Journal of Theoretical and Applied Information Technology
31st May 2020. Vol.98. No 10

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

ATMOSPHERIC TURBULENCE ALGORITHM MODEL FOR FLIGHT PROBLEMS INFORMATION SYSTEMS

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ABSTRACT

Natural disasters now occur frequently in Indonesia, especially those relating to atmospheric anomalies. The development of models for forecasting based convective cloud growth events is necessary to understand the symptoms of atmospheric anomalies. Comparisons of the analyses of the turbulence that affected the Etihad Airways EY-474 on May 7, 2016, and Batik Air ID6890 on October 24, 2017, are specific to disturbance occurring during sunny weather. The identity turbulence events experienced by Batik Air aircraft, flight number ID 6890 type B737-800 NG, and determine the best parameters for identifying turbulence in these events. To solve turbulence problems, a method for analyzing convective clouds using the global forecasting model. To determine the turbulence potential, a turbulence index is required, like that for the Richardson index (Ri). The Ri index takes into account the vertical wind shear and the stability of the air, which makes it ideal for describing clear air turbulence (CAT). In this study, negative Ri results tend to indicate mild confusion due to atmospheric conditions, whereas Ri < 0.25 has a high chance of turbulence. In this study, the results of the turbulent motion indicated by CAT and not stated.

Keywords: *Richardson Number, Flight Turbulence, Atmospheric Anomaly, WRF Model, Clear Air Turbulence*

1. INTRODUCTION

Developments in the field of aviation navigation and the installation of weather radars on aircraft have enabled aircraft to avoid lousy weather areas associated with convective clouds. However, unpredictable weather conditions can occur in areas where no convective clouds are present. This phenomenon is called clear air turbulence (CAT) or severe weather turbulence (TCC) [1]. Since CAT occurs in the absence of convective clouds, this makes it difficult to detect both visually and by weather radar [2]. CATs of mild to moderate intensities can cause shocks to the plane, and CAT with vigorous-intensity can make it difficult for the aircraft to maintain altitude and may even throw passengers from their seats. CAT can cause significant problems such as accidents, aircraft damage, fuel losses, and flight delays. The aviation disasters caused by wind turbulence are quite a number of events occurring in the tropics and subtropics, this is because they relate to unique atmospheric conditions with increasing growth of convective clouds leading to extreme levels due to climate change. The growth of convective clouds is the main cause of turbulence disasters. The application that quickly provides information is a necessity needed by the aviation world [3].

Parameters for identifying turbulence can use the Turbulence Index (TI), Richardson Number Index (Ri), and radiosonde parameters. The calculation of the Turbulent Index model and Richardson Numbers uses the calculation of the Vertical Wind Shear (VWS) deformation, which is refined in Weather Research Forecasting-Advanced Research WRF (WRF-ARW). Research that has used the Richardson number has conducted a study on identifying turbulence using these two parameters. The results obtained are TI2 has the best performance in detecting disturbance, while Ri is otherwise less able to show turbulence events [4].

In their study, [5] used the Ri index to determine the CAT intensity. However, their results indicated that turbulence could occur when Ri > 0.25 [5]. The turbulence index (IT) is better able to detect CAT events than the Ri. However, in previous studies that have used CAT analysis using the WRF-ARW model in Indonesia an area with active convective cloud growth, the results have shown that the Ri index is suitable for detecting turbulence in tropical regions and that a Ri value greater than 150 indicates relatively healthy turmoil [6].

Natural disasters now occur frequently in Indonesia, especially atmospheric anomalies. Aircraft accidents are caused by the extreme growth of convective clouds, otherwise known as cumulonimbus (Cb) clouds [7]. Indonesia's Meteorology, Climatology, and Geophysical Agency, BMKG, reported that this severe level of turbulence in Indonesia was due to a combination of waves in the Bukit Barisan Mountains in Southern Sumatra and Cb clouds around the flight path of the aircraft EY-474. Three days later, on May 7, 2016, the Etihad Airways EY-474 aircraft experienced turbulence at an altitude of about 41,000 feet above sea level. This incident resulted in the severe injury of three passengers and minor fractures to more than 17. Based on documentation from averald.com, turbulence occurred for 23 seconds in the West Bangka Belitung about 45 minutes before landing at Soekarno-Hatta Airport, which left 31 passengers injured. However, the plane was able to continue its journey until landing at Soekarno-Hatta Airport. Turbulence in the world of aviation is generally common. Although turbulence in the world aviation is frequent substantial confusion can occur suddenly, which can endanger passengers and crew. Flightradar24 obtained similar flight data for Batik Air aircraft, flight number ID 6890, on October 24, 2017 [8], which can be downloaded from www.flightradar24.com.

Based on the problems regarding turbulence, this paper will discuss the initial evaluation to find out the turbulence motion. The Richardson index calculation is a mathematical method that can be used to evaluate the presence or absence of turbulence, and this can be used as a decision making about information systems in the aviation world to find out phenomena that endanger the aviation world.

2. LITERATURE REVIEW

The turbulence phenomenon is caused by changes in airflow in terms of direction and velocity accompanying the thunderstorm, which changes air pressure and occurs only in a limited area. Within a short period, this airflow rotates outward while moving downward. This can happen either horizontally or vertically and is most often associated with strong temperature inversion or gradient density. Windshear that occurs below an altitude of 3000 feet is commonly known as low-level wind shear (LLWS), which is very dangerous for aircraft that are taking off or landing. Its effect on the plane will result in increased airflow on the wings so that this increased airflow will result in a sudden increase in aircraft speed. If the pilot is unaware of the indication of the wind shear, he will instinctively throttle back to reduce/compensate for the aircraft's speed. However, once the plane passes the wind shear zone, the wind suddenly turns into a downdraft. This event reduces the velocity of the air on the wing, which correlates with loss of lift force (stall), and the aircraft is likely to fall given the altitude at this time is not sufficient for recovery [10].

In the case of thunderstorms, convective weather will occur with temperature inversions in the form of wind gusts, downdrafts, microbursts, and gravitational waves that all kind LLWS. Besides, surface topography in the way of mountains, rivers, ravines, and including large hangars in addition to airport runways will also change the wind pattern contributing to LLWS. A microburst is a wind shear that comes from the flow of cold air from the bottom of the storm clouds with a design like a reverse mushroom plant. Cumulonimbus (Cb) clouds usually cause a microburst. When there is a storm in the dark cloud, there is a microburst which is the main enemy of the pilot, and anyone will try to avoid it. Because if there is a downdraft (downward force) caused by a microburst, no mercy of any aircraft can be slammed to the ground, some fatal aircraft accidents occur because of this microburst phenomenon. A microburst is an atmospheric turbulence phenomenon that is very influential on aircraft flights both during take-off and landing [11].

Research on the potential for turbulence in the Air Asia QZ 8501 plane crash event, analyzed meteorologically related to atmospheric conditions at the scene, and the potential for disturbance using MTSAT satellites. The Ri index value obtained is above 100, which indicates the potential for a reasonably sharp shock at the location around the incident. The turbulence index shows the value (2 - 4)$\times\ 10^{-7}s^{-1}$; this indicates the potential for mild turbulence while the turbulence index is valued (5 – 10)$\times\ 10^{-7}s^{-1}$, which means that turbulence is moderate to durable [4].

According to [6], the turbulence index (TI) is better able to detect CAT events than Richardson Number (Ri). However, previous research on CAT analysis using WRF-ARW in Indonesia conducted

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

by [12] shows that the Richardson Number turbulence index is suitable for detection in tropical regions with Ri values of more than 150, indicating strong turbulence.

The Richardson Number Index (Ri) is used to determine the intensity of the CAT. To find out the potential for turbulence, turbulence indexes such as Richardson Number (Ri) are needed. The Richardson Number Index (Ri) takes into account the value of Vertical Wind Shear and air stability. This makes Ri considered ideal to describe Clear Air Turbulence (CAT).

Research [5] which states that turbulence can occur when Ri> 0.25. Meanwhile, according to [9], the atmosphere with Ri> 0.25 has a high chance of disturbance. However, when compared with actual results, Ri is negative (Ri <0.25) tends to experience mild turbulence. From the WRF simulation model in [12] research, 2014, a Richardson Number (Ri) value <1 can be obtained so that it can be said the occurrence of CAT.

The Clear Air Turbulence (CAT) is defined as severe turbulence that suddenly occurs in an area without clouds, which causes a loud pounding on the plane. Observational studies using research aircraft have shown that the presence of high clouds, vertical wind shear, wind speed, the appearance of jet streams (a group of high-speed winds, blowing from east to west, at an altitude of 5 km or more) and the Richardson index have a high correlation with CAT [1].

Thermal turbulence occurs due to surface heating by solar radiation, which is caused by surface closure factors. It often occurs during the day when the wind conditions are small and can create unstable atmospheric conditions. Mountain wave turbulence or mechanical turbulence occurs due to wind friction with the earth's surface. It often occurs in mountainous areas because the uneven surface of the planet causes disturbance when the wind through the mountains [13].

3. RESEARCH METHODS

3.1 Materials

The Weather Research Forecasting-Advanced Research WRF (WRF-ARW) model is an advanced generation numerical model weather prediction system designed to serve operational prediction and atmospheric research needs. As the initial input for the WRF-ARW model, we used FNL data from NCEP-NCAR with a resolution of 0.25° × 0.25°.

GrADS is an interactive desktop tool used that provides easy access, manipulation, and visualization capabilities of geographic data. The data format is binary, GRIB, netCDF, or HDF-SDS (scientific data set). GrADS uses a four-dimensional data environment, namely longitude, latitude, vertical level, and time. In this study, the output from WRF was processed using GrADS software [14,15]

3.2 Methodology

Turbulence was reported to occur on May 7, 2016, between 06:00 UTC to 07:00 UTC. The location of the incident was at an altitude of 39,000 feet west of Bangka Island. The intensity reported by the pilot is severe turbulence. The time of the event used in this study was 07:00 UTC.

Table 1. shows Real dataThemperatur for Etihad Airways EY-474 and Batik Air ID6890.

3.3 Data Source

In this study, we used the following secondary data:

1. Flight data for the Etihad Airways EY-474 aircraft on May 7, 2016, and Batik Air aircraft, flight number ID 6890 dated October 24, 2017, obtained from Flightradar24 data listed in the analysis report written by [8]. These flight data were downloaded from the website www.flightradar24.com.
2. Final Global Assimilation System (FNL) data from the National Centers for Environmental Prediction National Center for Atmospheric Research (NCEP-NCAR) with a resolution of 0.25° × 0.25°. Data was downloaded from the website www.rda.ucar.edu/. Data were obtained for May 7, 2016, and October 23, 2017, at 06.00 UTC, 12:00 UTC, 18.00 UTC.
3. Multifunctional Transport Satellites (MTSAT) infrared (IR) and wave vapor channel data from the Meteorology and Geophysics Agency for May 7, 2016, and October 24, 2017, at 10:00 UTC
4. Data from the Radiosonde Kualanamu flight station for May 7, 2016, and 24 October 2017 at 00.00 UTC, 07.00 UTC, and 24.00 UTC. Sounding data were accessed from the website weather.uwyo.edu/ upper air/sounding.

3.4 Richardson Number

The Richardson (Ri) number is used to calculate the strength of turbulence, a comparison of the Brunt-Vais-Frequency Squared (N2) with VWS. Atmospheric stability parameters The Richardson number has real influence, so it is considered ideal to describe the Kelvin-Helmholtz Instability (KHI) mechanism as a cause of CAT [9]. The formula for determining Ri index values is as follows

$$Ri = \frac{g}{T_v} \frac{\frac{\delta T_v}{\delta z}}{\left|\frac{\delta V}{\delta z}\right|^2} = \frac{N^2}{S^2} \qquad (1)$$

where $N^2 = \frac{g}{T_v}\frac{\delta T_v}{\delta z}$ is the frequency of Brunt-Väisälä, g is the acceleration of gravity, T_v is the potential vertical temperature, $\frac{\delta T_v}{\delta z}$ is the potential temperature growth concerning altitude, and $S = \left|\frac{\delta V}{\delta z}\right|$ is the vertical wind shear, The classifications of Richardson Numbers for flight services are as follows:

1. Richardson Numbers between 0.25 to 1.0 are categorized as strong turbulence.
2. Richardson Number value of less than 0.25 is categorized as a weak turbulence area.

Table 1: Real data temperature, Wind Speed and Theta

Date	LEV	Temp(C)	Wind Speed (Knot)	Theta(K)
		Radiosonde	Radiosonde	Radiosonde
May 7, 2016, 00 UTC for Etihad Airways	850	17,6	10	304,6
	700	9	3	312,4
	500	-5,5	2	326,3
	400	-16,1	3	334
	300	-30,5	1	342,3
	250	-41,3	11	344,5
	200	54,3	27	346,6
	100	-79,7	6	373,5
Oktober 24 2017 00 UTC Batik Air ID6890	850	19,4	10	306,4
	700	10,2	9	313,8
	500	-5,5	9	326,3
	400	-13,7	3	337,1
	300	-29,5	10	343,7
	250	-39,5	20	347,2
	200	-52,5	29	349,5
	100	-80,5	8	371,9

Potential temperatures can be termined as follows:

$$\theta_{(i,j,k)} = T_{(i,j,k)}(1000/p_{(i,j,k)})\, R/Cp \qquad (2)$$

Where T is the ambient air temperature in units of K, p is the air pressure in groups of MB, R is the dry air constant, Cp is the specific heat of dry air at a fixed pressure, R / Cp is a constant whose value is 2/7, i is latitude, j is longitude, and k is the level. The algorithm implementation is listed in the C ++ MATLAB programming language [16, 17].

These atmospheric parameters become renewable to calculate whether there is turbulence motion by the CAT or not, it is arranged in an algorithm for the model of atmosphere turbulence motions. The algorithm for the atmospheric turbulence model is based on the Richardson formula combined with atmospheric conditions during the research.

3.5. Algorithms and numerical calculations.

The numerical calculates the Richardson number, *Ri*. This number determines whether the wind shear is strong enough to cause turbulence in statically.

The change in geopotential height usually determines the stability of the air. If the change in geopotential height is small, the flow is dynamically unstable and turbulent. This means that the Richardson number is less than the critical Richardson number, where the critical Richardson number is equal to 0.25. In this numerical calculates, you have eight input values:

1. The temperature at the highest geopotential height (T1)
2. The temperature at the lower geopotential height (T2)
3. Wind speed toward East at the highest geopotential height (U1)
4. Wind speed toward East at the lower geopotential height (U2)
5. Wind speed toward North at the highest geopotential height (V1)
6. Wind speed toward North at the lower geopotential height (V2)
7. Geopotential height at the highest geopotential height (z1)
8. Geopotential height at the lower geopotential height (z2)

The Richardson number calculate from formula one above whatever it is:

$$R_i = \frac{g(\Delta T_v + T_d \Delta z)\Delta Z}{T_v[(\Delta U)^2 + (\Delta V)^2]} \quad (2)$$

If g = 9.8 m/second
T_d (dry adiabatic laps rate)= 9,8 K/km

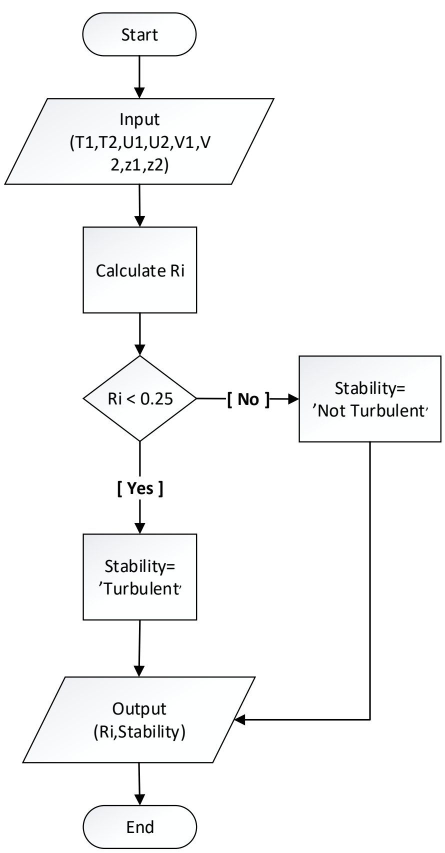

Figure 1: Flowchart and Pseudo Code

```
{Description}
{Determines whether the wind shear is strong enough to cause}
{turbulence in statically stable air used Ri}
{Dictionary}
T1: float {Temperature at the highest geopotential height}
T2: float {Temperature at the lower geopotential height}
U1: float{Wind speed toward East at the most top geopotential height}
U2: float {Wind speed toward East at the lower geopotential height}
V1: float{Wind speed toward North at the highest geopotential height}
V2: float {Wind speed toward North at the lower geopotential height}
z1: float {Geopotential height at the highest geopotential height}
z2: float {Geopotential height at the lower geopotential height}
  Ri: float {Richardson number}
  Stability: string {air stability}
{Algorithm}
input(T1,T2,U1,U2,V1,V2,z1,z2,g)
{Ri calculate}
  Ri=(9,8*((T1-T2)+9,8*(z1-z2))*((z1-z2)*1000))/
((T2+273.15)*(Pow((U1-U2),2)+(Pow((V1-V2),2))))

if (Ri< 0.25) then{turbulent check}
   Stability='Turbulent'
else {Ri>=0.25}
   Stability='Not Turbulent.'
output(Ri,Stability)
```

4. RESULTS AND DISCUSSION

Turbulence is an irregular flow and has a small scale that occurs in the average air movement. Its characteristics have an erratic rotating airflow direction [18]. Turbulence is an illegal air movement and, at times, produces some small eddy that travels in the air. This is due to random fluctuations in wind flow, frontal zones, convective, temperature variations, and pressures. Turbulence can be considered as a distorted disorder from average conditions [19]. For example, convective turbulence that occurs due to convective clouds. Inside this cloud, there is massive turbulence, especially during rain and thunderstorms [20]. Physically the motion of the turbidity is strongly influenced by vertical wind shear conditions and atmospheric stability, which form the ideal CAT

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

conditions. Atmospheric conditions can be known from the frequency associated with internal gravity waves, and this is very dependent on the acceleration of gravity, the temperature of the vertical potential, and vertical wind shear. Based on the above, it will be known turbulence motion patterns due to the effect of CAT or not. This model runs in three domains, and domain 3 (DO3) is used for research areas with a resolution of 4 km. The Richardson number obtained from WRF output as shown in Figures 1. shows that turbulence in the region has a range of values > 3.5 where according to [9], critical limits occur with high-intensity turbulence at costs < 0.25 and moderate-intensity 0.25-1, The results Ri index of Etihad Airways EY-474 with Ri values obtained 0 can show the turbulence, while the results of Batik Air aircraft, flight number ID 6890 purchased are outside the threshold, so it can be stated that there is no indication of turbulence at the scene can occur when the value of Richardson > 1. Grell Devenyi scheme can describe the movement of clouds and signs of rain-related to air stability [21].

Table 1. in the form of radiosonde data for measurement of temperature, wind speed, and theta or potential temperature. WRF output data are validated using radiosonde data, which is real atmospheric parameter data.

The variables calculated for correlation and RMSE are theta data that play a direct role in the calculation of Richardson numbers; besides, it also calculated the correlation value and RMSE.

Table 1. from temperature data and wind speed. RMSE from theta data output from WRF and radiosonde data. The calculation results are set out in Table 2. for wind speed, and in Table 3. for the temperature, and Table 4. for the theta is shown below.

In the figures above (Figures 1.), a white circle indicates the Ri index value in layers 250 MB to 200 MB at 00.00 UTC, 07.00 UTC, and 14.00 UTC. When the Ri index value is 0 all three times, this indicates high turbulence. According to [9], Ri < 0.25 means high turbulence, This can be taken as an analysis for flight information from http://flightradar24.com Etihad Airways aircraft with flight number EY-474 on the Abu Dhabi-Jakarta flight route. Turbulence is estimated to occur around the waters of Palembang and Bangka Island.

Table 2: Wind speed data validation

Date	LEV	Wind Speed (knot)		Correlation	Difference (data radiosonde-data model)	RMSE
		Model	Radiosonde			
May 7, 2016, 00 UTC for Etihad Airways	850	7,56485962	10	0,699414861	2,43514038	11,71340511
	700	3,446494603	3		-0,446494603	
	500	5,104030242	2		-3,104030242	
	400	8,558105839	3		-5,558105839	
	300	21,18090715	1		-20,18090715	
	250	32,01745143	11		-21,01745143	
	200	34,57749463	27		-7,57749463	
	100	18,02303457	6		-12,02303457	
Oktober 24 2017 00 UTC Batik Air ID6890	850	0,622891361	10	0,784403093	9,377108639	8,014674821
	700	2,75328078	9		6,24671922	
	500	9,620436293	9		-0,620436293	
	400	10,96479915	3		-7,96479915	
	300	20,62866092	10		-10,62866092	
	250	27,90680348	20		-7,90680348	
	200	35,91971925	29		-6,91971925	
	100	17,98684019	8		-9,98684019	

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 3: Temperature data validation

Date	LEV	Temp(C) Model	Temp(C) Radiosonde	Correlation	Difference (data radiosonde-data model)	RMSE
May 7 2016 00 UTC for Etihad Airways	850	17,3365	17,6	0,999844655	0,2635	0,5595573
	700	8,79864	9		0,20136	
	500	-5,48964	-5,5		-0,01036	
	400	-15,6904	-16,1		-0,4096	
	300	-31,3883	-30,5		0,8883	
	250	-41,6764	-41,3		0,3764	
	200	-53,1616	-54,3		-1,1384	
	100	-79,7164	-79,7		0,0164	
Oktober 24 2017 00 UTC Batik Air ID6890	850	16,8123	19,4	0,999596943	2,0635	1,56276114
	700	9,78151	10,2		1,40136	
	500	-5,22931	-5,5		-0,01036	
	400	-15,8438	-13,7		1,9904	
	300	-30,9242	-29,5		1,8883	
	250	-40,8402	-39,5		2,1764	
	200	-51,6822	-52,5		0,6616	
	100	-80,0481	-80,5		-0,7836	

Table 4: Theta data validation

Date	LEV	Temp(C) Model	Temp(C) Radiosonde	Correlation	Difference (data radiosonde-data model)	RMSE
May 7 2016 00 UTC for Etihad Airways	850	304,308	304,6	0,999188237	0,292	0,850649458
	700	312,281	312,4		0,119	
	500	326,432	326,3		-0,132	
	400	334,68	334		-0,68	
	300	341,104	342,3		1,196	
	250	344,125	344,5		0,375	
	200	348,489	346,6		-1,889	
	100	373,765	373,5		-0,265	
Oktober 24 2017 00 UTC Batik Air ID6890	850	303,759	306,4	0,997728228	2,641	1,752965844
	700	313,368	313,8		0,432	
	500	326,75	326,3		-0,45	
	400	334,468	337,1		2,632	
	300	341,762	343,7		1,938	
	250	345,39	347,2		1,81	
	200	350,83	349,5		-1,33	
	100	373,121	371,9		-1,221	

Journal of Theoretical and Applied Information Technology
31st May 2020. Vol.98. No 10

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

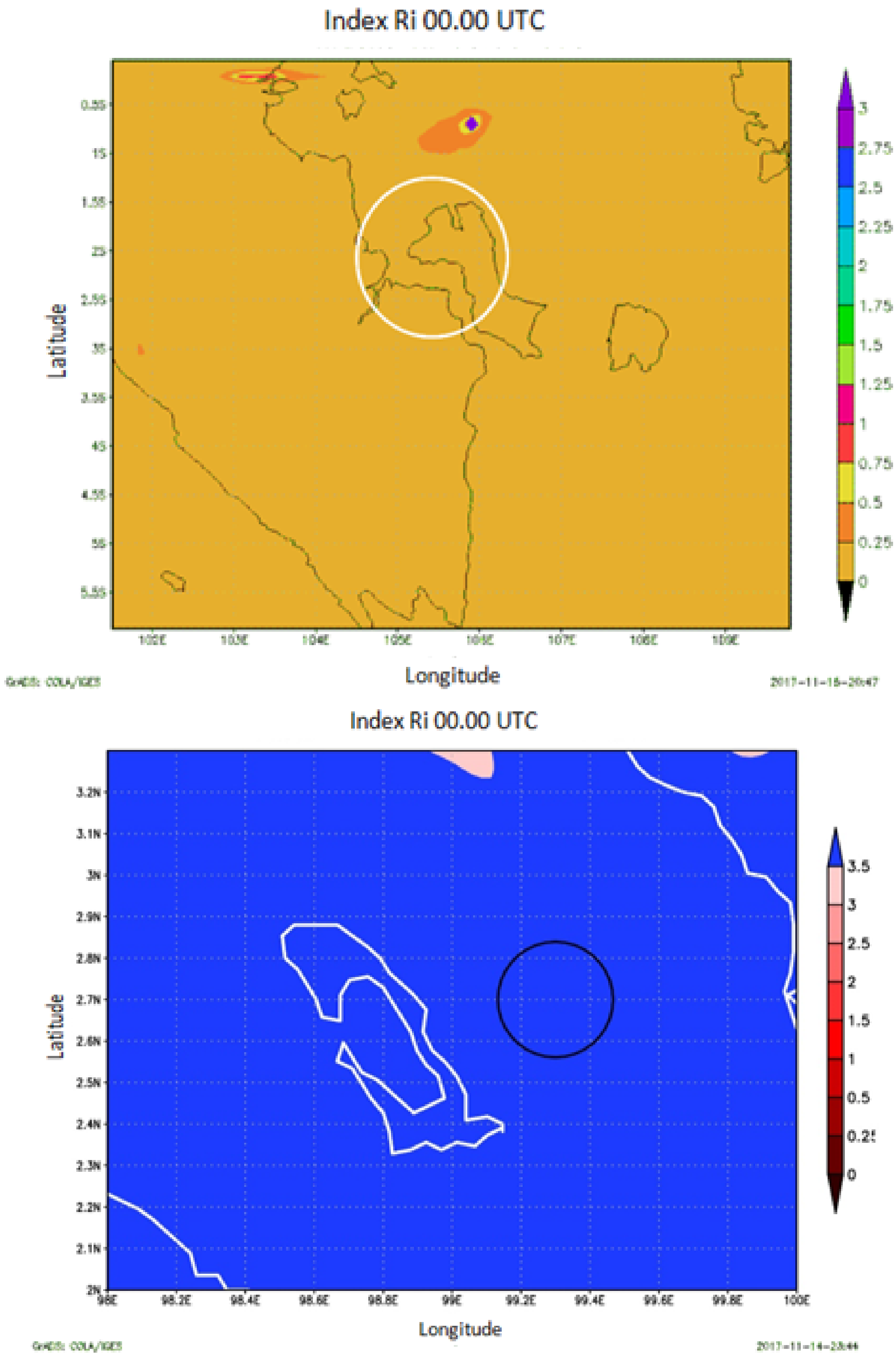

Figure 1: Ri index layers 250 MB to 200 MB at 00.00 UTC
(Etihad Airways EY-474 and Batik Air aircraft, flight number ID 6890)

Flight data from Batik Air flight flight2424 ID6890 around the scene is flanked by two clouds, which are high clouds or convective clouds. The location of events that are within this convective cloud can occur turbulence called the Near Cloud Turbulence (NCT) event. This NCT event is one example of the Clear Air Turbulence (CAT) event. Richardson's number is > 3.5. The results obtained are outside the threshold, so it can be stated that there is no indication of turbulence at the scene. Based on the two cases above, to analyze the turbulence motion, it is not sufficient to calculate only the Richardson index. Some analyses of turbulence consider the convective cloud conditions such as the albedo conditions, which indicate a thick cloud, and include properties such as convective clouds, wind shear, and wind vectors to complement the turbulence analysis [7, 22, 23].

Decision-making systems are approaches that can be used as information technology support that can make quick and accurate decisions [24]. This decision-making system for air transportation disaster management is a combination of software, hardware, and technology that provides information to support decision making. This decision-making system can be implemented as an atmospheric turbulence mitigation that is performed in a web-based technology application. With the web technology for making atmospheric turbulence E-mitigation, the system can be accessed online, from anywhere, anytime with transparency, and can be trusted. The air transportation disaster management decision-making system can be in the form of a submission of reports to users that will be provided either with text or graphics and can be viewed with a variety of variations and multi-dimensions [24, 25, 26, 27].

By making a Decision-Making System like this, a more accurate, clear, and organized decision will be obtained. That is because to make a decision based on mathematical calculations (Richardson index), where the input variables used are based on atmospheric conditions data. The results will help users to be fast and capable of making decisions or provide accurate and reliable information. The more complete the data provided, the accuracy of the information as input to make decisions will be more secure [28, 29, 30, 31].

5. SUMMARY AND CONCLUSION

The results of our Richardson index (Ri index) calculations show a value of 0, which indicates high turbulence. In accordance with [9], Ri < 0.25 indicates high turbulence. The results Ri index of Etihad Airways EY-474 with Ri values obtained 0 is able to show the turbulence. While the Ri index of Batik Air aircraft, flight number ID 6890, is less able to show the turbulence well because it is more than the threshold determined by Ellell, with Ri values obtained > 3.5 in the area of turbulence. However, to perform more in-depth analyses of the occurrence of turbulence than is possible with the Ri index, further analysis calculations are required.

Flight mitigation decision making system from turbulence disasters is an important factor to analyze, this is to find out earlier the occurrence of these conditions. The Richardson index calculation is a scientific study to evaluate the occurrence of turbulence in the aviation world, as well as being packaged into an aviation disaster mitigation information system application. The above results obtained can be used as flight security information systems.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Diponegoro University for the funding allocated for this research via Research Fundamental of Higher Education DRPM Dikti 2019.

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