WRF-ARW Numerical Model Sensitivity Test on Simulation of Loud Rain in The South Kalimantan Area

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Abstract: On January 13-14, 2021, there was heavy rain in the South Kalimantan region, causing more than 10,000 houses and the main provincial road to be flooded, and also 2 main bridges collapsed. Based on observations at the Syamsudin Noor Meteorological Station Banjarmasin, the rainfall values on January 13 and 14 2021 were 51 mm and 249 mm, respectively. Meanwhile, at the Banjarbaru Climatology Station, it was recorded on January 13-14, 2021, at 45.9 mm and 255.3 mm, respectively. The amount of rainfall recorded at the Banjarmasin Meteorological Station and Banjarbaru Climatology Station makes this condition interesting to study. This simulation uses FNL data with temporal and spatial resolution of 3 hours and $1^\circ \times 1^\circ$, respectively. In this study, the downscaling stage was carried out 2 times with domain 1 of 16 km and domain 2 of 6 km. Furthermore, the input data is running by testing as many as 9 parameterization schemes. Based on the results of the WRF rainfall output with the microphysics scheme (Kessler), the PBL scheme (Yonsei University Scheme) and the cumulus scheme (Kain-Fritcsh) showed the best value and the smallest error value compared to the other 8 schemes. Based on the CAPE value and air humidity, it proves that the atmospheric conditions are unstable and there is significant growth of convective clouds in the South Kalimantan region. The results of the stremaline analysis also show the presence of strong wind bends that result in the accumulation of air masses and indications of orographic rain in the west of the Meratus Mountains.

Keywords: WRF; Simulation; Rainfall; Parameterization.

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Article history: Received 14 June 2023, Accepted 01 August 2023, Published October 2023.
http://dx.doi.org/10.12962/j24604682.v19i3.17421

I. INTRODUCTION

In kompas.com daily, from 13 to 14 January 2021, stated that extreme weather had occurred, namely, heavy rain accompanied by lightning and strong winds which had an impact on the flood disaster in the South Kalimantan region. Floods occurred in most areas of the regencies of Banjarmasin, Banjarbaru, Banjar, Tanah Laut, Barito Kuala, Tapin, Hulu Sungai Selatan, Hulu Sungai Utara, Balangan, and Tabalong. Based on BPBD data, the impact of this extreme weather resulted in the submerging of more than 10,000 houses in the South Kalimantan region. The flood disaster also caused the main roads of South Kalimantan Province to be inundated and two main bridges to collapse [1].

Rainfall with high intensity was recorded on January 13 2021 of 51 mm and on January 14 2021 of 249 mm at the Syamsudin Noor Meteorological Station Banjarmasin. Meanwhile, the Banjarbaru Climatology Station recorded 15.9 mm of rainfall on January 13, 2021, and 255.3 mm of rain on January 14, 2021. Based on this data, the accumulated rainfall for two days at the Syamsudin Noor Meteorological Station was 300 mm, and the accumulated rainfall at the Banjarbaru Climatology Station totaled 271.2 mm. According to the BMKG Head Regulation Number 009 of 2010, a heavy rain event can be categorized as an extreme weather phenomenon [2].

Weather simulation around the equator is quite difficult to do. Indonesia's position in the tropics results in relatively warm humidity throughout the year, high evaporation, and high rainfall. The interaction between the sea and the land, and the interaction between the local scale and the larger scale in Indonesia make weather and climate patterns in each region different and complex [3]. Therefore we need a mesoscale weather simulation method that is able to describe the actual atmospheric conditions [4]. In this study, the WRF-ARW model was used to simulate heavy rain.

WRF-ARW (Weather Research and Forecasting - Advanced Research WRF) is a numerical weather model that can simulate atmospheric conditions in an area. WRF-ARW can help better assess meteorological phenomena [5]. The WRF-ARW model requires parameterization to calculate processes occurring in the atmosphere. That is because the WRF-ARW model cannot fully solve the atmospheric equation explicitly [6]. Microphysical and cumulus parameterization is a parameterization contained in the WRF-ARW model that explains the process of cloud formation and rain in the model. WRF-ARW model can be used to study the phenomenon of heavy rain.

Different weather patterns between regions require testing numerical weather models such as selecting parameterization schemes, initial conditions, and spin-up times to produce the best predictions [7].

The purpose of this research is to determine the best WRF-ARW model parameterization scheme configuration that can be used to simulate heavy rain events in the cities of Banjar-

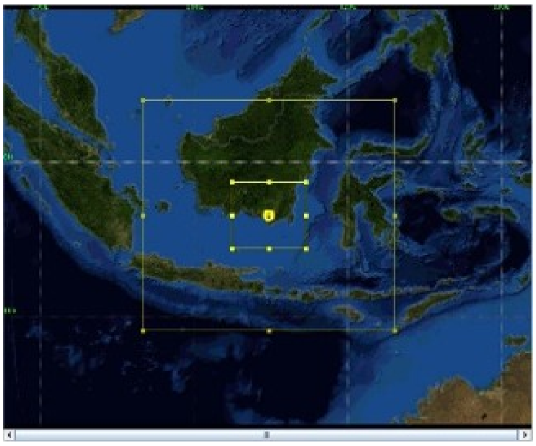

FIG. 1: Domain Settings using the Domain Wizard on the WPS process

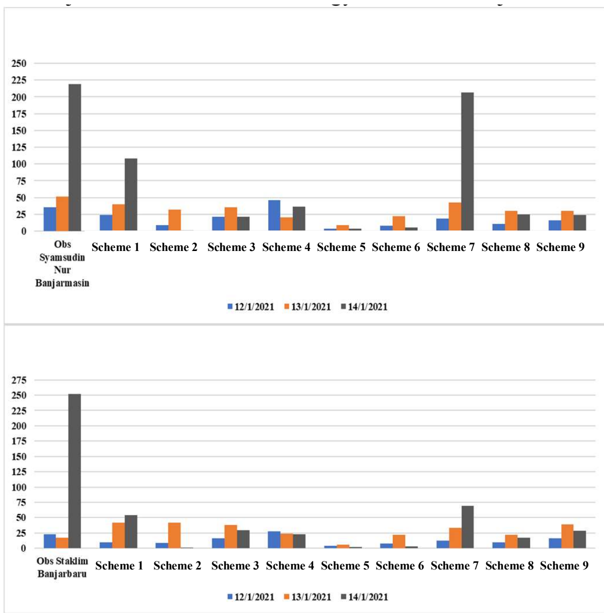

FIG. 2: Graph of rainfall comparison per day, on 12-14 January 2021 between observation measurements with nine parameterization schemes at the Syamsudin Noor Meteorological Station Banjarmasin (top) and Banjarbaru Climatology Station (bottom)

masin and Banjarbaru. The best configuration of the parameterization scheme can be used to determine the atmospheric conditions that occurred when heavy rains occurred in the region on 13-14 January 2021. The results of this study can be used as a reference in analyzing and predicting the potential for extreme rain hydrometeorological disasters in Indonesia in the future.

II. METHODOLOGY

This research was carried out in several work steps, namely identifying the time and place of flooding in the South Kalimantan region, identifying rain cloud growth using the Himawari-8 satellite, running rainfall prediction simulations using the WRF-ARW model with 9 (nine) selected scheme configurations, verifying the results and analysis.

The data used as input data for the WRF-ARW model is FNL (Final Analysis) data from 12 January 2021 at 00 UTC to 14 January 2021 at 00.00 UTC. This FNL data can be accessed at http://rda.ucar.edu with a spatial resolution of $1^\circ \times 1^\circ$ and a temporal resolution of 6 hours. The length of data used in the event simulation is 48 hours, with 24 hours for the spin-up time and a further 30 hours for the event simulation analysis period.

In the WPS (WRF Preprocessing System) process, the WRF-ARW model uses the WRF Domain Wizard to make it easier to define domains, create name lists automatically, and run WPS (geogrid.exe, ungrib.exe, and metgrid.exe) automatically. So that all the output from the WRF Domain Wizard can be directly used to run the WRF model. Domain 1 (D01) is located between 106.51-123.88 E and 10.26 LS-3.68 LU with a resolution of 18 km, domain 2 (D02) is located between 112.19-117.17 E and 5.62 LS-1.09 LS with a resolution of 6 km. The center point of the domain in this study is at the Syamsudin Noor Banjarmasin Meteorological Station, which is at 3.437 South Latitude and 114.75 East Longitude Fig. 1.

Then the running WRF process (real.exe and wrf.exe) is carried out with the configuration as shown in Table I. Apart from microphysical settings, another parameterization scheme is the default setting, namely the Dudhi scheme for the long-wave radiation scheme based on simple efficient integration applied to absorption and scattering of sunny and cloudy. The YSU Boundary Layer (PBL) scheme reduces non-local mixing effects and includes explicit entrainment fluxes of heat, moisture, and momentum, as well as differences in PBL specification heights. Kain-Fritsch Cumulus parameterization scheme (new Eta) based on CAPE calculations, Grell Devenyi scheme, Betts Miller Janjic scheme based on convective adjustment including deep and shallow convection.

The Kessler scheme is a simple warm cloud schematic and includes water vapor, clouds, and rain. The microphysical processes included are: the production, falling, and evaporation of rain, accretion and autoconversion of cloud water, and production of cloud water from condensation [8]. YSU's PBL (Yonsei University Scheme) scheme is a Planet Boundary Layer scheme developed by the staff of the Department of Atmospheric Sciences at Yonsei University to produce a more realistic model of the PBL structure and its development [9]. The KF scheme is mass flux parameterized and uses the Lagrangian parcel method, and in general, it can be grouped into three parts: 1) convective trigger function, 2) mass flux formulation, and 3) closing assumptions. The initial version of the KF scheme used a simple cloud model with updraft and downdraft humidity and was modified for use by the NWP (Numerical Weather Prediction) model [10]. The physical options in the configuration settings for the WRF model scheme in this study are shown in Table I below. The experimental names of the various WRF model parameterization schemes tested in this study are shown in Table II.

TABLE I: WRF Model Parameterization Scheme Configuration

Arrangement Running WRF	Information Domain 1	Domain 2
history_interval	180 sec	60 sec
time_step	60 sec	60 sec
e_we	100	88
e_sn	91	79
ra_sw_physics	Dudhi scheme	Dudhi scheme
bl_pbl_physics	YSU scheme	YSU scheme
cu_physics	Kain Fritsch (new Eta) scheme Betts Miller Janjic Grell Devenyi	Kain Fritsch (new Eta) scheme Betts Miller Janjic Grell Devenyi
mp_physics	WRF Single-Moment 6 Class (WSM6) Kessler Perduelin	WRF Single-Moment 6 Class (WSM6) Kessler Perduelin

TABLE II: Experiment Name WRF Model Parameterization Scheme

Experiment Name	Parameterization Scheme Microphysics	PBL	Cumulus
Scheme 1	WRF Single-Moment 6-Class (WSM6)	Yonsei University Scheme (YSU Scheme)	Kain Fritcsh
Scheme 2			Betts Miller Janjic
Scheme 3			Grell Devenyi
Scheme 4	Kessler	Yonsei University Scheme (YSU Scheme)	Kain Fritcsh
Scheme 5			Betts Miller Janjic
Scheme 6			Grell Devenyi
Scheme 7	Perduelin	Yonsei University Scheme (YSU Scheme)	Kain Fritcsh
Scheme 8			Betts Miller Janjic
Scheme 9			Grell Devenyi

Verification of the simulation results from each WRF-ARW model scheme used rainfall observation data from the Syamsudin Noor Meteorological Station in Banjarmasin and the Climatology Station in Banjarbaru. Spatial verification uses daily rainfall data from the GSMAP (Global Satellite Mapping of Precipitation) satellite which can be accessed from the site ftp://hokusai.eorc.jaxa.jp. The GSMaP data used is GSMaP_NRT daily data, which contains real-time rain rates (mm/hour) as long as the data format is *.DAT.GZ. The daily rain intensity rain rate data has a spatial resolution of $0.25^\circ \times 0.25^\circ$.

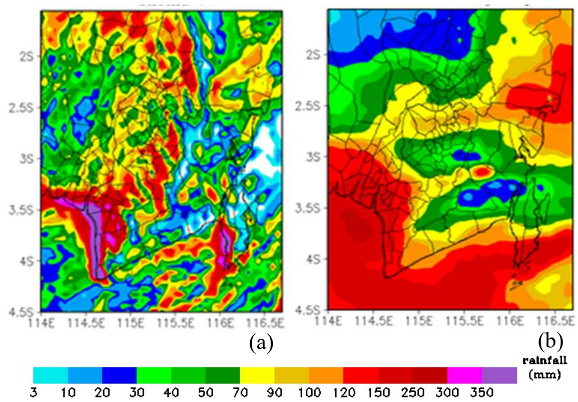

FIG. 3: Spatial analysis of rainfall on 12 14 January 2021 for the South Kalimantan area of the 7 WRF-ARW model scheme (a) and the accumulation of GSMAP from the Himawari satellite (b)

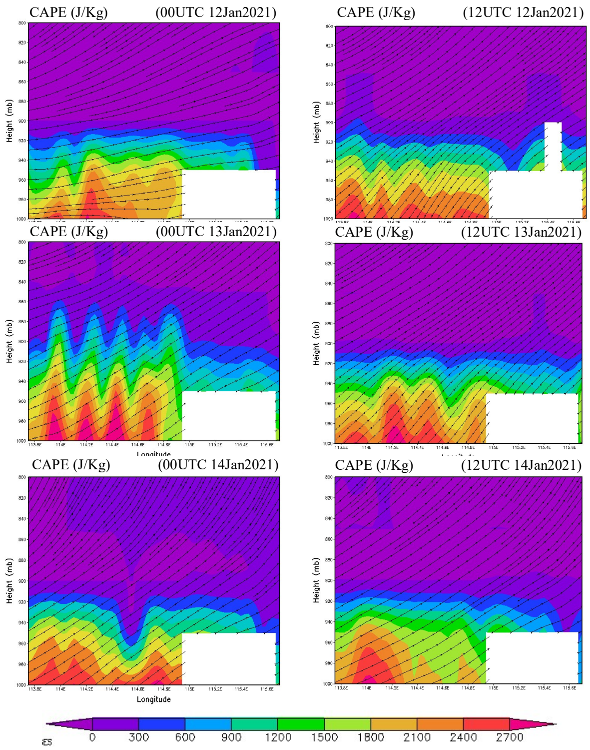

FIG. 4: Cape values from January 12 to 14, 2021 1000 mb layer to 800 mb layer

III. RESULT AND DISCUSSION

Fig. 2 is a comparison diagram between obs rainfall at the Syamsudin Noor Meteorological Station Banjarmasin and Banjarbaru Climatology Station with rainfall output from the WRF model. Based on the daily rainfall values for January 12-14 2021 as shown in Fig. 2, the estimated rainfall for the WRF model from the parameterization results for scheme 7 is the best and approaches the actual rainfall compared to the other 8 schemes at the Syamsudin Noor Station in Banjarmasin and

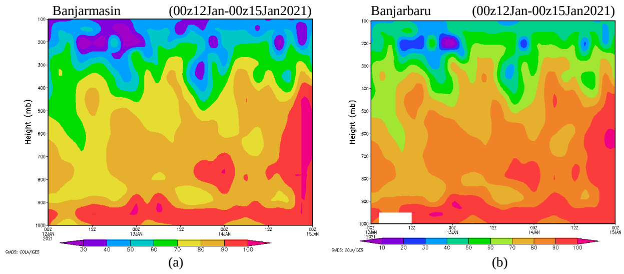

FIG. 5: Relative Air Humidity (%) layer 1000-100 mb from January 12 to 14, 2021 at Banjarmasin (a), and Banjarbaru (b)

the Climatology Station in Banjarbaru.

Based on Table III, the lowest RMSE (Root Mean Square Error) value at the Syamsudin Noor Banjarmasin Meteorological Station occurs in parameterization scheme 7 with a value of 12.950, which means that the scheme can predict the amount of rainfall with the smallest difference in error to the amount of observed rainfall compared to the other eight schemes. As for the Banjarbaru Climatology Station, the lowest RMSE value is shown by scheme 7 with a value of 105.838 where this value shows the smallest value. Based on the RMSE, shows that scheme 7 is the best scheme that can predict the amount of rainfall in the South Kalimantan region.

Fig. 3 is estimated rainfall accumulation data from the output of the parameterization scheme of the 7 WRF models in the South Kalimantan region on January 12-14 2021 compared to the GSMAP satellite. Scheme 7 uses the cumulus KF (Kain-Fritcsh) scheme which is used to predict the conditions for convective cloud growth to occur. This scheme uses a simple cloud model that takes into account the equations of mass flux, updraft and downdraft, humidity, entrainment and detrainment and simple microphysical processes [11].

Fig. 4 shows the Convective Available Potential Energy (CAPE) values on 12-14 January 2021 in the South Kalimantan region, especially to the west of the Meratus mountains (areas that experienced flooding). Convective Available Potential Energy (CAPE) is the amount of energy a parcel of air can lift a certain distance vertically in the atmosphere [12]. CAPE can also indicate that the atmosphere is in an unstable condition [13]. It is stated that the air column will experience strong convection if the CAPE value is greater [14]. The CAPE value is well used to identify the level of atmospheric stability and the potential for convective activity.

Based on the CAPE map in Fig. 4. The CAPE value of the surface layer up to 925 mb ranges from 900-2700 J/kg. The highest CAPE value was over 2700 J/Kg in the 1000-950 mb layer on January 13, 2021 at 00 UTC. This value indicates a very unstable level of atmospheric stability with strong intensity. The unstable atmospheric conditions indicate that there is potential for convective activity to occur and produce heavy rains of quite a long duration. This is similar to the results of research conducted in the Bogor area which shows that between variations in the atmospheric stability index and increased rainfall are directly proportional, as well as the growth of cumulonimbus clouds during heavy rain events [15].

TABLE III: Statistical Error (RMSE) values for nine output rainfall parameterization schemes for the WRF model with obs rain gauges at the Syamsudin noor Banjarmasin Meteorological Station and Banjarbaru Climatological Station

Experiment Name	Banjarmasin	Banjarbaru
scheme 1	64.835	115.274
scheme 2	127.191	145.904
scheme 3	115.038	128.937
scheme 4	107.099	132.334
scheme 5	128.334	144.864
scheme 6	125.294	143.964
scheme 7	12.950	105.838
scheme 8	113.713	135.870
scheme 9	113.745	129.751

Air humidity is the amount of water vapor contained in the air or atmosphere [16]. It can be seen from the surface layer (1000-800 mb) before and during the rain event that the air condition in the Banjarmasin and Banjarbaru areas is quite saturated with a value of 80 100%. In the middle layer (700-500 mb) 80-100% and in the top layer (500 200 mb) the air humidity is still very saturated in the range of 60-100%. This indicates that the air condition is very humid during periods of heavy rain and supports the condensation process in the formation of rain clouds.

Fig. 6 shows the air temperature conditions in the South Kalimantan region on January 12-14 2021. It can be seen that the air temperature in the South Kalimantan region varies with values ranging from 20-27 °C. The lowest air temperature in the South Kalimantan region on January 12-14 2021 worth 20 °C precisely at the top of the Meratus mountain range. The western slopes (leeward) of the Meratus mountains have hotter air temperatures due to adiabatic processes than the slopes above the wind (windward), and when returning to the ground surface to the east of the Meratus mountains the temperature returns warmer than when the air has not yet climbed the mountains [17].

Water vapor transport is one of the main components in the formation of rain clouds. Large air masses and changes in water vapor transport can shift places where rain forms. The process of moisture transport at the equator occurs when water vapor moves from north to south or vice versa. According to Zhou (2003) the pressure limit used in the water vapor transport equation is from the surface to a height of 300 hPa [18]. This is because water vapor is only concentrated in the lower troposphere.

The results of the analysis of water vapor transport from January 12, 2021, at 00 UTC to January 14, 2021, at 12 UTC show that there is a movement of water vapor transport from the west. Based on the water vapor transport map in the 925-300 mb layer, on January 12, 2021, at 00 UTC it began to be seen that there was a fairly high intensity of water vapor (1000-1200 kg/ms-1) in the Meratus mountain range (Fig. 7). On January 12, 2021, at 12 UTC in the southern region of South Kalimantan Province, an increase in water vapor intensity of more than 1200 kg/ms-1 was evenly seen.

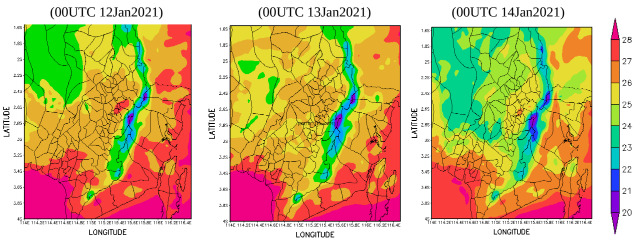

FIG. 6: Air temperature (°C) on 00 UTC from January 12 to 14, 2021 for South Kalimantan

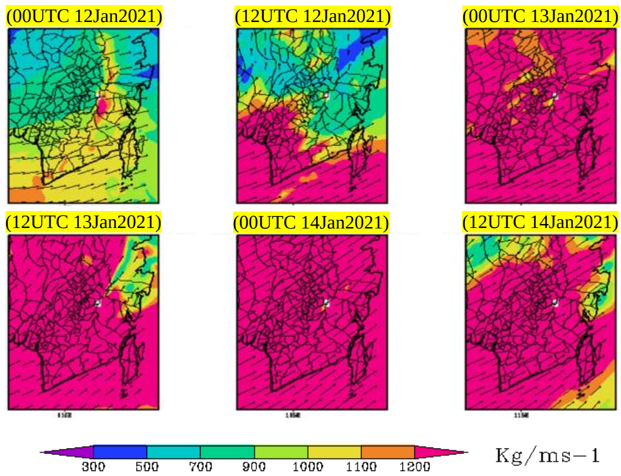

FIG. 7: Layer water vapor transport of 925-300 mb from January 12 to 14, 2021 for the South Kalimantan region

The increase in the intensity of water vapor is increasingly widespread throughout the South Kalimantan region until January 14, 2021, at 12 UTC.

The large water vapor transport value indicates the potential for rain clouds to cause flooding in the South Kalimantan region. That is like the results of previous studies which state that water vapor has an important role in predicting future rainfall and large amounts of water vapor can cause high rainfall [19, 20].

Streamline wind is a condition of wind currents that blow which is drawn based on a tangent or parallel to the wind data in the area they are located [21]. Fig. 8 shows streamline analysis is carried out from an altitude of 3000 feet to the top of the atmosphere (925mb layer and above) to see the actual wind without the influence of frictional forces and the influence of topography.

Based on Fig. 8, from 12 to 14 January, the wind blew from the southwest-west with an average speed of 2-3 knots. That confirms that in January, the South Kalimantan region enters the rainy season (the dominant wind is from the west (Asian monsoon) that carries wet air). Based on the streamlined map, from 12 to 14 January 2021, there was a disturbance in the form of a shear line in the South Kalimantan region.

The existence of the Meratus Mountains in the South Kalimantan region causes the wind that carries the water vapor to move up the mountains, climb the slopes and get higher (Fig. 8). The higher the water vapor carried by the wind, the higher the potential for condensation to occur. This is because the higher the upper layer, the colder the air temperature (Fig. 8). This condensation or condensation will form rain cloud seeds or water droplets. After experiencing saturation, the water droplets that are above will reduce the water content in them. These falling water droplets are called orographic rain [17].

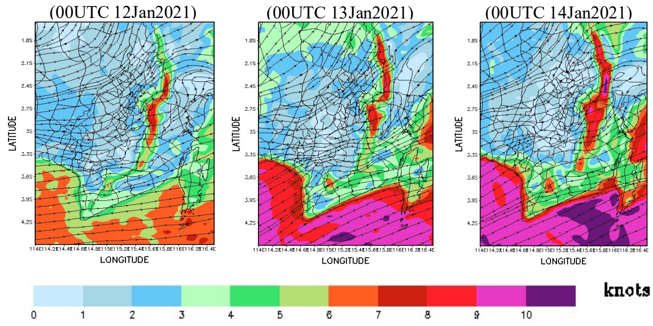

FIG. 8: Streamline layer of 3000 feet January 12-14 2021, South Kalimantan area

Based on Fig. 9, an analysis of the time series of cloud growth from the infrared channel Himawari satellite imagery. The process of convective cloud growth begins on January 13, 2021, around 03.30 UTC, marked by the beginning of a decrease in the cloud top temperature in Banjarmasin City to -68 °C. Convective activity continued until around 06.00 UTC there was an extreme decrease in the cloud top temperature to -75 °C. At 09.30 UTC the cloud top temperature rose to -33.3 °C, indicating that at that time the dissipation phase began. After that, on the same day, the clouds experienced a growth phase again at around 13.30 UTC marked by a decrease in the cloud top temperature to -68 °C. The cloud top temperature increased from 18.30 UTC to -40 °C, then the cloud top temperature remained constant until January 14, 2021, at 06.00 UTC. This indicates that the clouds are dominated by convective clouds (Cumulonimbus) and rain clouds (Nimbostratus) throughout the day.

IV. CONCLUSION

In general, the WRF-ARW model was quite good at simulating the phenomenon of heavy rain in the South Kalimantan region on January 12-14 2021, which was demonstrated by the WRF-ARW model's ability to identify convective cells. The best parameterization scheme that can predict rainfall in the South Kalimantan region is shown by scheme 7 with the smallest RMSE value compared to other parameterization schemes with a value of 12,950 at the Syamsudin Noor Banjarmasin Meteorological Station and an RMSE value of 105,838 at the Banjarbaru Climatology Station. The best parameterization scheme for the WRF model in this study can be used as a reference in operational forecasting of heavy rains in the South Kalimantan region.

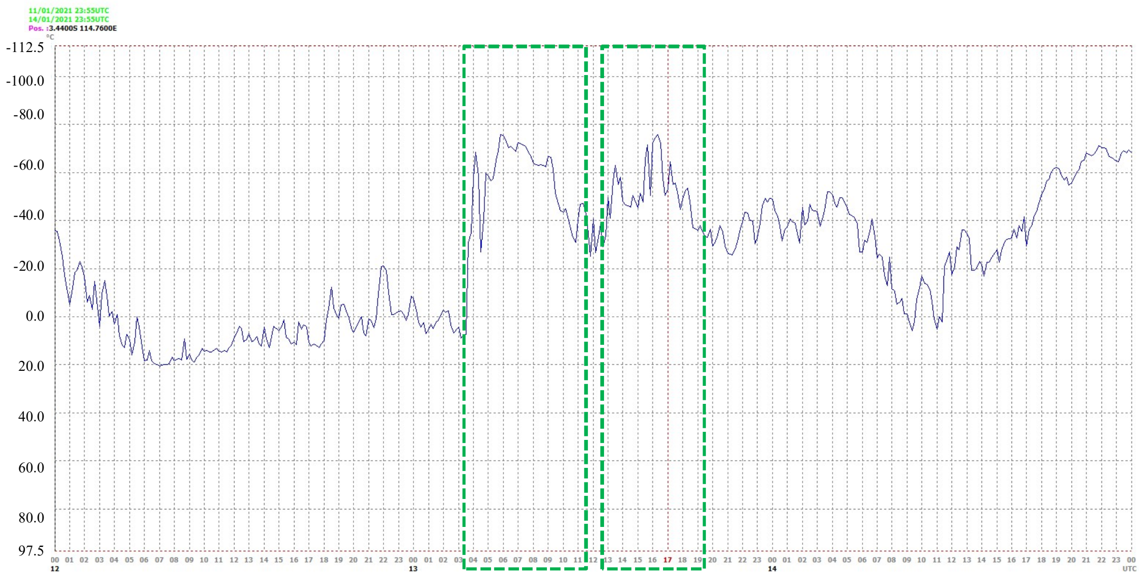

FIG. 9: Cloud top temperature time series (himawari satellite) from January 12 to 14, 2021 at the Syamsudin Noor Meteorological Station Banjarmasin

Based on the CAPE value and air humidity, it is clear that the atmospheric conditions are unstable and there is significant convective cloud growth in the South Kalimantan region. A large amount of water vapor transport indicates the potential for rain clouds to cause flooding in the South Kalimantan region. The results of the analysis of airflow (streamline) and temperature indicate the existence of a shear line (strong wind bend) which results in the accumulation of air masses and indications of orographic rain occurring to the west of the Meratus Mountains. Comparing the results of the analysis with Himawari satellite imagery clarifies the conditions that occur during heavy rains with the lowest cloud top temperature of -75 °C indicating very heavy rain that occurred.

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