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Analysis of Atmospheric Dynamics during Tailwind Phenomena on the Runway of Kualanamu Airport

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Abstract

A tailwind, a wind component in aviation, can pose risks during aircraft takeoff and landing by blowing from the aircraft's rear. At Kualanamu Airport on August 02, 2022, Air Navigation Indonesia (AirNav) reported an incident where an aircraft had to abort landing due to a tailwind on the runway. This study analyzes the atmospheric dynamics contributing to tailwind disruptions on that specific day. The analysis involved various steps, including assessing upper-level air humidity using reanalysis data processed with the GrADS application, evaluating air instability through the computation of TT, KI, and SI indexes using the RaOB application, and examining cloud formation using Himawari-9 EH satellite imagery. The analysis revealed the presence of Cumulonimbus clouds around Deli Serdang Regency on August 02, 2022, which led to tailwind effects at Kualanamu Airport. Cumulonimbus clouds are often associated with unstable atmospheric conditions and can generate severe weather events like thunderstorms, heavy rainfall, and strong winds. Cumulonimbus clouds indicate the likelihood of convective activity and strong winds. The strong winds caused by these clouds probably disrupted the Tailwind on the runway at Kualanamu Airport.

Introduction

Kualanamu Airport, situated in the Deli Serdang Regency of North Sumatra Province, holds an essential position as a bustling hub for both domestic and international flights, catering to a substantial volume of takeoff and landing operations. Being one of Indonesia's busiest airports, the paramount concern is ensuring flight safety in every aspect of operations. Weather conditions play a crucial role, particularly during the critical phases of takeoff and landing, where even minor variations can significantly impact these operations' overall safety and efficiency. Factors such as wind speed, direction, temperature, precipitation, and visibility, among others, must be meticulously evaluated and considered to ensure the highest standards of aviation safety and operational effectiveness at Kualanamu Airport. By implementing comprehensive meteorological monitoring systems, sophisticated forecasting techniques, and robust decision-making protocols, airport authorities and air navigation services collaborate closely to proactively manage potential weather-related risks and challenges.

According to Air Navigation Indonesia (AirNav) at Kualanamu Airport, data indicates that on August 02, 2022, an aircraft with flight number WON 1223 had to execute a *go-around* maneuver due to a tailwind on the runway. The recorded wind speed reached 20 knots at 09.37 UTC or 16.37 WIB. A go-around is a decision made by the aircrew to abort a landing and divert to an alternate location when there is a perceived danger to the aircraft. In this specific case, the go-around was prompted by a tailwind exceeding the threshold of 10 knots, posing a significant risk to the aircraft's safety [1]. These findings highlight the critical role of tailwind conditions and the importance of assessing and managing them during aircraft operations to ensure the safety of flights at Kualanamu Airport.

Tailwind is a weather phenomenon in aviation characterized by wind blowing from the rear (tail) of the aircraft, which reduces its lift [2]. This can impact the aircraft's approach speed, ground speed, and braking distance, potentially compromising control and safety during landing [3]. To ensure safe operations, pilots actively avoid tailwinds during takeoff and landing due to the associated risks they pose to the aircraft. Previous research conducted by Fadholi (2013) focused on analyzing aviation's wind components, including tailwinds, without considering the atmospheric dynamics during tailwind occurrences on the runway [4]. The research findings indicated that tailwinds are more prevalent during the rainy season at Depati Amir Airport's runway. In another study by Rais A.F. et al. (2022), they analyzed the weather conditions on the runway using radar and satellite images [5]. The results revealed that strong winds originated from Cumulonimbus clouds near the runway. These studies shed light on the importance of considering the atmospheric dynamics and specific weather conditions, such as Cumulonimbus clouds, to understand and mitigate the impact of tailwind disturbances during aircraft operations on the runway.

In addition to previous research, this study aims to further enhance the understanding of atmospheric dynamics during tailwind conditions by analyzing the air humidity at upper levels of the atmosphere and assessing air instability. By examining the air humidity at higher altitudes, valuable insights can be gained regarding the moisture content and the potential for cloud formation, which play crucial roles in determining the overall atmospheric stability. Furthermore, evaluating the instability of the air through various indexes will provide valuable information regarding the likelihood of convective activity and the potential occurrence of severe weather events, including the formation of Cumulonimbus clouds. The primary objective of this study is to investigate and determine the atmospheric dynamics on the runway of Kualanamu Airport during tailwind occurrences, aiming to contribute to a comprehensive understanding of the meteorological factors influencing flight operations at the airport.

Theory and Calculation

In aviation, wind direction and speed are the most important weather elements. As ICAO Annex 3 (2010) mentioned, weather information, including wind direction and speed data, is needed for takeoff and landing [6]. During takeoff and landing, wind influences can interrupt the process, such as Tailwind. Based on the Aerodrome Meteorological Observation and Forecast Study Group (AMOFSG) Ninth Meeting 2011 [67], Tailwind can be calculated by using this formula:

$$TW = -ff * cos(WD - RW) \quad (1)$$

where TW is Tailwind speed (knots), ff = Wind speed (knots), RW = Runway direction and WD = Wind Direction

The Grid Application Development Software (GrADS)

GrADS is an interactive desktop program or tool to facilitate access, manipulation, and visualization of earth science data [8]. In addition, GrADS is software for grid applications and includes intermediate-level tools for users developed by the Center for High-Performance Software Research, Rice University, Houston [9]. The visualization capabilities of GrADS make it easier for users to interpret and understand complex datasets. It allows for visually appealing displays, such as contour plots, maps, time series, and cross-sections, which aid in analyzing meteorological and climate data. Overall, GrADS is a valuable tool for researchers, meteorologists, and climate scientists, enabling them to analyze and present earth science data in a more accessible and visually informative manner.

The Instability of Air

The instability of air can be analyzed using upper-air observation data. This data can be obtained from observations using Rawinsonde (Rason). Rawinsonde observations produce upper air data that can be processed using the RaOB (Rawinsonde Observation Program) application, producing air instability indexes. Many studies on air instability index have been conducted, one of them by Budiarti et al. (2012), who reviewed atmospheric stability index intervals more suitable for low latitudes [10]. Because the existing index intervals are studied in subtropical regions, it is necessary to study further the index intervals that are more suitable for the tropics. The stability indexes studied were Total-Totals Index, K-Index, and SWEAT.

a. K-Indeks (KI)

KI measures the potential for convective activity based on vertical temperature and atmospheric humidity. This index value is calculated based on the temperature values in the 850 mb, 700 mb, and 500 mb and the dew point temperature values in the 850 mb and 700 mb levels. Here is the KI formula:

$$KI = T850 - T500 + Td850 - T700 - Td700 \quad (2)$$

T is the air temperature, and Td is the dew point temperature.

If the air temperature gap between the 850 mb and 500 mb levels is greater, the air humidity will be higher, so the KI value will be greater. If the KI value is greater, the potential for convection will be higher. The results of previous research show that the KI value will get higher diurnally during the day due to unstable atmospheric conditions [9].

b. Total - Totals Index (TT)

Total-Totals Index (TT) is one of the indexes that can determine the convection process combined from vertical totals and cross totals. Vertical totals are the difference between the environmental temperature in the 850 mb and 500 mb levels, and the cross totals are the difference between the dew point temperature in the 850 mb level and the environmental temperature in the 500 mb level. Here is the TT formula:

$$TT = T850 - T500 + Td850 - T500 \quad (3)$$

T is the environmental temperature, and Td is the dew point temperature.

The higher air temperature and humidity in the 850 mb level, followed by the lower air temperature conditions in the 500 mb level, show that the TT value will be greater, indicating an increasingly unstable atmospheric condition. These conditions will trigger the growth of convective clouds, especially for Cumulonimbus growth.

c. SWEAT

SWEAT (Severe Weather Threat Index) is an index to see the potential for severe weather by calculating other mechanisms that can trigger severe weather. Here is the SWEAT formula:

$$SWEAT = 12Td850 + 20(TT - 49) + 2f850 + f500 + 125(s + 0{,}2) \quad (4)$$

where Td = dew point (°C), TT = Total-totals Index (°C), f = wind speed (knots)
and s = wind direction sin at 500 mb and 850 mb levels (degree)

Below are the atmospheric stability intervals of these indexes

Table 1. Atmospheric Stability Index Intervals for Tropical Regions [9]

Index	Weak	Moderate	Strong
TT	<42	42-46	>46
KI	<29	29-37	>37
SWEAT	<132	135-239	>239

Weather Satellite

In Indonesia, the weather satellite used by the Meteorology Climatology and Geophysics Agency (BMKG) is the Himawari-9 IR Enhanced satellite. The Himawari 8 and 9 satellites are equipped with the Advanced Himawari Imager (AHI) sensor, which offers improved temporal, spectral, and spatial resolutions compared to the previous series [11]. The Himawari-9 satellite with its Advanced Himawari Imager sensor provides meteorologists with high-quality and timely information for weather forecasting, monitoring, and analysis in Indonesia. This advanced satellite technology plays a vital role in improving the accuracy and reliability of weather predictions. It helps ensure the safety of aviation operations and other sectors that rely on weather information.

The Himawari-9 EH product utilizes radiation observations at a wavelength of 10.4 micrometers to determine the temperature of cloud tops. The resulting temperature information is presented using specific colors representing different cloud formations. In the Himawari-9 EH product, the color scheme indicates the extent of cloud formation and the potential for Cumulonimbus cloud development. The color scale ranges from black or blue, representing areas with minimal cloud formation or brightness, to colors such as orange and red, indicating significant cloud growth and the possibility of Cumulonimbus cloud formation [12].

Experimental Method

The methods used in this study involved several steps for data collection and processing, which are described as follows:

Step a: Downloading reanalysis data from the National Oceanic and Atmospheric Administration (NOAA) website. The data was obtained from the webpage https://psl.noaa.gov/data/gridded/data.ncep.reanalysis2.html [13].

Step b: Processing the reanalysis data using the Grid Analysis and Display System (GrADS) application. The data was adjusted to the specific case study time on August 02, 2022. This process resulted in obtaining air humidity conditions at the upper levels of the atmosphere on the day of the tailwind incident. Additionally, the air humidity conditions at the upper level on the day before and after the incident were also analyzed to compare the changes from July 31, 2022, to August 3, 2022. The specific atmospheric levels analyzed were 1000mb, 700mb, and 500mb, commonly used and considered standard in atmospheric studies [14]. The processing and visualization of the data using the GrADS application are shown in Figure 1.

Step c: Analyzing the instability of the air by calculating three indexes: Total Totals (TT), K-Index (KI), and Showalter Index (SI). These indexes were computed using upper air observation data that were processed with the Raob application. The upper air data used in the analysis was collected from the Meteorological Station of Kualanamu. The specific time selected for the analysis was August 2, 2022, at 00:00 UTC, which was the observation time closest to the go-around incident caused by the Tailwind.

Step d: Analyzing the temperature of the cloud tops in the Himawari-9 EH satellite images to determine the type of clouds formed. The satellite image times selected for analysis were 09:20, 09:30, 09:40, and 09:50 UTC, covering the period before and after the tailwind event occurred.

These steps were undertaken to analyze the air humidity conditions, air instability, and cloud formations during the tailwind event at Kualanamu Airport.

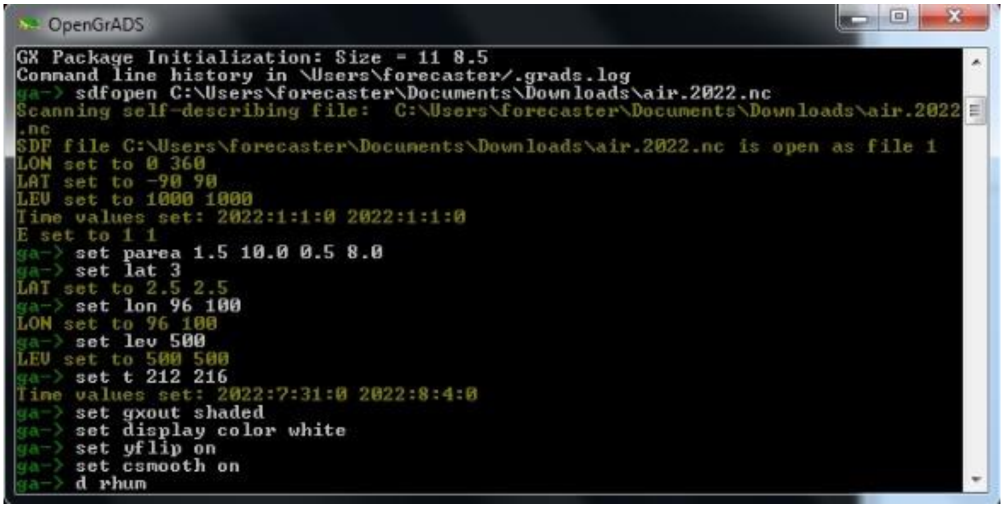


Figure 1. Data processing display using the GrADS application

Result and Discussion

Analysis of Air Humidity in the Upper Level of the Atmosphere

Kualanamu Airport was the focus of the air humidity analysis in this study [15]. The results obtained from processing the data using the GrADS application are displayed in Figure 2. The analysis specifically examines the air humidity at the 1000mb (a), 700mb (b), and 500mb (c) levels of the upper atmosphere on August 02, 2022. The image represents the latitude 3.38.17.95N, corresponding to the coordinates of Kualanamu Airport. The x-axis represents the longitude coordinates ranging from 96E to 100E, while the y-axis represents the dates from July 31, 2022, at 00:00 UTC to August 4, 2022, at 00:00 UTC. The black square indicates the location of Kualanamu Airport, and the selected times for analysis include the range of the tailwind incident.

Based on the color legend provided on the right, the analysis reveals that at the 1000mb level (a) around Kualanamu Airport, the air humidity values ranged from approximately 85% to 89% between 00:00 UTC and 12:00 UTC on August 2, 2022. At the 700mb level (b), the air humidity values ranged from about 70% to 80% during the same time period. Furthermore, at the 500mb level (c), the air humidity values ranged from approximately 65% to 75%. These findings indicate a decrease in air humidity with increasing altitude, suggesting drier conditions in the upper levels of the atmosphere. However, the air humidity values at the 1000mb and 700mb levels indicate relatively humid conditions in the lower layers, indicating the potential for rain in the Kualanamu Airport area [16]. These results provide valuable insights into the air humidity conditions at different atmospheric levels, highlighting the potential for precipitation and its impact on flight operations at Kualanamu Airport.

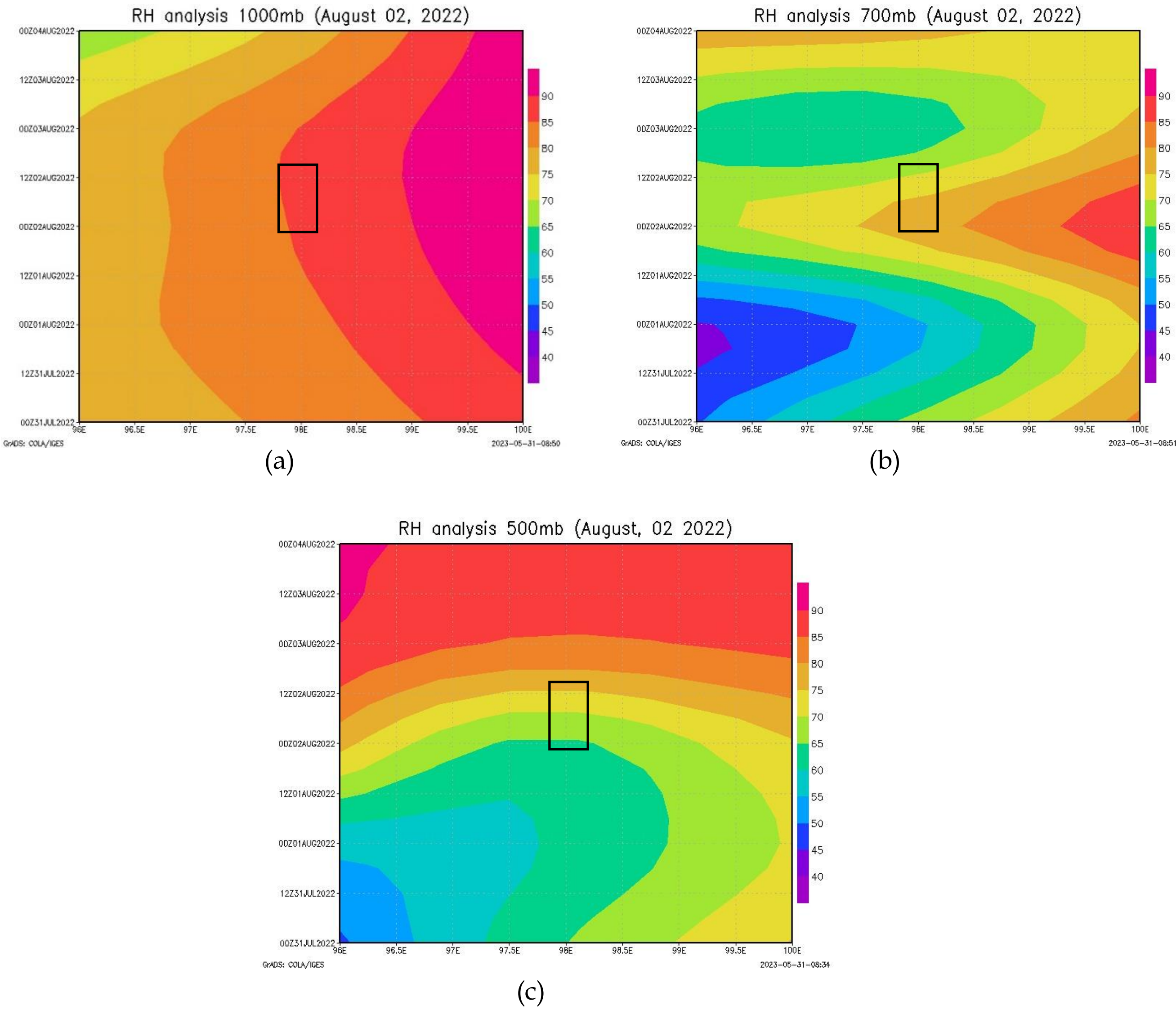


Figure 2. RH analysis at 1000mb (a), 700mb (b), and 500mb (c) levels on August 02, 2022

Analysis of the air instability

Below are the results of data processing using the RaOB application on August 02, 2022, at 00.00 UTC which produces an air instability index.

Table 2. The Air Instability Index on August 02, 2022 at 00.00 UTC

Index	Value	Potential
TT	46,3	Moderate
KI	39,0	Strong
SWEAT	208,0	Moderate

Based on the results of data processing using the RaOB application on August 02, 2022, at 00:00 UTC, the following air instability indexes were obtained:

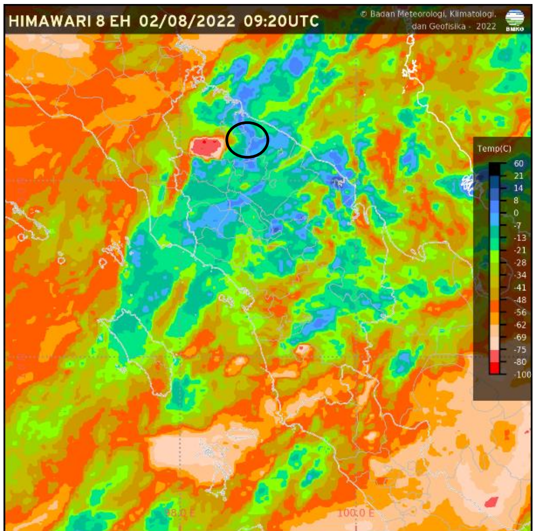
a. TT Index: The value of 46.3 indicates a moderate potential for convection to occur. This index evaluates the temperature difference between atmospheric levels and provides insights into the likelihood of convection and convective cloud formation.
b. KI Index: The value of 39.3 indicates a strong potential for convection to occur. The KI index considers the vertical temperature gradient and moisture in the atmosphere, providing information on the potential for convective processes.
c. SWEAT Index: The value of 208 suggests a moderate potential for severe weather to occur. The SWEAT index combines various atmospheric parameters, such as wind shear and instability, to assess the potential for severe weather events.

From these indexes, it can be inferred that on August 02, 2022, there was the potential for a convection process to occur, which could result in the formation of convective clouds. These convective clouds may lead to adverse weather conditions, including the possibility of strong winds such as tailwinds.

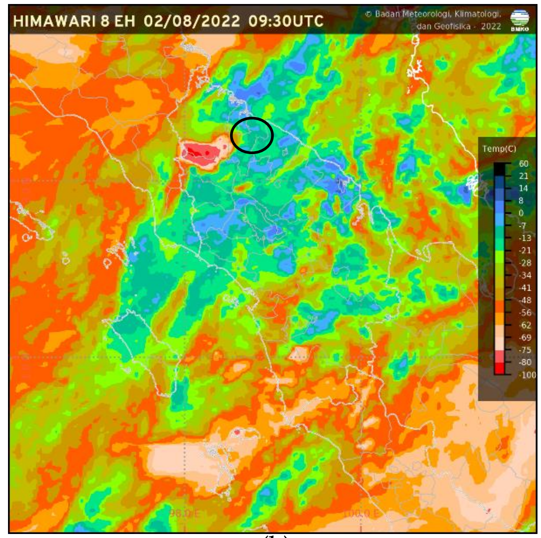
Satellite Image Analysis

Figure 3 shows the satellite images of North Sumatra and its surrounding areas, specifically focusing on the cloud top temperatures where significant clouds such as Cumulonimbus clouds have very low cloud top temperatures marked with orange to red colors [12]. Kualanamu Airport, located in Deli Serdang Regency, is marked in the black circle in the image. Based on the description and analysis of the satellite imagery, it is evident that on August 02, 2022, there was convective cloud growth in the west of the Deli Serdang Regency area.

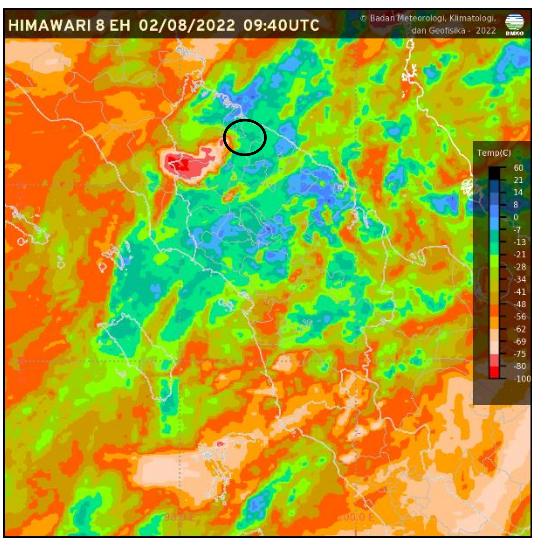
In Figure 3(a), which represents the satellite image at 09:20 UTC, convective cloud growth is observed. As time progresses, the cloud growth expands, as seen in Figure 3(b) at 09:30 UTC, Figure 3(c) at 09:40 UTC, and Figure 3(d) at 09:50 UTC. The expansion and persistence of the convective clouds indicate the development of Cumulonimbus clouds. Cumulonimbus clouds are known for having very low cloud top temperatures, and they are often associated with severe weather conditions such as thunderstorms. As mentioned, the orange to red colors in the satellite image indicates the areas with significant cloud top temperatures, including the Cumulonimbus clouds. These clouds can produce strong winds in their surrounding areas, which could result in the tailwind disturbance experienced on the runway of Kualanamu Airport. The analysis of the satellite imagery and identification of Cumulonimbus clouds provide valuable evidence supporting the connection between convective cloud growth, strong winds, and the tailwind disturbance at Kualanamu Airport. This information further emphasizes the importance of considering weather conditions, particularly significant cloud formations, in ensuring flight safety during takeoff and landing operations.

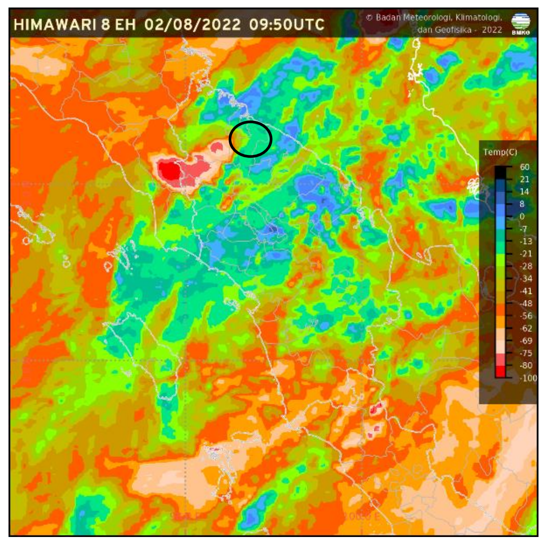


(a)



(b)





(c)

(d)

Figure 3. Analysis of Himawari 9 Satellite Images on August 02, 2022, at 09.20 UTC (a), 09.30 UTC (b), 09.40 UTC (c), and 09.50 UTC (d)

Conclusion

Based on the analysis of atmospheric dynamics, it is concluded that the air mass conditions on August 02, 2022, were unstable, leading to a convection process. This convection process resulted in the growth of Cumulonimbus clouds around the Deli Serdang Regency area, which in turn impacted the Kualanamu Airport area. Cumulonimbus clouds are often associated with unstable atmospheric conditions and produce severe weather phenomena such as thunderstorms, heavy rain, and strong winds. In this case, Cumulonimbus clouds indicate convective activity and the potential for strong winds. The strong winds generated by these Cumulonimbus clouds likely caused the tailwind disturbance on the runway at Kualanamu Airport.

Acknowledgment

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