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Clear Air Turbulence Mitigation Due to Climate Change in Indonesia

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ABSTRACT

Natural disaster nowadays often occur in Indonesia due to climate change, especially those related to atmospheric dynamics anomalies. The latest clear air turbulence (CAT) is often experienced by air transportation. Turbulence is a very interesting phenomenon since it is very difficult to solve even though the symptoms have long been aware of. Turbulence modeling in fluid physics in the atmosphere is a very important thing and an effort to explain a problem that is hard to solve (turbulence) becomes very interesting. In this research, turbulence motion calculation was carried out by physical parameters object's deformation motion, either horizontally, or vertically as well as atmosphere gradient wind shift based on the data of the weather from radiosonde of the research's site. As the case study, a calculation from the phenomenon of Batik Air's aircraft ID6890 experiencing the turbulence on 24 October 2017 will be carried out. The calculation result shows turbulence index value in the point of even was located at around $2 – 8 \times 10^{-1}s^{-Z}$ showed that turbulence did occur.

Key words: *Physics Dynamics, index Turbulence, CAT, Aviation, Transportation disaster*.

Introduction

Climate change effect makes the weather parameter as one of the factors causing the incident in the aviation world. Almost 75% of aircraft accidents occurred because of bad weather factor (Hermawan and Abidin, 2006). One of the bad weather conditions encountered by the aviation world is turbulence on a plane. Turbulence is a flow of air that moves randomly to all directions that have a small scale that occurs in average air motion (Gernowo *et al.*, 2020). Turbulence is a common thing to occur and it does not make plane crashes. However, turbulence could make other events that could cause other events leading to plane crashes (Vahada *et al.*, 2015). One of the types of turbulence is convective turbulence caused by convective clouds. These clouds are known as cumulonimbus which in the cloud, big turbulence occurs especially when it is raining and in the thunderstorm (Blackadar, 2000).

Based on BNPB data, natural disasters caused by anomalous dynamics of the atmosphere in Indonesia occupy the highest number, as in Figure 1. Floods are followed by turbulence disasters. Turbulence disasters as mentioned include Cyclone, Typhon, CAT, and windshear, with events during the period 2000 to 2020 (BNPB data).

The development in the field of aviation navigation enables airplanes to avoid bad weather area that has convective clouds using weather radar in

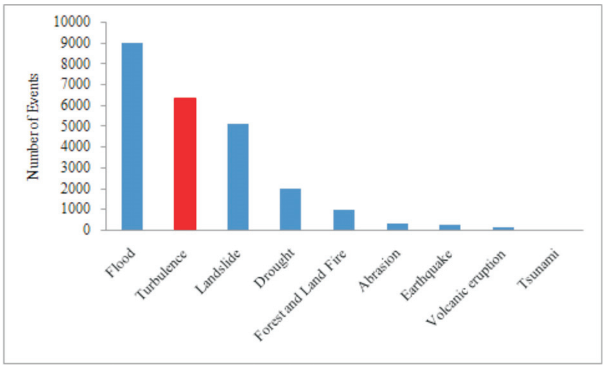


Fig. 1. Number of Natural Disaster Events in Indonesia during the period 2000 to 2020.

the aircraft. However, there are conditions of unpredictable weather in the area where convective clouds do not present, this phenomenon is called Clear Air Turbulence (CAT) which is unpredictable (Keller, 1981; Jaeger and Sprenger, 2007; Vankatesh and Mathew, 2013). CAT is a type of turbulence that has no convective clouds in its appearance. Therefore, such type of turbulence is hard to detect either visually or using weather radar (Gernowo *et al.*, 2017; Gernowo *et al.*, 2020). CAT with light to medium intensity may shock the aircraft, while strong intensity may make the aircraft difficult to maintain its altitude even the passengers could be thrown away from their seats (Molarin, 2013). CAT could cause some loss such as accidents, damage to the aircraft, fuel loss, and flight delays (Kim and Chun, 2017; Kim *et al.*, 2011).

Physically, turbulence motion in the atmosphere is a flow of air that moves in a medium, and then occur layers of flat airflow abreast with the medium surface. Such airflow as mentioned above is called laminar airflow. Boundary layer also occurs in this laminar airflow, so that the speed of the air layer close to the object's surface would be smaller than the speed of the airflow in farther from the object's surface. In the boundary layer, the influence of viscosity is relatively bigger so that the profile of speed is not uniform. Outside the boundary layer, there is no viscosity influence so that the flow could be treated as in viscid flow. The upper layerof the boundary layer is a thin layer on the solid surface where the fluid flows where the influence of viscosity is relatively big (Taylor *et al.*, 1992).

Study Method

Turbulence Index

Index to identify CAT could use Turbulence Index (TI). (Kim *et al.*, 2015) conducted research using such a parameter to detect the occurrence of turbulence and such research stated that TI2 had the best performance in detecting turbulence. (Rozas, 2002) in his research showed that index turbulence was divided into two TI1 and TI2 which was used to count the horizontal deformation and Vertical Wind Shear, as for the difference between TI2 and TI1 was that T12 was added by convergence element in its calculation. According to (Ellord and Knapp, 1992) the physical basic description to use the formula of the relationship between horizontal deformation and vertical wind shift could be indicated as CAT objective indicator was first proposed by (Moncuso and Endlich, 1966) Furthermore, (Ellord and Knapp, 1992) developed such indicator so that Turbulence Index TI1 and TI2 to predict the turbulence.

$$TI1 = \left((\partial u/\partial z)^2 + (\partial v/\partial z)^2\right)^{1/2} \times \left(\left((\partial u/\partial x - \partial v/\partial y)^2 + (\partial v/\partial x + \partial u/\partial y)^2\right)\right)^{1/2} \quad ..\ (2)$$

$$TI2 = \left((\partial u/\partial z)^2 + (\partial v/\partial z)^2\right)^{\frac{1}{2}} \times \left(\left(\left((\partial u/\partial x - \partial v/\partial y)^2 + (\partial v/\partial x + \partial u/\partial y)^2\right)\right)^{\frac{1}{2}}\right) - (\partial u/\partial x + \partial v/\partial y) \quad ..\ (3)$$

Where the term $((\partial u/\partial z)^2 + (\partial v/\partial z)^2)^{1/2}$ is Vertical Wind Shift in s^{-1} unit, Horizontal Deformation (DEF) is the result of Deformation Summation Tension (DST) added by Deformation Shift Horizontal (DSH), where tension deformation physically is $(\partial u/\partial x - \partial v/\partial y)$ in s^{-1}unit, while Deformation Shift Horizontal (DSH) $(\partial v/\partial x + \partial u/\partial y)$ in s^{-1} unit, and $-(\partial u/\partial x + \partial v/\partial y)$ is the convergence (CVG) in s^{-1}unit [19]. The threshold used by TI1 follows the condition issued by The National Meteorology Centre (NMC). NMC has 2 models with their threshold i.e. Nested Grid Model (NMG) and Aviation Model (AVN). Index T12 uses threshold from Air Force Global Weather Central (AFGWC).

Model Parameter Estimation

The data used as the initial input model WRF-ARW is data Final Global Assimilation System (FNL) from National Centres for Environmental Prediction - National Centre for Atmospheric Research (NCEP-NCAR) with 1^o x 1^o resolution. Other supporting data was satellite image Himawari from the Board of Meteorology Climatology and Geophysics. The tools used in this research were WRF Domain Wizard v1.30, model WRF-ARW V.3.1.1, and Grid Analysis and Display System (GrADS).

The flight data of Batik Air aircraft with the flight number ID 6890 dated on 24 October 2017 from the Flightradar24 data manifested in the analysis report written by (Sampe, 2017). The flight data could be downloaded at www.flightradar24.com.

Radiosonde Data from Kualanamu airport dated on 24 October 2017 at 00.00 UTC and 12.00 UTC, data sounding accessed from website weather .uwyo.edu/upperair/sounding.html.

The parameter to identify the turbulence could use Turbulence Index (TI) counted based on FNL data and radiosonde parameter (Table 1). The Turbulence Index model calculation used deformation Vertical Wind Shear (VWS) run in Weather Research Forecasting-Advanced Research WRF (WRF-ARW) with programming from formulation of Turbulence Index.

WRF-ARW Modelling

Weather Research and Forecast (WRF) model application could be used to analyze the atmosphere dynamic since WRF model have developed an advanced generation model of mesoscale assimilation system prediction to help understanding and system prediction about atmosphere circulation anomaly. WRF model is the newest model developed from MM5 Model applied in various problems and covers some advantages such as (NCAR, 2014):

1. The model uses a vertical coordinate following the terrain, hydrostatic-pressure with the peak model of constant pressure surface with grid horizontal (Arakawa-C grid).
2. The model time integration scheme uses the third order of Runge-Kutta scheme and spatial discretion using the second and sixth-order schemes.
3. The model supports either ideal application or real data with a various selection of lateral conditions and unlimited.
4. Microphysics calculation and turbulence index.
5. Cumulus parameterization

This model is run in 3 domains Figure 2 and 3 steps are used to downscaling of NCEP-FNL global data, and this is done to obtain an analysis of turbulence events within a radius of 3 km in the horizontal direction. The domain 1 and 2 simulation process is done simultaneously in one WRF system model

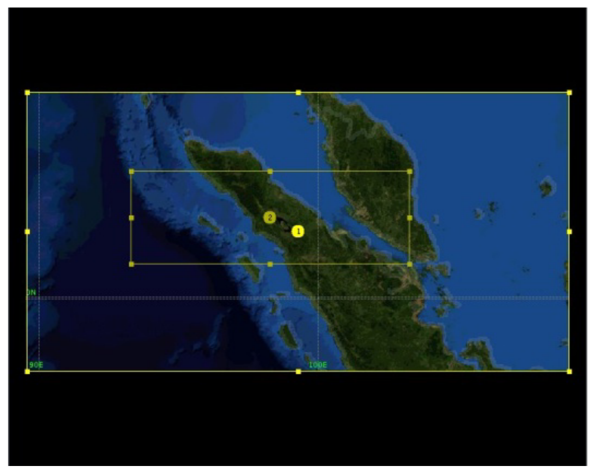


Fig. 2. Research area downscaling

Table 1. Real data temperature, Wind Speed and Theta

Date	LEV	Temp(^{o}C) Radiosonde	Wind Speed (Knot) Radiosonde	Theta(K) Radiosonde
October 24 2017 12 UTCBatik Air ID6890	850	17	11	303,9
	700	9,6	8	313,1
	500	-5,3	12	326,5
	400	-16,1	8	334
	300	-30,1	20	342,8
	250	-40,3	26	346
	200	-53,5	38	347,9
	100	-79,7	14	373,5
October 24, 2017, 00 UTCBatik 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

(WPS), while for domain 3 it is done using the Ndown.exe command from the WRF model. The resolution of three domains namely; domain resolution 1 30 km, domain resolution 2 10 km, domain resolution 3 5 km (Skamarock *et al.*, 2005).

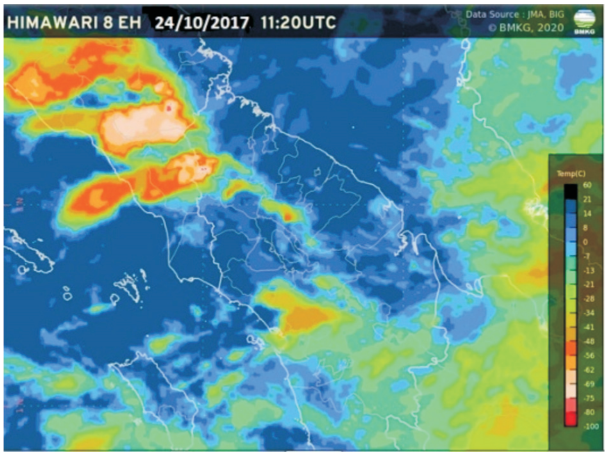


Fig. 3. Himawari Satellite Image (source BMKG)

The risk of clear air turbulence in the boundary layer to airplane flight

Risk in aviation safety can be estimated by different approaches. One of them is based on the evaluation of CAT events to avoid an incident or plane crash in flight (Kim and Chun, 2017). Figure 3.shows Himawari satellite image on 24 October 2017 at 11 UTC around the site of occurrence. Based on the satellite image, it was shown that there were clouds with weak growth, where according to (Bumrungklang *et al.*, 2017) warm temperature or positive in canal IR shows the surface of the earth without cloud covering it and the contrary, the cold temperature or negative shows convective clouds. High clouds such as Cirrus also show cold temperature, albedo from canal VIS is needed to differentiate the types of clouds. Thin clouds have a low albedo of around 30%. Thick cloud such Cumulus, Altocumulus has an albedo between 40 - 70 %, and Cumulonimbus has albedo > 70%.

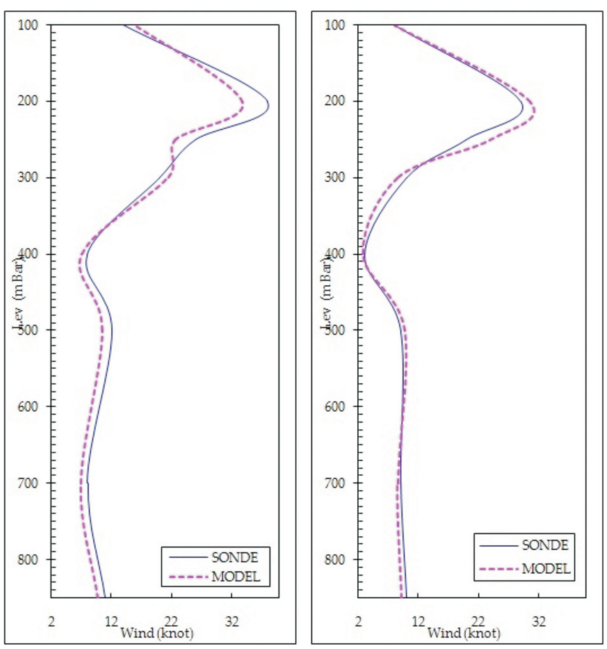


Fig. 4. Wind Speed data validation on October 24 2017 12 UTC and October 24, 2017, 00 UTC Batik Air ID6890

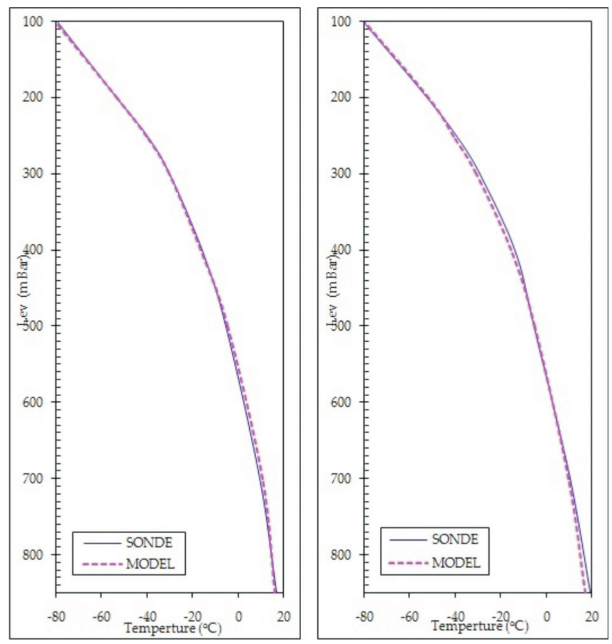


Fig. 5. Temperature data validation on October 24 2017 12 UTC and October 24, 2017, 00 UTC Batik Air ID6890

Besides, satellite images could also represent the clouds with a peak temperature of less than -40°C indicated that the presence of high clouds around the location. The location of the occurrence in between such convective clouds the turbulence called Near Cloud Turbulence could occur (NCT). Where NCT, according to (Lane *et al.*, 2012) is the turbulence caused by the upper layer of outflow thunderstorm. Such outflow would later cause a gravitation wave that could decrease the stability or cause Kelvin Helmholtz Instability (KHI). Such NCT event was one of Clear Air Turbulence (CAT) events (Overeem, 2002; Munandar, 2014).

Figure 4, 5, and 6 were data output of WRF validated using radiosonde data which constituted real atmosphere parameter data. The variable considered was the correlation and its RMSE, from the temperature data, and wind speed. RMSE of the theta data of WRF output and radiosonde data on 24 October 2017 12 UTC, and 24 October 2017 00 UTC. The result shows the correlation of the WRF output data and radiosonde data in a percentage correlation of around 99.9% and it could be said that the output result of WRF is valid data.

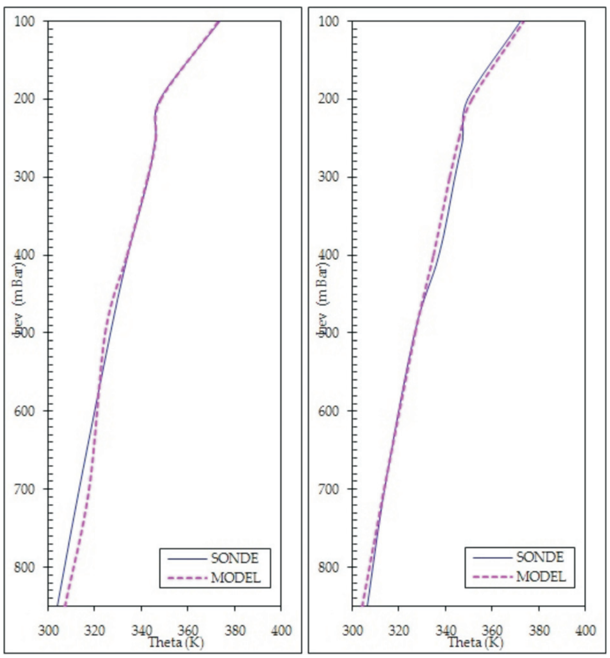


Fig. 6. Tethadata validation on October 24 2017 12 UTC and October 24, 2017, 00 UTC Batik Air ID6890

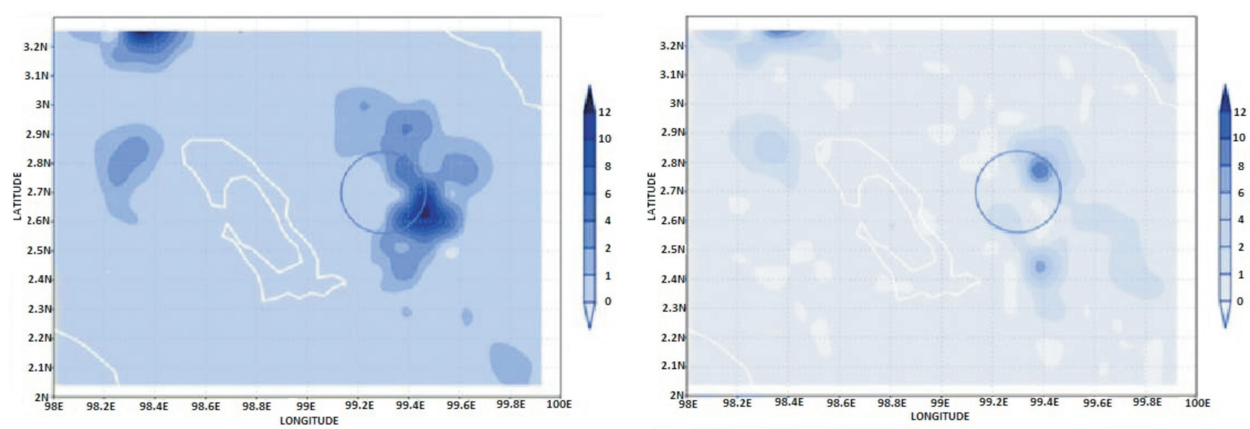
Figure 7 and Figure 8 shows the score of turbulence index in the site of occurrence was around which according to (Ellord and Knapp, 1992) TI1 and TI2 score obtained indicated the occurrence of turbulence with medium intensity. TI1 and TI2 had horizontal and vertical components. Therefore, it could be suggested that the cause of the turbulence was from the factor of deformation motion.

Discussion

The identification result shows that turbulence occurs in the research area are CAT. The warm temperature on the satellite image indicates that the cloud peak temperature comes from the low clouds or surfaces without cloud cover. Low albedo indicates the thin cloud covering in such an area. Convective Available Potential Energy (CAPE) in the research area shows that the air tends to be stable or weak to medium convection Figure 2. It shows that there is a potential growth of convective clouds. However, the satellite image does not show any convective clouds on the site.

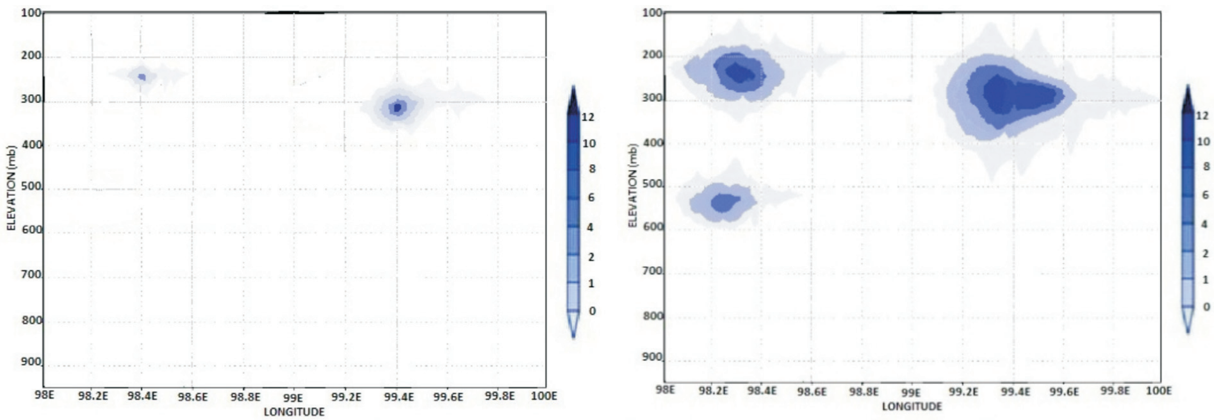
The difference of the occurrence site of CAT between what is reported by the pilot and the finding result on the satellite image allows CAT reported after the aircraft passes through the turbulence area. Such a pattern indicates the presence of turbulence. The air parcel raised above would be back to the initial level when the environment temperature equals to the parcel temperature. This occurrence keeps repeating so that it forms a wave pattern (Sampe, 2017).

Figure 6 and Figure 7 provides information that



T11 T12

Fig. 7. Horizontal profile at the altitude of between 250 and 200 MB index TI1, TI2, in the research area at the event of its occurrence. The blue circle is the research area.



T11 T12

Fig. 8. Vertical profile at the altitude of between 250 and 200 MB index TI1, TI2, in the research area at the event of its occurrence

there is a turbulence area with bigger intensity outside the observation area. Such location takes place in the northeast of the research location. The output of the WRF-ARW model could capture the phenomenon of CAT but the exact location could not be assured just yet (Gernowo *et al.*, 2018; Gernowo *et al.*, 2019; Minor, 2000).

Conclusion

In the paper, we propose to use aphysically formula; it could be analyzed a deformation force both vertical and horizontal could be used to explain the turbulence motion. In turbulence flow, particles move in random tracks caused by the momentum exchange from one medium to another. Big scaled turbulence flow, as the airwaves motion is the inability of an object to change mechanic energy through viscose work, which generally the turbulence intensity would increase along with the increase atmospheric anomaly. Naturally, the flow would go through a transition process from laminar flow to turbulence flow. This could explain that the phenomenon of turbulence motion is a very complicated physical phenomenon. The formula of the deformation motion in the turbulence index is an approach used to early predict the occurrence of such a phenomenon.

The identification results show that the turbulence that occurred was CAT. WRF/ARW model can simulate the occurrence of CAT through the index of TI1 and T12. In this research, the TI2 index had the best performance in detecting CAT. In this research, there was a growth pattern of VIS canal satellite image clouds, Horizontal CAPE and TI profile indicate the presence of KHI which caused CAT. Such a pattern could be used as an indicator of CAT occurrence. Analyzed physically, it was proven that the phenomenon of the deformation motion dynamic in the atmosphere (turbulence index formula) could be used to predict the occurrence of atmosphere anomaly, as the mitigation of non-convective turbulence disaster.

The increase in the incidence of turbulence due to climate change is the reason that prediction models are needed in an effort to minimize casualties.

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Disclosure Statements

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