A Preliminary Comparative Study on the Feasibility of a Multipurpose Numerical Weather Model for Prediction of Cumulonimbus Clouds in Indonesia

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***Abstract*—Prediction of cumulonimbus (Cb) clouds in Indonesia is a necessity for civil aviation operations. The ability comparison of numerical weather prediction (NWP) multimodel to predict Cb clouds in order to obtain the best model was investigated in this study. NWP models used in this research were Australian Community Climate and Earth-System Simulator (ACCESS), Integrated Forecast System High Resolution (IFS HRES), Icosahedral Nonhydrostatic (ICON), Weather Research Forecast-Central Information and Processing System (WRF-CIPS), and Weather Research Forecast-Indonesia NWP (WRF-INA) whose performance is tested by calculating the probability of detection (POD), probability of false detection (1-POFD) and proportion correct (PC). The results show that the IFS HRES model is the best model compared to other models. For further studies, the research should be conducted at another time that has a different Cb cloud frequency distribution from this study**

***Index Terms*—Cumulonimbus, Multimodel, NWP**

I. Introduction

In operational aeronautical meteorology, the presence of cumulonimbus (Cb) clouds is very important information to provide and is considered significant [1]. The Cb cloud is informed in the form of codes and images resulting from the aeronautical meteorology personnel assessment or numerical weather prediction (NWP). Globally, NWP is provided by the world area forecast center (WAFC) London and Washington with a resolution of 0.25°. Cb clouds are dense clouds that have vertical growth that can reach the tropopause and look like mountains or large towers. In the tropics, the tropopause is generally at an altitude of 18 km or FL590 [2]. Cb clouds can produce tailwinds that interfere with take-off and landing [3], microburst and low level windshear [4], heavy rain [5], turbulence [6], icing [7] and lightning [8].

Forecasting weather parameters involving moisture such as rain and clouds with NWP in Indonesia is still a challenge. The reason is, Indonesia consists of thousands of islands surrounded by internal waters as well as two large oceans, namely the Pacific Ocean and the Indian Ocean as the main moisture source which of course has different weather characteristics compared to the continent which only consists of land and oceans which only consist of oceans which must be taken into account in the NWP. [9]. As a result, Cb clouds that grow in Indonesia have a higher frequency than other areas seen in Eastman and Warren's research [10].

Many researches on Cb cloud prediction in Indonesia have been carried out. Based on the stability index from upper air observations, the prediction of Cb clouds for up to 12 hours (t+12) has a good ability with the assumption that the stability index is stationary for 12 hours at each study location [11], [12]. Using NWP with longer prediction duration, t+36 and better spatial resolution than WAFC, Sani and Ismanto [13] calculated the stability index for prediction of Cb clouds in Bima and Rais et al. [14] calculated the coverage of the Cb cloud from the precipitation output in Indonesia with good accuracy. However, these studies generally only examine the prediction of Cb clouds with one NWP model which is not necessarily the best NWP model. Therefore, a study that involves the comparison of many NWP models with a resolution of 9 km - 0.125° to get the best NWP model that can complete these shortcomings. This study aims to obtain the best model so that it can be used as an alternative to using WAFC products. [15] [16] [17] [18] [19]

II. Literature review

Turbulence phenomena are caused by changes in the direction and speed of air currents accompanying thunderstorms, which change atmospheric pressure and occur only in limited areas. For a short time, this air current rotates outwards and moves downwards. This can occur both horizontally and vertically and is most commonly associated with strong temperature inversions or density gradients. Wind shear that occurs below 3000 feet is commonly known as low-level wind shear (LLWS), which is very dangerous for aircraft taking off and landing. The effect on the aircraft is to increase the airflow in the wings, resulting in a sudden increase in aircraft speed due to this increased airflow. If the pilot is not aware of the wind shear indication, it will instinctively adjust the throttle to slow or compensate for the aircraft speed. However, as soon as the aircraft passes the wind shear zone, the wind suddenly turns downward. This event is correlated with loss of lift (stall) by reducing the airspeed of the wing, which is likely to cause the aircraft to fall given that the altitude at this point is not sufficient for recovery [20].

Thunderstorms produce convective weather with temperature reversals in the form of gusts, downdrafts, microbursts and gravitational waves, all of which cause LLWS. In addition, surface topography in the form of mountains, rivers and valleys, including large hangars in addition to airport runways, also changes wind patterns to help LLWS. Microburst is a wind shear caused by a stream of cool air from the bottom of a thundercloud with a design reminiscent of an inverted mushroom. Cumulonimbus (Cb) clouds typically produce microbursts. When a storm rages in the dark clouds, the pilot's main enemy is a micro-explosion, which everyone tries to avoid. Because the downdraft (downforce) caused by the micro-detonation prevents the aircraft from falling to the ground, this micro-detonation phenomenon causes some fatal accidents. Micro-explosion is a phenomenon of atmospheric turbulence that greatly affects aircraft flight during take-off and landing [21]. [22] [23]

A survey of potential turbulence in the Air Asia QZ 8501 plane crash and a meteorological analysis of on-site atmospheric conditions and potential disturbances using MTSAT satellites. The obtained Ri index is 100 or more, which means that there is a possibility of a rather severe impact on the area around the accident site [24].

According to [25], the turbulence index (TI) detects CAT events better than the Richardson number (Ri). However, a previous study [26] of CAT analysis using WRFARW in Indonesia found that the Richardson Number Turbulence Index is suitable for the detection of tropical regions with Ri values greater than 150, indicating severe turbulence.

The Richardson index (Ri) is used to determine the strength of the CAT. To determine the turbulence potential, you need a turbulence index, such as the Richardson number (Ri). The Richardson number (Ri) takes into account the values of vertical wind shear and air stability. Therefore, Ri is ideal for describing clear air turbulence (CAT). [27] [28] [29] [30] [31]

CAT (Clear Sky Turbulence) is defined as severe turbulence that occurs suddenly in a cloudless area and has a significant impact on aircraft. Observational studies using research aircraft have shown that the presence of high clouds, vertical wind shear, wind speed, the appearance of jet streams (groups of high-speed winds blowing from east to west at altitudes above 5 km), and the Richardson index are highly correlated with CAT [32]. I have a relationship. [33] [34] [35]

Thermal turbulence occurs when a surface is heated by solar radiation due to a surface occlusion factor. This often occurs during the day when winds are weak and can create unstable atmospheric conditions. Midwife turbulence, or mechanical turbulence, is caused by wind friction against the earth's surface. This often occurs in mountainous areas because the uneven surface of the planet is a concern when winds blow through the mountains. [36] [37] [38] [39] [40]

III. Methodology

In this study, the authors use Himawari-8 satellite imagery as observations of Cb clouds. The algorithm used follows the maximum and minimum limits used in the research of Suseno et al. [41] and Hamada et al. [42] by using two channels, namely IR1 and IR2 channels. The limit values are based on IR1-IR2 with a maximum value of 2°C and a minimum of -2°C and IR1 with a maximum value of 259°C (Figure 1).

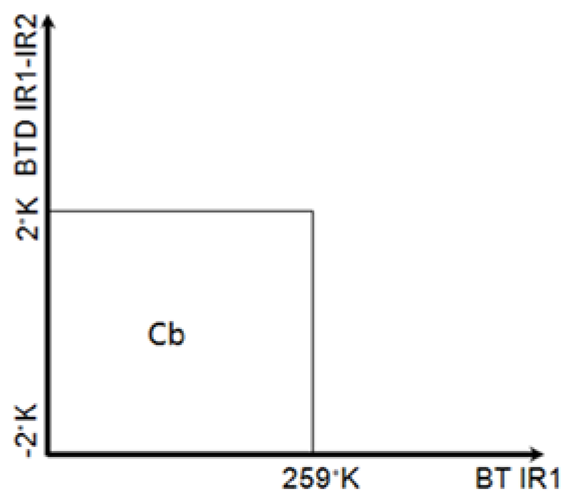

Fig. 1. Illustration of Cb threshold with Himawari-8 . satellite image source: processed products, 2021

As a predictive output, the authors post-processed the operational NWP precipitation model. Rainfall was used to calculate the number of convective clouds with a limit of 50 persen for the estimation of Cb clouds following the research of Slingo and Slingo [43]. The 50 persen limit is the best limit in determining the Cb cloud area [15]. The operational NWP models used are the Australian Community Climate and Earth-System Simulator (ACCESS), Integrated Forecast System High Resolution (IFS HRES), Icosahedral Non Hydrostatic (ICON), Weather Research Forecast-Central Information and Processing System (WRF-CIPS). and Weather Research Forecast-Indonesia NWP (WRF-INA) with spatial/temporal resolutions of 0.12°/102 hours, 0.125°/120 hours, 0.125°/120 hours, 0.1°/120 hours and 9 km/72 hours, respectively. The initial conditions for each model are 18-24 May 2021. Based on this resolution and the maximum temporal resolution of the WAFC output of 36 hours, the authors divide the model capability verification period into 6-36, 39-72, 75-102 and 105-120 hours.

Test the ability of the model based on the values of probability of detection (POD), probability of false detection (1-POFD) and proportion correct (PC). POD or hit rate describes the model's ability to predict Cb clouds. 1-POFD or false alarm rate indicates the model's ability to predict the absence of Cb (Non-Cb) clouds. While the PC shows the accuracy of the model predicting Cb or Non-Cb clouds. All of these parameters have a maximum value of 1. The algorithm used is as follows [44] :

$$POD = \frac{a}{a+c} \tag{1}$$

$$1 - POD = 1 - \frac{b}{b+d} \tag{2}$$

$$PC = \frac{a+d}{a+b+c+d} \tag{3}$$

Table 1. Cb and Non-Cb contingencies.

		Observasi	
		Cb	Non-Cb
Prediction	Cb	a	b
	Non-Cb	c	d

source: processed products, 2021

A condition that can occur between a Cb cloud and a Non-Cb cloud when switching to an algorithm after combining observations into a prediction table.

IV. Results and Discussion

A. Cumulonimbus Cloud Frequency

Based on Figure 2, the highest frequency of Cb clouds is in western Papua, southern Maluku, Arafuru Sea, Tolo Bay, northern Pacific Ocean, western Papua and northern Kalimantan. Cb clouds are not visible in most of Java to Nusa Tenggara with a frequency close to 0 persen. This pattern is a seasonal pattern of Cb cloud frequency which reaches its peak in the December-February period around Java to Nusa Tenggara [45].

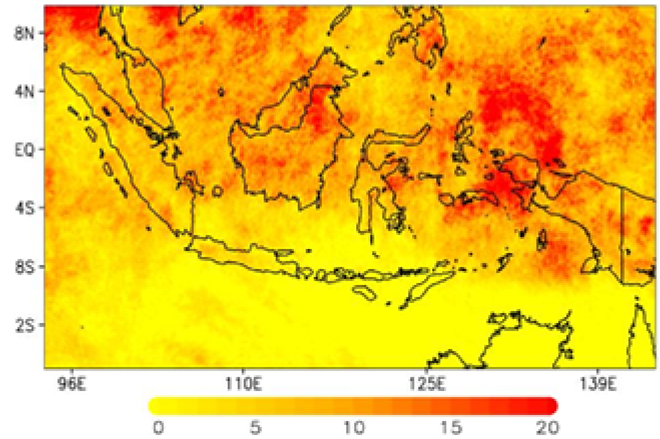

Fig. 2. Cb cloud frequency (persen) in May 18-24
source: processed products, 2021

B. Spatio-temporal Comparison Cumulonimbus Cloud Prediction

In figure 3, POD ACCESS has high value in the area of large Cb cloud frequency, except in northern Kalimantan. POD decreases as the period increases. 1-POFD and PC ACCESS are of small value in areas of high Cb cloud frequency, but increase as the period increases. POD IFS has a large value in the Cb frequency area, especially during the periods 6-36, 39-72 and 75-102 hours in Figure 4. While 1-POFD and PC IFS also have a small value in the large Cb cloud frequency area with a pattern that gets bigger as the prediction period increases. Figure 5 and Figure 6 show that the POD,1-POFD and PC ICON and WRF TIPS patterns have the same characteristics as IFS, but with a smaller value. With the shortest prediction period, POD, 1-POFD and PC WRF-INA have the same pattern as the other 4 models in Figure 7. For northern Kalimantan, only POD IFS has high value in the 6-36 hour period and POD WRF-CIPS and WRF-INA were of high value during periods of 6-36 and 39-72 hours. The decrease in POD value is a common pattern for predicting cloud cover using NWP as in Ye and Chen's research [46], but PC has increased because its value is more like 1-POFD than POD which was also found in Rais et al.'s study. [15]. This happens because the frequency of Cb clouds is 20 persen so that the NWP model detects Non-Cb more. The difference is shown by the PC value of radiosonde-based Cb cloud prediction for a period of 12 hours [13] and WRF for a period of up to 36 hours [14] which is closer to POD because it seems that the frequency of Cb clouds is more common in each research area.

In general, the POD values for all NWP models were still below 0.5 and decreased over the prediction period in Figure 8, except for the ACCESS model which increased during the 75-102 hour period. The largest POD is shown by the IFS model and the lowest is the ACCESS model. The largest IFS POD may be related to the best precipitation performance of the IFS model compared to other models as in the study of Kerns et al.

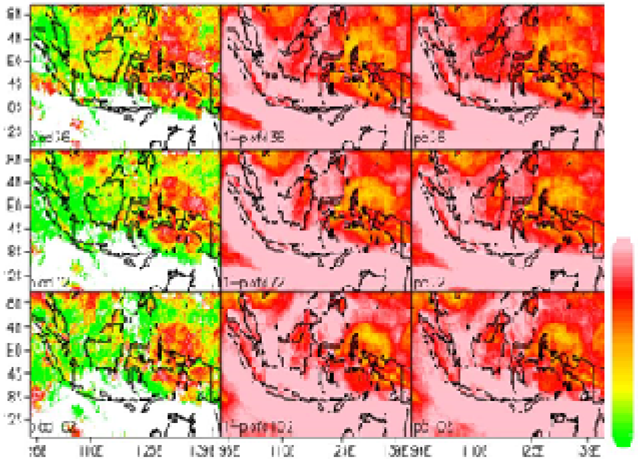

Fig. 3. POD, 1-POFD and PC prediction of ACCESS model Cb cloud in Indonesia in the period of 6-36 hours, 39-72 hours and 75-102 hours
source: processed products, 2021

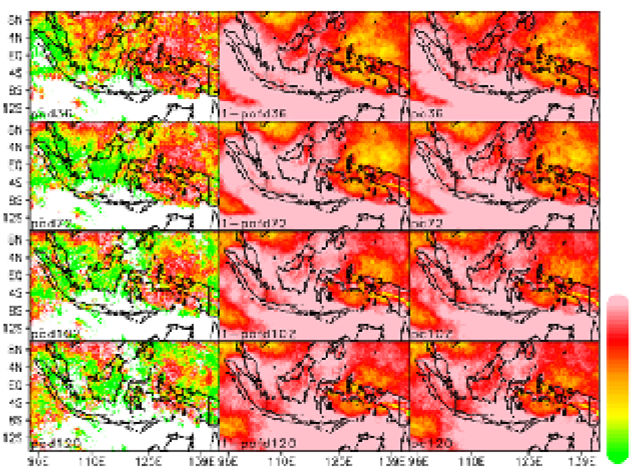

Fig. 4. POD, 1-POFD and PC prediction of the Cb cloud model IFS HRES in Indonesia in the prediction period of 6-36 hours, 39-72 hours and 75-102 hours and 103-120 hours
source: processed products, 2021

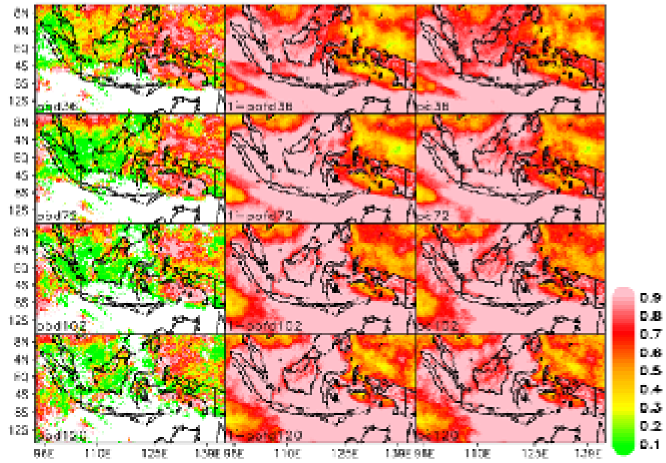

Fig. 5. Indonesia in the prediction period of 6-36 hours, 39-72 hours and 75-102 hours and 103-120 hours
source: processed products, 2021

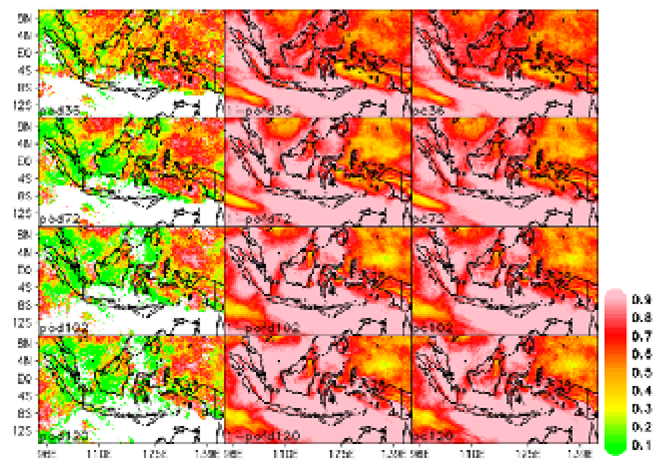

Fig. 6. POD, 1-POFD and PC prediction of the WRF-CIPS Cb cloud model in Indonesia in the prediction period of 6-36 hours, 39-72 hours and 75-102 hours and 103-120 hours
source: hprocessed products, 2021

[47], Ran et al. [48] and Abdolmanafi and Montana [49]. The 1-POFD and PC values of all NWP models are around 0.8 and have an increasing pattern with increasing prediction period, except for the INA-NWP model which decreased in the 39-72 hour period and IFS HRES and ICON which also decreased in the 105-120 period. o'clock. Maximum PC and 1-POFD were shown by the WRF-INA, ACCESS, and IFS models in the 3-36, 39-102 and 105-120 hours periods, respectively. PC and 1-POFD WRF-CIPS are the lowest compared to others.

V. Conclusion

The comparison of predictions of Cb clouds in Indonesia up to t+120 using the NWP ACCESS, IFS HRES, ICON, WRF-CIPS and WRF-INA models was studied in this study to find alternative reference models other than the products issued by WAFC. From the results and discussion, the IFS HRES model is the best model because it has the largest POD and 1-POFD and a PC that is not too far from other NWP models. This result is of course related to the distribution of the Cb cloud frequency in Indonesia which is not large on 18-24 May 2021. Therefore, studies at other times are needed to complete the next study. [50] [51] [52] [53] [54]

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Author Contribution Statement

The 1st author is the main contributor to designing research methods, coding programs, conducting data analysis and interpretation, and making publication manuscripts; The 2nd author

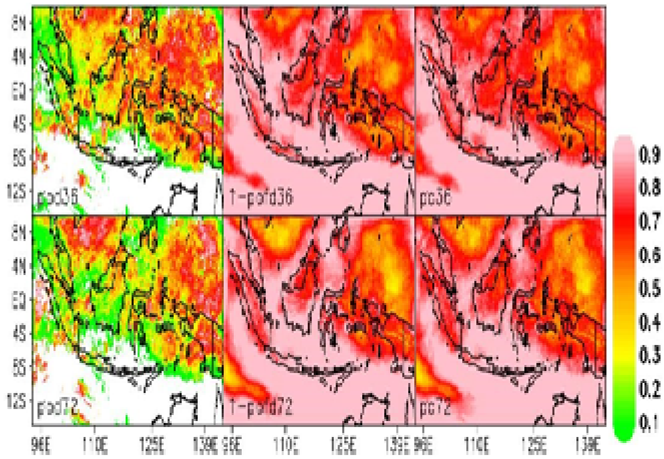

Fig. 7. POD, 1-POFD and PC prediction of the WRF-INA Cb cloud model in Indonesia in the prediction period of 6-36 hours and 39-72 hours
source: processed products, 2021

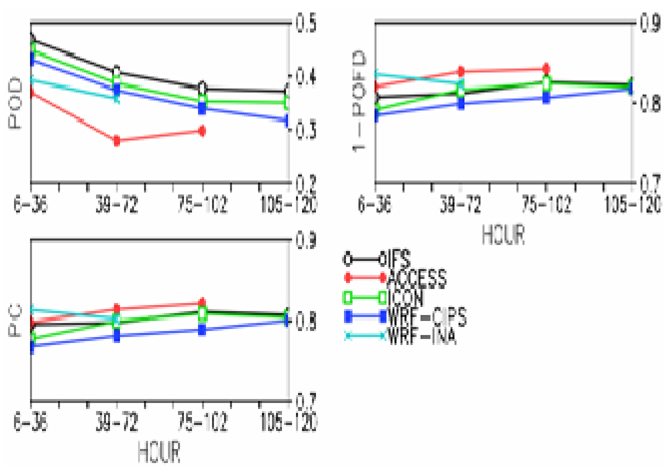

Fig. 8. POD, 1-POFD and PC prediction of the WRF-CIPS Cb cloud model in Indonesia in the prediction period of 6-36 hours, 39-72 hours and 75-102 hours and 103-120 hours
source: processed products, 2021

made the publication manuscript. The third author reviews the publication manuscript. [57] [58] [59]

Conflict of Interest

A statement that the research is not involved in any conflict of interest. The author declares that the research is not involved in any conflict of interest. [60] [61] [62]

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