026; Irawan & Effiyaldi, 2021; Waruwu, 2024; Wu et al., 2009; Yulfiarti et al., 2026). The product developed is a decision support system (DSS) for aviation weather operations, delivered as a web-based dashboard whose data are drawn entirely from BMKG open-data services; the system has been deployed online and is publicly accessible without any intermediary at https://metar-lanud-ua8ocy57xypdivjtinbqew.streamlit.app/. The overall research stages are summarized in figure 1.

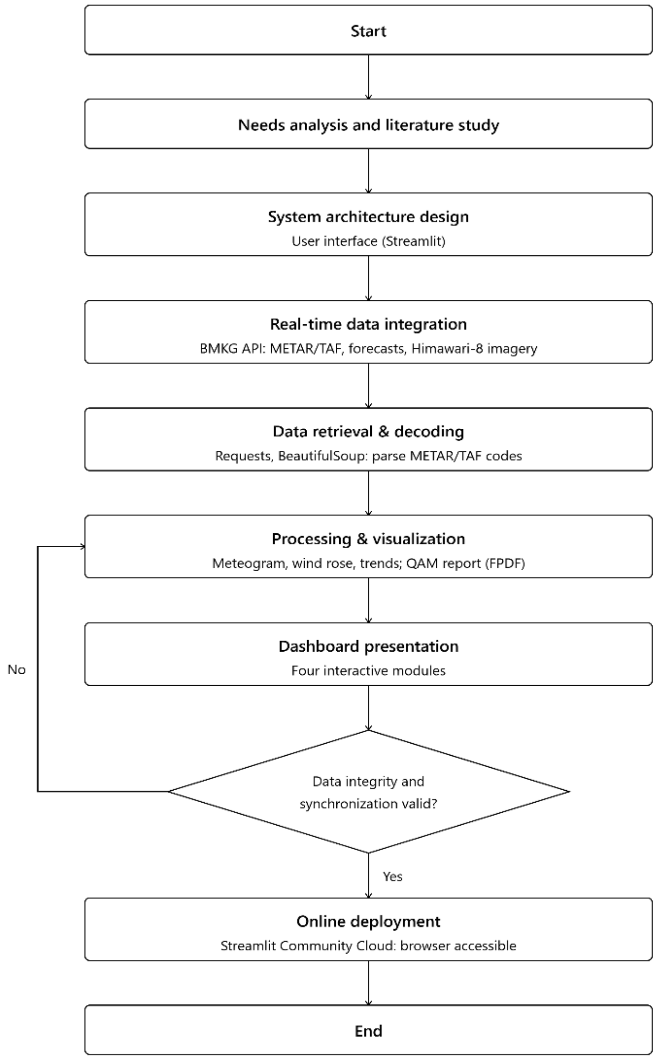

Fig 1. Flowchart of Decision Support System Development

Study Area

The study object is the aerodrome of Roesmin Nurjadin Air Force Base (Lanud RSN), Pekanbaru, Riau Province, Indonesia (ICAO: WIBB; approximately 0.46°N, 101.44°E). The Sultan Syarif Kasim II Class I Meteorological Station and Roesmin Nurjadin Air Force Base share the same runway within a single aerodrome (WIBB, Pekanbaru) in the form of a civil military enclave, so the surface observations collected by the station are representative of the meteorological conditions at the air force base. This location was selected because of its high level of military flight activity, which requires accurate and timely meteorological information to support weather briefing and the planning of military flight operations. Geographically, Pekanbaru lies in the eastern lowlands of central Sumatra, to the lee of the Bukit Barisan mountain range, and is strongly influenced by the Asian Australian monsoon and the convective regime of the Maritime Continent; these physical settings underlie the operational weather interpretation discussed later. The research location is shown in figure 2.

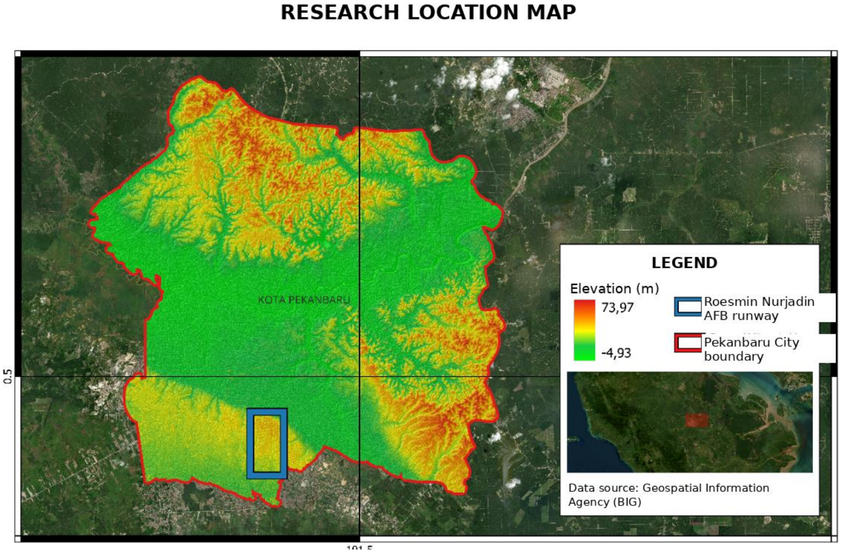

Fig 2. Research location: the aerodrome of Roesmin Nurjadin Air Force Base (WIBB), which shares a runway with the Sultan Syarif Kasim II Meteorological Station in Pekanbaru, Riau

Data Sources

All data used are real-time and obtained entirely from BMKG open-data services through API calls, without any offline historical dataset. Four complementary sources are used. First, METAR/SPECI observations and TAF aerodrome forecasts are retrieved from the BMKG aviation service (web-aviation.bmkg.go.id), containing surface wind, visibility, significant weather, cloud, temperature, dew point, and QNH pressure. Second, grid-based weather forecasts from the BMKG forecast API (cuaca.bmkg.go.id) provide temperature, relative humidity, wind direction and speed, and precipitation down to the district and city level. Third, Himawari infrared satellite imagery from BMKG is used to monitor cloud cover and convection. Fourth, international METAR services (AviationWeather.gov/NOAA and the OGIMET archive) serve as a fallback when the primary source is unavailable and also provide the most recent 24-hour METAR history. Station coverage includes dozens of Indonesian Air Force bases selected by ICAO code, with Roesmin Nurjadin Air Force Base (WIBB), Pekanbaru, as the primary reference station.

Research Tools

The system was developed in the Python programming language with supporting libraries. Requests, configured with a retry and fallback mechanism, was used for API calls, and Beautiful Soup for parsing the METAR/TAF codes from the BMKG service pages. Pandas and NumPy were used for data manipulation and aggregation, and Plotly for interactive visualizations, including meteograms, wind roses, and trend charts. Automated meteorological reports (QAM) were generated in PDF format using FPDF. The web interface was built with the Streamlit framework; the source code was managed in a GitHub repository and deployed online through Streamlit Community Cloud, allowing the system to be accessed through a web browser without installing additional software.

System Development Procedure

The development procedure follows the real-time data flow. First, the user selects an air base (ICAO code) or a forecast location. Second, the system calls the BMKG API and, if the primary source does not respond, automatically switches to the nearest station or a fallback source. Third, the raw METAR/TAF response is decoded into physical parameters wind, visibility, cloud, temperature, dew point, and pressure (QNH). Fourth, the grid forecast data are flattened into time series of weather parameters. Fifth, the parameters are visualized interactively and, for METAR specifically, summarized into a QAM report in PDF format. Finally, for the reference station, the most recent 24-hour METAR history is compiled into a five panel meteogram. The entire process runs automatically whenever data are requested, so the display always reflects the latest conditions.

Because the system depends entirely on network connectivity, data-retrieval reliability received particular attention. The Requests session was configured with tiered retries, and when a requested station is unavailable, the system displays data from the nearest station while notifying the user. A manual-input mode is also provided as a backup when communication links are lost, so that observation codes can still be processed and weather briefing can continue. These layered mechanisms maintain system availability across varying network conditions without changing the data source, which remains BMKG.

The decoded data are presented using Plotly as meteograms (parameter changes over time), wind roses (distribution of wind direction and speed), and trend charts for temperature, humidity, wind, and precipitation. Each visualization is accompanied by interpretive context that translates atmospheric behaviour into operational meaning for example, high temperature in relation to reduced air density and aircraft performance, a narrowing temperature dew point difference in relation to fog potential, and wind direction and speed in relation to the crosswind and headwind components along the runway.

Data Integrity Verification

At this stage, evaluation focused on verifying data integrity so that the information presented by the system is accurate. Verification was carried out through two tests. First, a decoding-accuracy test compared the decoded parameter values (wind, visibility, cloud, temperature, dew point, and QNH) against the raw METAR/TAF codes displayed side by side; the system was considered valid when the decoded values were identical to the source codes. Second, a live-data synchronization test checked the accuracy of the BMKG API calls by comparing the information on screen with official BMKG data at the same time, including testing the fallback mechanism when the primary source was unavailable. Usability evaluation and operational-impact testing with flight-operations personnel were not conducted at this stage and are recommended as future work.

RESULT AND DISCUSSION

The Developed Decision Support System

The resulting product is a web-based aviation weather decision support system presented through a Tactical Weather Operations Dashboard interface whose data are drawn entirely from real-time BMKG services and which has been deployed and made publicly accessible without any intermediary. The system consists of four modules controlled through a single tabbed navigation bar and is designed to be usable without a programming background. The architecture and inter module data flow from the API sources, through Python processing, to presentation for operations personnel are summarized in figure 3.

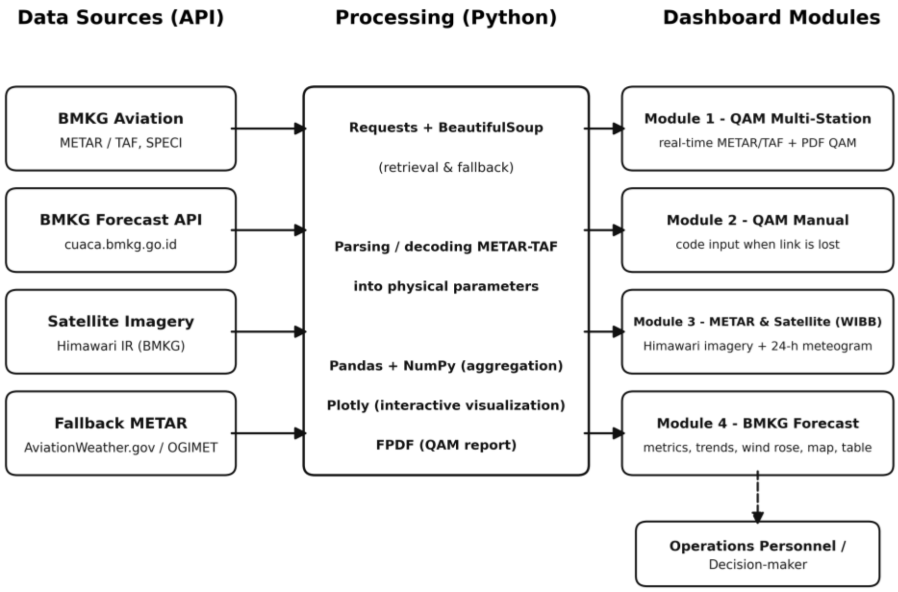

Fig 3. System architecture: BMKG API data sources, processing with Python, and presentation through four dashboard modules to operations personnel

The first module, automated multi-station METAR/TAF retrieval, displays the latest observations and forecasts for the selected air base together with a downloadable QAM report; if the primary station is offline, the system automatically displays data from the nearest station. The second module, manual-input mode, allows personnel to enter observation codes directly when communication links are lost, so that briefing can continue. The third module focuses on the reference station, Roesmin Nurjadin (WIBB), combining the latest METAR report, Himawari infrared satellite imagery, and a five-panel meteogram summarizing temperature and dew point, wind speed, QNH pressure, visibility, and significant-weather markers (rain, thunderstorm, and fog) over the past 24 hours. The fourth module presents BMKG grid-based forecasts as current-condition metrics (temperature, humidity, wind, and rainfall), trend charts, a wind rose, a location map, and a forecast table. The QAM-retrieval module and the WIBB station module of the deployed system are shown in figure 4 and figure 5, respectively.

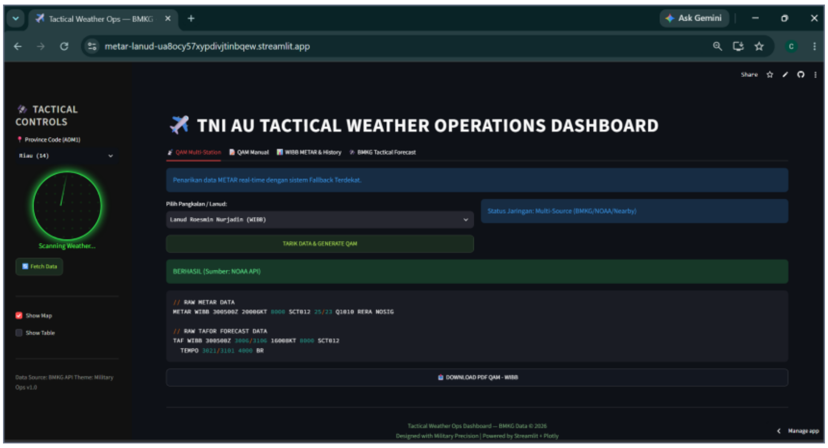

Fig 4. The QAM Multi-Station module of the deployed system (WIBB): real-time METAR/TAF retrieval from the BMKG API with a nearest-station fallback mechanism and QAM report generation

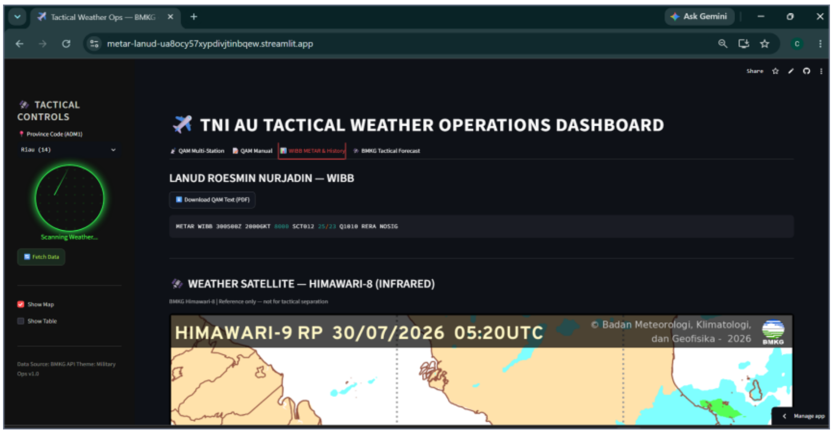

Fig 5. The WIBB station module: the latest METAR report and Himawari infrared satellite imagery from BMKG for monitoring cloud cover and convection

Data Integrity Verification

Data-integrity verification showed that the decoded parameter values were consistent with the raw METAR/TAF codes displayed side by side, and that the BMKG API calls were synchronized with the official data at the same time; the fallback mechanism also functioned as designed. The system therefore presents accurate and trustworthy weather information to support operational decision-making.

Example of Decoded Output

To illustrate the system output, table 1 details the interpretation of one actual METAR report retrieved by the system, together with its operational implications.

Table 1. Interpretation of one actual METAR report from the system (METAR WIBB 300500Z 20006KT 8000 SCT012 25/23 Q1010 RERA NOSIG)

Code element	Decoded value	Interpretation and operational implication
20006KT	Wind 200° / 6 knots	Light wind; compute the crosswind/headwind component relative to the runway heading
8000	Visibility 8000 m	Below 10 km; monitor the trend toward the VFR threshold

Code element	Decoded value	Interpretation and operational implication
SCT012	Scattered cloud, base ≈ 1200 ft	Low ceiling; note approach and landing minima
25/23	Temperature 25°C; dew point 23°C (2°C spread)	Air near saturation; increased fog/low-cloud risk
Q1010	QNH 1010 hPa	Altimeter setting; aircraft altitude reference
RERA	Recent rain	Wet runway; potential standing water and increased stopping distance

The principal value of the system lies in its ability to translate each element of live weather data into an operationally meaningful parameter. Table 2 maps the real-time weather parameters to the underlying physical and meteorological concepts and to their operational relevance, providing the analytical framework for the discussion that follows.

Table 2. Mapping of real-time weather parameters, physical/meteorological concepts, and operational relevance

Parameter (real-time)	Physical/meteorological concept	Operational relevance
Wind direction and speed	Fluid dynamics and circulation	Crosswind/headwind component for take-off and landing
Temperature and pressure (QNH)	Ideal gas law and air density	Density altitude and aircraft performance; altimeter setting
Temperature–dew point spread	Saturation and condensation	Fog/low-cloud potential; VFR/IFR limits
Visibility and cloud base	Light extinction and LCL	Landing minima; delay/divert decisions
Cloud, significant weather (RA/TS/FG), IR imagery	Convection and radiation physics	Thunderstorm avoidance; route safety

The dynamics of the atmospheric flow are evident in the wind pattern. The forecast module presents a wind rose and wind-trend charts that show wind direction and speed directly; by observing these outputs over time, operations personnel can identify the prevailing wind direction and relate it to the Asian Australian monsoon circulation, which reverses the regional air-mass flow twice a year (Aldrian & Susanto, 2003). Operationally, this information is important for estimating the crosswind and headwind components that govern take-off and landing decisions.

Humidity, saturation, and the foehn effect can be read from temperature and dew point. The meteogram displays temperature together with dew point, so their difference (the dew point depression) can be read directly: a wide difference indicates dry air. Physically, an air mass descending the leeward slope of the Bukit Barisan range undergoes adiabatic compression, so its temperature rises and its moisture-holding capacity increases, while the actual water-vapour content has already been reduced by precipitation on the windward side; this combination produces dry air through the rain shadow mechanism (Harjupa et al., 2021; Roe, 2005; Stoddard & Pu, 2024). Operationally, a narrowing temperature dew point difference serves as an early warning of potential fog or low cloud over the Riau region, which is relevant to flight decisions.

The relationship among temperature, pressure, and air density can be read from temperature and QNH. The system displays the actual air temperature together with the QNH pressure. Because, at a given pressure, air density decreases as temperature rises, as described by the ideal gas law, higher daytime temperatures indicate less dense air, with implications for density altitude and aircraft performance a longer take-off distance and reduced lift (Cagnoni et al., 2026; Mustofa et al., 2024). The QNH value is used directly for the altimeter setting and altitude reference.

Radiative cooling and phase change are apparent in the 24 hour meteogram. On clear nights with light winds, the release of longwave radiation from the surface drives a temperature decrease; as the temperature falls toward the dew point seen as a narrowing temperature–dew-point difference on the meteogram the lifting condensation level lowers, so fog or low cloud may form (Bartok et al., 2022; Gultepe et al., 2023; Vorndran et al., 2023). The significant-weather markers (fog/FG, rain/RA, thunderstorm/TS) on the meteogram panel confirm such events, so personnel can anticipate early-morning fog formation that reduces visibility. During the day, increased insolation drives surface heating and the convection characteristic of the Maritime Continent, which can be monitored through Himawari infrared imagery for thunderstorm avoidance (Aslam, 2025; Wu et al., 2009). The diurnal cycle of heating and cooling can thus be monitored directly over a 24 hour window in support of operational decisions.

The system also aids the anticipation of hazardous phenomena such as wind shear. Although surface wind speed is generally light, central Sumatra is prone to the passage of squall line convective systems (Sumatra squalls) that can produce sudden strong winds and low level wind shear (Diong et al., 2026). By monitoring the significant-weather markers and satellite imagery in real time, personnel can obtain an early warning of potential strong winds and mechanical turbulence that are hazardous to flight. In this way, a single system integrates diverse parameters wind dynamics, thermodynamics, and convection into one coherent operational display.

Operational Value of the System

As a decision support system, the dashboard offers several operational benefits. First, rapid situational awareness: transforming dense weather codes into concise parameters and visualizations accelerates the reading of conditions before flight (Bharath et al., 2024; Oktaviarini et al., 2024). Second, reliability: the nearest-station fallback mechanism and the manual-input mode maintain the availability of information even when the network or the primary station is disrupted. Third, standardized briefing: the automatic generation of QAM reports in PDF format standardizes briefing documents and reduces manual transcription errors. Fourth, broad coverage and immediacy: live data from the BMKG API for dozens of air bases enable real-time, cross-station monitoring (Irawan & Effiyaldi, 2021; Nugraha et al., 2022; Song & Ye, 2025).

Limitations and Future Work

This study has limitations that should be noted. Evaluation so far covers only data-integrity verification and has not empirically tested the effectiveness of the system with respect to the speed or accuracy of personnel decision-making. Some phenomena, such as radiation fog and wind shear, are explained on the basis of theory and comparative case studies rather than direct measurement. Usability evaluation and operational-impact testing with flight-operations personnel therefore constitute an important next step for quantitatively validating the benefits of the system, alongside the future integration of predictive nowcasting capabilities.

CONCLUSION

The objective of designing and implementing a real-time aviation weather decision support system for flight operations at Roesmin Nurjadin Air Force Base was achieved: a publicly deployed, browser-based system now draws exclusively on BMKG open-data services and converts coded meteorological information into parameters that operations personnel can act on directly. The study therefore answers its guiding question by showing that live, multi-source open data observations, terminal forecasts, gridded predictions, and satellite imagery can be consolidated into a single operational tool whose outputs were confirmed to be consistent with the official source data.

Practically, the system can support pre-flight weather briefing and go/no-go reasoning before every sortie, standardize documentation through automatically generated QAM reports, and remain usable during network disruption through its fallback and manual-input modes; because it runs in a web browser without local installation, it can be extended to other air bases that depend on the same open-data services. To strengthen these findings, further work should evaluate usability and operational impact with flight-operations personnel, incorporate short-range predictive nowcasting, and validate performance across multiple stations, so that the system's contribution to the speed and accuracy of operational decisions can be established empirically.

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