Analysis of the influence hybrid mass coordinate on WRF-ARW models to the turbulence simulation of Batik airlines aviation (case study October 24, 2017)

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Abstract. The influence of hybrid sigma coordinate is better to represent turbulence in America than basic sigma coordinate. Therefore, it is necessary to search the effect of these coordinates on turbulence simulations in Indonesia due to the analysis of different atmospheric conditions from America. In this research, two experiments are performed using two different vertical coordinates with a case study flight turbulence from Batik Airlines on October 24, 2017. The two different vertical coordinates are the hybrid sigma coordinate and basic sigma coordinate. The data used are NCEP-FNL, Himawari-8 satellite image data, and sounding data. Based on the result of this research, simulation using hybrid sigma coordinate shows isentropic lines that have the potential turbulence during and after turbulence event. Richardson number value about 0.1 – 0.2 and intensity of the energy dissipation rate is 0.06 $m^{2/3}s^{-1}$. According to the Richardson number value and intensity of the energy dissipation rate, the hybrid sigma coordinate simulation shows turbulence potential more significant than the basic sigma coordinate.

Keywords : Turbulence, Hybrid sigma coordinate, Turbulence intensity

1. Introduction

Weather is one of the most essential factors in the aviation system. Turbulence contributed 71% of the total 446 aircraft accidents in 2000-2011 [1]. Many studies have focused on predict turbulence because the impact of turbulence is quite harmful to passengers and airlines.

The turbulence incident of Batik Airlines on October 24, 2017 occurred at 09.59 UTC at an altitude of 25,500 feet [2]. As a result of the turbulence, one person has injured, and two people suffered minor injuries. According to the pilot’s reports, the intensity of turbulence is moderate. Furthermore, the turbulence caused by two convective systems that produce multilevel outflows [3].

The previous study about turbulence in Indonesia used the WRF-ARW model with the basic terrain-following as a vertical coordinate type. However, the basic terrain-following has errors in the top layer are caused numerical errors in the form of noise, especially from the topography on the surface [4]. This problem can be solved using the hybrid terrain-following because the middle and upper-level coordinate surfaces are more closely related to the constant pressure surface. The hybrid terrain-following also
reduces vertical wind perturbation errors around the troposphere near the presence of jet streams with extreme winds. Meanwhile, the turbulence did not cause by Jetstream in Indonesia. The atmospheric conditions in Indonesia are different from the American region. Therefore, this study analyses turbulence events using a hybrid sigma coordinate on the Batik Airlines ID 6890 aircraft with the Jakarta-Medan flight route on October 24, 2017 by WRF-ARW model.

2. Design and Method
The data used are National Centers for Environmental Prediction (NCEP), Global Tropospheric Analyses (final analyses; FNL), Himawari-8 satellite image data, and sounding data. In this research, two experiments are performed using two different vertical coordinates with a case study flight turbulence from Batik Airlines on October 24, 2017. The two different vertical coordinates are hybrid sigma coordinate (HSC) and basic sigma coordinate (BSC). Hybrid option “two” for HSC and “zero” for BSC. Then model output verified by calculating the correlation coefficient and standard deviation error with the sounding data. We calculated Richardson Number (Ri) to identify potential turbulence in the atmosphere, Turbulence Kinetic Energy (TKE), and Energy Dissipation Rate (EDR) to identify the intensity of turbulence from both vertical coordinates.

Table 1. Configuration of WRF-ARW

| Configuration of WRF-ARW |
|-------------------------|
| Microphysics scheme     |
| Cumulus scheme          |
| Longwave radiation scheme |
| Shortwave radiation scheme |
| Planetary Boundary Layer scheme |
| Hybrid Option           |
| WRF Single-Moment 6-class Scheme |
| Kain-Fritsch            |
| RRTM Longwave Scheme    |
| Dudhia Shortwave Scheme |
| Mellor-Yamada-Janji Scheme (MYJ) |
| 0 or 2                  |

3. Result and Discussion

3.1 Verification Model
Model output verified to determine the ability of the model to represent events according to the time available in the verification data. If the verification results at that time are good, the phenomena that occur at other times can be well represented. There are two kinds of verification used in this study, namely qualitative and quantitative.

In quantitative verification, radiosonde data used from the Kualanamu Meteorological Station on October 24, 2017 at 00 UTC and 12 UTC and October 25, 2017 at 00 UTC. This data used to verify the WRF-ARW output using the basic sigma coordinate and hybrid sigma coordinate.

The results of the verification are briefly shown in the Taylor diagram (Figure 1). Based on the Taylor diagram, it can be concluded that the two simulations of the WRF-ARW model are considered in good agreement with observation data because they only have slight differences and not too significant.

For qualitative verification, cloud top temperature in WRF-ARW’s variable compared with the IR1 channel of Himawari-8 satellite imagery. The convective core is identified from the cloud top temperature of less than 221 K, which follows a threshold used by Yang et al. [5]. The location of the turbulence is marked with a purple circle in Figure 2. Blue lines show cloud top temperature less than 221 K. The simulation results using a hybrid sigma coordinate show no convective core at 10.00 UTC to 10.10 UTC (Figure 2). The IR1 channel of Himawari-8 Satellite imagery does not show any convective core at 09.40 to 10.10 UTC at the turbulence location. While the simulation results using
basic sigma coordinate show a convective core at the turbulence location from 09.40 UTC to 10.00 UTC.

Figure 1. Taylor Diagram by verification model. The asterisk symbol shows observation data.

Figure 2. Comparison between IR1 data from Himawari-8 satellite imagery (line 2), with cloud top temperature from hybrid sigma coordinate simulation (line 1), and basic sigma coordinate simulation (line 3). From left to right shows the data at 09.40 UTC, 09.50 UTC, 10.00 UTC, on October 24, 2017. The circle symbol shows the location of turbulence.
In the Himawari-8 satellite image’s plot, there is a cloud cluster on the upper right. This cloud cluster is also seen at the exact location simultaneously and time from the simulation results using the hybrid sigma coordinate. In contrast, the simulation results using the basic sigma coordinate shows the position of the cloud clusters has shifted slightly downward. This comparison is valid because the area is not a domain two boundary, so it is not affected by the effect of the boundary on the model.

Based on comparing the IR1 channel Himawari-8 satellite image with the WRF-ARW’s Cloud Top Temperature output (Figure 2), the simulation using the hybrid sigma coordinate shows more correspond to the Himawari-8 satellite image than the basic sigma coordinate.

3.2 Pressure Perturbation

In this subsection, we focused on a cross-vertical sections from 2.5°N and 99 °E – 100 °E taken along line AB as shown in Figure 3.

The two simulations show different results in the pressure perturbation parameter. In Figure 4, the hybrid sigma coordinate simulation shows that the area affected by the surface reaches a height of 8 km. Meanwhile, the basic sigma coordinate simulation shows that the area affected by the surface reaches a height of 16 km. It can be seen from the pressure perturbation pattern that follows the topography on the surface. The effect of the hybrid sigma coordinate is also seen in the horizontal area at 99.5 °E – 100 °E. In this area, the influence from the surface only reaches an altitude of 7 km. Whereas in the basic sigma coordinate simulation results, the area affected by the surface reaches an altitude of 11 km.

Based on the results of the two simulations, the hybrid sigma coordinate has more negligible effect on the surface of perturbation pressure compared with the basic sigma coordinate. From this difference in surface influence, other meteorological parameters showed differences. Analysis of these parameters has discussed in the following subsection. The other parameters are plotted on 99.5 °E – 99.75 °E.
Figure 4. Comparison of pressure perturbation between hybrid sigma coordinate (a,b,c) and basic sigma coordinate (d,e,f). (a) and (d) shows data at 09.50 UTC, (b) and (c) shows data at 10.00 UTC, (c) and (f) shows data at 10.10 UTC on October 24, 2017. The asterisk symbol shows the location of turbulence.

3.3 Vertical Wind

The Vertical wind is used to determine the vertical airflow pattern. We would focus on the location of the turbulence first. Based on the simulation using a hybrid sigma coordinate, downdraft with velocity 0.1 m/s occurs at the turbulence location (Figure 5.a), then increased to 0.15 m/s at 10.10 UTC (Figure 5.b). Updraft with a velocity of 0.1 – 0.2 m/s can be seen at 10.10 UTC (Figure 5.c). There is a wave-like pattern on the isentropic line from 09.50 UTC to 10.10 UTC at an altitude of 9.5 km along the vertical section. The wave pattern of the isentropic line caused by cooling from updraft, as pointed by Kim et al. [6]. It has seen a powerful updraft at 99.5 °E. If the updraft is getting stronger, it will form overturning isentropic then form a breaking gravity wave, thus potentially causing turbulence.

Meanwhile, for the simulation using a basic sigma coordinate, the turbulence area has a different vertical wind pattern. Downdraft with a vertical wind speed of 0.3 – 0.4 m/s at the turbulence location (Figure 5.d). Then, airflow changed to updraft with vertical wind speeds of 0.1 – 0.15 m/s at 10.00 UTC. The airflow was still updraft with a speed of about 0.2 – 0.25 m/s at 10.10 UTC. The isentropic created a straight line (not wavy), so it cannot cause turbulence.

The simulation using a hybrid sigma coordinate shows a wind pattern can cause turbulence in the form of an isentropic wavy line at 10.00 UTC to 10.10 UTC compared with simulation using the basic sigma coordinate, which does not show any potential wind patterns of turbulence.
Figure 5. Comparison of vertical wind between hybrid sigma coordinate (a,b,c) and basic sigma coordinate (d,e,f). (a) and (d) shows data at 09.50 UTC, (b) and (c) shows data at 10.00 UTC, (c) and (f) shows data at 10.10 UTC on October 24, 2017. The solid black line shows isentropic, the solid purple line show the altitude of turbulence in the atmosphere, and the dashed purple line shows the location of turbulence.

3.4 Potential airflow turbulence

The Richardson number (\(Ri\)) is used to determine the turbulence potential of a laminar flow. \(Ri\) less than 0.25 indicates that laminar flow has the potential to become turbulence [7]. Meanwhile, when the value more than 1.0, the flow does not have the potential to become turbulence. At the location of the turbulence, two simulations have almost the same Richardson number values in the range 0.1 – 0.2 (Figure 6). It indicates that the area has the potentially become turbulent.

However, the contrast pattern at 2 – 8 km altitude along the vertical section. The hybrid sigma coordinate simulation shows the Richardson number value in the range of 0.25 – 1.0 at 10.00 UTC to 11.00 UTC (Figure 6.a and b). It means that the flow has the potential to become turbulent. At the same height and time, the basic sigma coordinate simulation has Richardson number values exceeding 1.0. It means that the area does not have the potential to become turbulent.

At an altitude of 9.5 – 17 km along the vertical section, the two simulations have the same pattern of Richardson number values. At an altitude of 17 km, the two simulations show that the flow does not have the potential to become turbulent. Based on the results of the two simulations, we can conclude that the simulation using hybrid sigma coordinate show more potential areas become turbulence than the simulation using basic sigma coordinate.
3.5 Turbulence Intensity

The turbulence kinetic energy (TKE) is obtained by adding up the average kinetic energy and the tke_pbl variable from the PBL Mellor Yamada Janjic (MYJ) parameterization. Then it is used to analyze turbulence in this study. Kinetic energy describes the amount of energy possessed by a flow. When the kinetic energy is more than 0 (zero), there will be a dissipation term (ε), which is the magnitude of the weakening energy of the turbulence if the value of ε is high, more significant turbulence occurs and can be used as an indicator of turbulence called EDR [8]. At the location of turbulence, the two simulations have the same kinetic energy value at 09.50 UTC to 10.00 UTC at 0.1 – 0.2 m²/s² (Figure 7). However, the contrast pattern is particularly at 2 – 8 km altitude. In the hybrid sigma coordinate simulation, the value of the kinetic energy at 99.55 °E reaches 2.25 m²/s² at 09.50 UTC to 10.10 UTC (Figure 7.a and b). The higher kinetic energy is caused by the effect of updraft and downdraft from the presence of clouds (see Figure 2). It is quite different from the basic sigma coordinate simulation that the kinetic energy is only about 0.25 – 1.00 m²/s².

The different pattern is also seen at an altitude of 9.5 – 17 km along the vertical section. Hybrid sigma coordinate shows kinetic energy of 2.25 m²/s² at 09.50 and weakening until 10.10 UTC (Figure 7.a until 7.c). While at the same height, the basic sigma coordinate shows kinetic energy at 99.6 °E only about 1.00 – 1.50 m²/s² and getting stronger and broader until 10.10 UTC at 1.25 – 2.00 m²/s² (Figure 7.d until f). The strong kinetic energy in this area is caused by the downdraft from the vertical airflow (see Figure 5) so that the TKE value is higher than other areas. The strong downdraft is caused by a cloud outflow at 99.55 °E (see Figure 2) so that the vertical wind speed in the area is relatively high.

Based on the explanation above, the simulation using the hybrid sigma coordinate shows more significant turbulence kinetic energy than the basic sigma coordinate. It can be seen from the hybrid sigma coordinate before turbulence (at 09.50 UTC), during turbulence (at 10.00 UTC), and after turbulence (at 10.10 UTC).
TKE can be used to calculate EDR. EDR is used to determine the intensity of turbulence [8]. EDR of 0.01 $m^{2/3}s^{-1}$ categorized as weak turbulence [9]. An EDR of 0.22 $m^{2/3}s^{-1}$ categorized as moderate turbulence, and an EDR of 0.46 $m^{2/3}s^{-1}$ categorized as strong turbulence. At the location of turbulence, the two simulation results have EDR values about 0.03 – 0.06 $m^{2/3}s^{-1}$. It indicates that the region is categorized as weak turbulence.

![Figure 7. Comparison of Turbulence Kinetic Energy (TKE) between hybrid sigma coordinate (a,b,c) and basic sigma coordinate (d,e,f). (a) and (d) shows data at 09.50 UTC, (b) and (c) shows data at 10.00 UTC, (c) and (f) shows data at 10.10 UTC on October 24, 2017. The dashed line shows the location of turbulence and the solid line show the altitude of turbulence in the atmosphere.](image)

However, the different pattern is also seen at an altitude of 2 – 8 km along the vertical section. In hybrid sigma coordinate simulation, the EDR value at 99.55 °E reached 0.46 $m^{2/3}s^{-1}$ at 09.50 to 10.10 UTC (Figure 8.a until 8.c). It indicates that the region has strong turbulence. Meanwhile, the basic sigma coordinate simulation shows an EDR value of 0.05 – 0.15 $m^{2/3}s^{-1}$, which is categorized as weak turbulence. Hybrid sigma coordinate shows an EDR value of 0.15 – 0.46 $m^{2/3}s^{-1}$, which is classified as weak to strong turbulence at an altitude of 9.5 – 17 km. However, the EDR value was getting weaker until 10.10 UTC (Figure 8.c). Meanwhile, at the same height, the results of the basic sigma coordinate show EDR at 99.6 °E about 0.1 – 0.22 $m^{2/3}s^{-1}$ until 10.10 UTC.

Based on the explanation above, the hybrid sigma coordinate shows a higher EDR value of 0.06 $m^{2/3}s^{-1}$ in the vertical section compared with the basic sigma coordinate, which is 0.05 $m^{2/3}s^{-1}$ during turbulence (at 10.00 UTC). A higher EDR value indicates that the turbulence intensity of the hybrid sigma coordinate is stronger than the basic sigma coordinate.
Figure 8. Comparison of EDR between hybrid sigma coordinate (a,b,c) and basic sigma coordinate (d,e,f). (a) and (d) shows data at 09.50 UTC, (b) and (c) shows data at 10.00 UTC, (c) and (f) shows data at 10.10 UTC on October 24, 2017. The dashed line shows the location of turbulence and, solid line shows the altitude of turbulence in the atmosphere.

4. Conclusion
Hybrid sigma coordinate simulation shows wavy isentropic lines at an altitude of 9.5 km at 10.00 to 10.10, which can trigger turbulence. In contrast, the basic sigma coordinate simulation results do not show wavy isentropic lines at the same time and altitude. In this case study, the simulation using the hybrid sigma coordinate represents more turbulence than the basic sigma coordinate. Based on the Richardson number value at an altitude of 9.5 km at 10.00 UTC, the two simulations show potential area become turbulence with an EDR intensity of $0.06 \, \text{m}^{2/3} \, \text{s}^{-1}$ in the hybrid sigma coordinate simulation and $0.05 \, \text{m}^{2/3} \, \text{s}^{-1}$ in basic sigma coordinate.

5. References
[1] Eick, D 2013 Turbulence related accidents & incidents National Transportation Safety Board Washington
[2] KNKT 2017 Aircraft accident investigation report PT Batik Air Boeing 737800 PK-LBY Inflight from Jakarta to Medan Republic of Indonesia October 24, 2017 preliminary KNKT.17.10.31.04 Komite Nasional Keselamatan Transportasi Republic of Indonesia Indonesia
[3] Verayanti, Ni Putu Tiana 2018 Simulasi numerik pengaruh moist convection terhadap pembentukan near cloud turbulence menggunakan model WRF-ARW (studi kasus turbulensi Batik Airlines tanggal 24 Oktober 2017 dan Hong Kong Airlines tanggal 6 Mei 2016) Sekolah Tinggi Meteorologi Klimatologi dan Geofisika Indonesia
[4] Park, S.H., Joseph B.K., and Jung H.K 2019 Hybrid mass coordinate in WRF-ARW and its impact on upper-level turbulence forecasting Monthly Weather Review 148 971 – 85
[5] Yang, X., Fei Jianfang, Xiaogang Huang, Xiaoping Cheng, Leila M.V.C., Hongrang He 2015 Characteristics of Mesoscale Convective Systems over China and Its Vicinity Using Geostationary Satellite FY2 Journal of Climate 28 4890 – 907
[6] Kim, Jung Hoon and Hye Yeong Chun 2011 Statistic and possible sources of aviation turbulence over south korea Journal of Applied Meteorology and Climatology 50 311 – 24

[7] Stull, R. B 1988 An Introduction to Boundary Layer Meteorology Kluwer Dordrecht Academic Publishers 175 – 79

[8] Trier, S. B., R. D. Sharman, and T. P. Lane 2012 Influence of moist convection on a cold-season outbreak of Clear-Air Turbulence (CAT) Monthly Weather Review 140 2477 – 496

[9] Sharman R. D, L. B. Cornman, G. Meymaris, J. Pearson, and T. Farrar 2014 Description and derived climatologies of automated in situ eddy dissipation-rate reports of atmospheric turbulence Journal of Applied Meteorology and Climatology 53 1416 – 32

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