

Identification Characteristic Dispersion of Volcanic Ash Using PUFF Model with Weather Radar on Eruption of Mt. Rinjani August 2016

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Abstract— Observing volcanic ash dispersion becomes critical following the abundance incidents of aircraft damage caused by volcanic ash, especially for Indonesia on the Pacific ring of fire. To enable an accurate forecast of volcanic ash dispersion, model PUFF offers information regarding the direction of volcanic ash dispersion based on height and size of volcanic ash. This research shows that model PUFF serves better explanation over volcanic ash advisory from VAAV Darwin and information derived from the Himawari-8 satellite. This research also further suggests for PUFF model to utilize data regarding eruption time and plume's height provided in the interpretation result of weather radar.

Keywords—PUFF model; weather radar; dispersion of volcanic ash

I. INTRODUCTION

Indonesia has hundreds of active volcanoes which potentially cause frequent volcanic eruptions, as a result of the country being situated on the Pacific ring of fire. The position of Indonesia is bringing the consequence that the life of the nation and the state will also be influenced by volcanism [1]. Since the incident of aircraft crash due to volcanic ash in 1982 that has occurred in Indonesia, International Civil Aviation Organization (Volcanic Ash Advisory Centres) is very attentive in providing the information of volcanic ash transport and dispersion that may endanger the flight path [2].

Volcanic ash is an object which is often not visible and unobservable on the airborne radar. Therefore, the use of remote sensing is needed in volcanic ash observation. Some of the information on the spread of volcanic ash are Volcanic Ash Activity Report and SIGMET issued by BMKG based on information obtained from PVMBG.

Volcanic ash forecasting is an important instrument in hazard assessment and operational volcano monitoring. The analysis uses volcanic ash transport models to determine the forecast of future ash clouds location [3]. Some of the information shown about the spread of volcanic ash are the extent, the dispersion, and the direction of volcanic ash dispersal which is obtained using the PUFF model. In order to avoid volcanic hazards, especially for aviation safety purposes, the amount of dispersion modelling has been

configured and expanded under the VAAC activities [4]. The PUFF model is currently used by three VAAC such as VAAC Anchorage, VAAC Washington, and Air Force Weather America (AFWA) [5]. The PUFF model requires wind field input data of both horizontal u (zonal) and v (meridional) wind field. PUFF uses 3-dimensional Lagrangian formulation for advection, turbulent diffusion, and sedimentation [6]. Besides using the wind field data, PUFF model also requires data on eruptions such as eruption time, volcano location, and the plume height. More optimal observation of the height of the plume uses the remote sensing support, such as weather radar. Weather radar is able to observe very fine volcanic ash particles with a radius of more than 5 km away from the volcanic observation post [7].

Weather radar is one of the remote sensing instrument with good spatial and temporal resolution in identifying volcanic dust material and can provide information of the height of the eruption air column [8]. Several countries already use weather radar to provide forecasts of volcanic ash altitude and early warning especially related to volcanic aviation hazards. Information on the height of volcanic dust eruption obtained using the weather radar observation is way better because it is able to predict the amount of ash and concentration of volcanic ash within the radar coverage area [9].

II. MATERIAL AND METHOD

This research use single polarization weather radar data from the Selaparang Meteorological Station on August 1, 2016, at 050 UTC. The products used are CMAX, VCUT, and MCAPPI. Other data used are GFS (Global Forecast System) data, pilot balloon observation data from Selaparang Meteorological Station, raw data of Himawari-8 satellite, and Mount Rinjani eruption data issued by VAAC Darwin.

The research methodology used is descriptive analysis method, both on weather radar display and PUFF model display. Weather radar will be used in determining the plume height, classification of ash based on altitude, and dispersion of volcanic ash based on wind direction that is observed by weather radar using products such as the following:

1) *Column Maximum (CMAX)*: The product is used to display the maximum reflectivity value of volcanic ash in single column volume scan.

2) *Vertical Cut (VCUT)*: The product is used to view the vertical structure of the maximum reflectivity of volcanic ash by cutting the volume echo data vertically.

3) *Multiple Constant Altitude Plan Position Indicator (MCAPPI)*: The products are used to view the direction of movement of volcanic ash each layer by analyzing the radial velocity value (v).

Then, the result of the weather radar data processing which is in the form of eruption time and height of plume will be inserted into PUFF model. The result of the PUFF model will be compared to the information that is released by VAAC Darwin, Himawari-8 satellite, and wind data from pilot balloon observation in Selaparang Meteorological Station.

III. RESULTS AND DISCUSSION

A. Characteristic of Weather Radar Analysis

1) *Reflectivity Value Analysis*: Volcanic ash have a different characteristic with the cloud, especially when it observed from weather radar. The difference is the value of reflectivity observed by weather radar. Characteristics of volcanic ash observed on weather radar have a reflectivity value from -20 dBZ to 20 dBZ [10], as in Fig. 1.

	dBZ
Fine Ash, Tumbling	-12.7484
Fine Ash, Oblate	-12.0257
Fine Ash, Prolate	-13.1592
Coarse Ash, Tumbling	17.1295
Coarse Ash, Oblate	17.8018
Coarse Ash, Prolate	16.8287

Fig. 1 Classification of volcanic ash reflectivity value

The initial phase of the eruption of Mount Rinjani on August 1, 2016, started at 040 UTC. It can be seen in the echo intensity pattern of dBz radar which is still at the height of 6 km and at an interval of 10 minutes later, the eruption reached 7.2 km and extended (Fig. 2).

The height of volcanic ash at 050 UTC shown in Fig.2 is suitable to Fig. 1, where the height of volcanic ash reached 7.2 km. This is illustrated in Fig. 3.

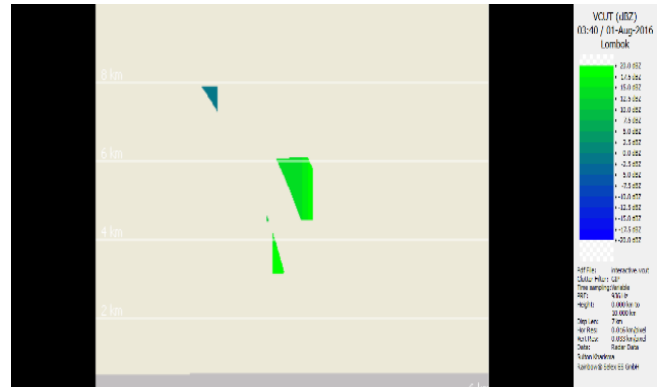


Fig. 2 Reflectivity value of VCUT 040 UTC

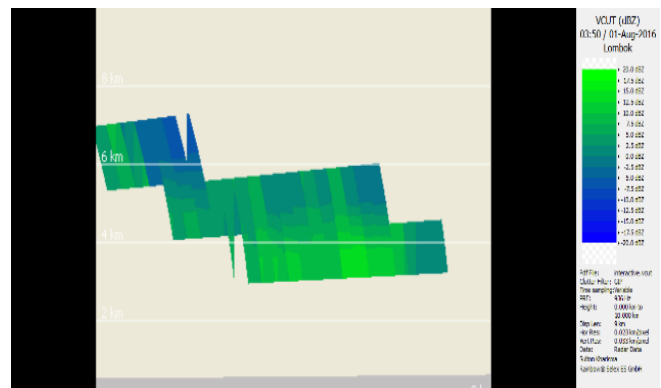


Fig. 3 Reflectivity value of VCUT 050 UTC

The dispersion of volcanic ashes also expanded at 050 UTC as seen on Fig. 4, so that largest eruption phase is also at 050 UTC. This analysis becomes the base of input data PUFF model.



Fig. 4 MAX reflective value 050 UTC

2) *Velocity Value Analysis*: It can be seen that object caught by the radar sheer away from the radar on largest eruption phase which is at 050 UTC. This is corresponding

to Doppler's radar concept which is also measured object movement whether it is leaving or approaching the centre of the radar which is stated that every moving object will encounter signal frequency changes based on object velocity.

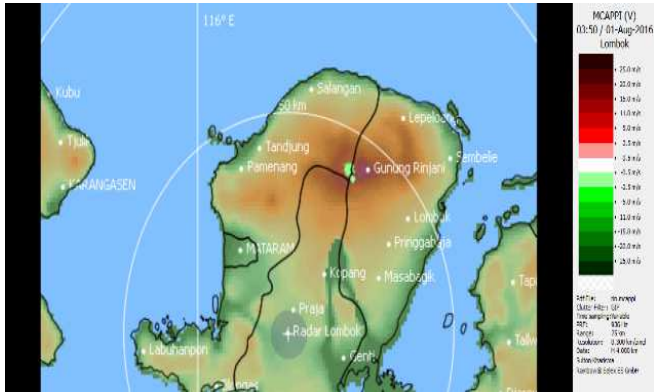


Fig. 5 Velocity value MCAPPI 4 km 050 UTC

It also indicates that the object observed by radar is not cluttered. Based on weather radar interpretation, information about eruption time was at 040 UTC (11.40 WITA) with the plume height reached 7.2 meters.

B. PUFF Model

PUFF is used to produce a model of the volcanic particles movement through the 3-dimensional Lagrangian equation for advection, fallout, as well as turbulent diffusion based on random-walk techniques [11]. The Lagrangian method presumes that volcanic ash cloud consists of several particles of a particular size. In time intervals Δt , the vector position of each particle in particular height is calculated from t to $(t + \Delta t)$ then it can be assumed the equation becomes [6]:

$$R_i(t + \Delta t) = R_i(t) + W(t) \Delta t + Z(t)\Delta t + S_i(t)\Delta t \quad (1)$$

$R_i(t)$ is the vector of the i -th particle position at time t , $W(t)$ is an advection vector in the form of horizontal wind velocity in each layer, $Z(t)$ is a vector that describing turbulent dispersion with Brownian motion, and $S_i(t)$ is a sedimentation vector (fallout) as the result of gravity effect depending on the size of the i -th particle. As an effort to obtain better weather forecasts, the spatial resolution should be increased by downscaling using forecasting model in regional scale (WRF model). In this research, GFS data used is up to 20 hours ahead prediction.

The input data obtained from weather radar will be used as input data for the running process using GFS data until it obtains particle coordinate data, height, size as well as a lifetime of volcanic ash particles output from PUFF model. Then, the data is processed using GIS to be mapped based on height as well as the size of volcanic ash particles.

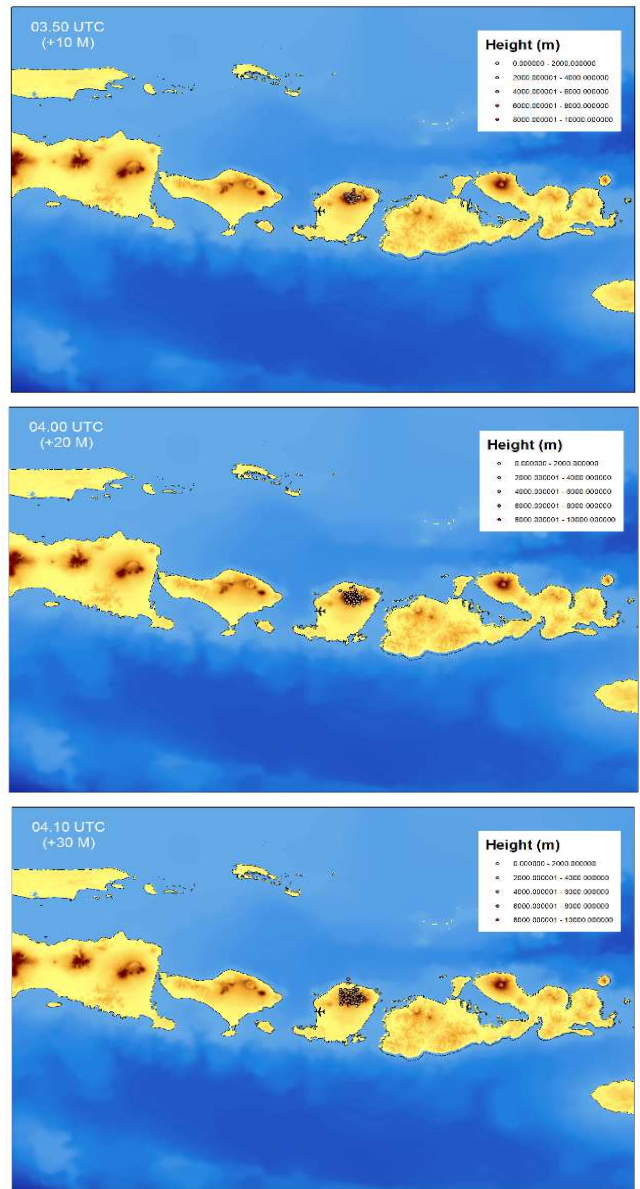


Fig. 6 Dispersion volcanic ash from PUFF model based on height in first 30 minutes

The result of PUFF model is divided into 5 level based on its height, which are 0-2 km, 2-4km, 4-6km, 6-8km, and 8-10km. In the first 30 minutes, it can be seen that the maximum height only reached 6-8 km, which means it had not reached maximum plume. particles at 4-10 km level tend to move to the west, while particles at 0-4 km level tend to move to the east in the first 30 minutes after the eruption.

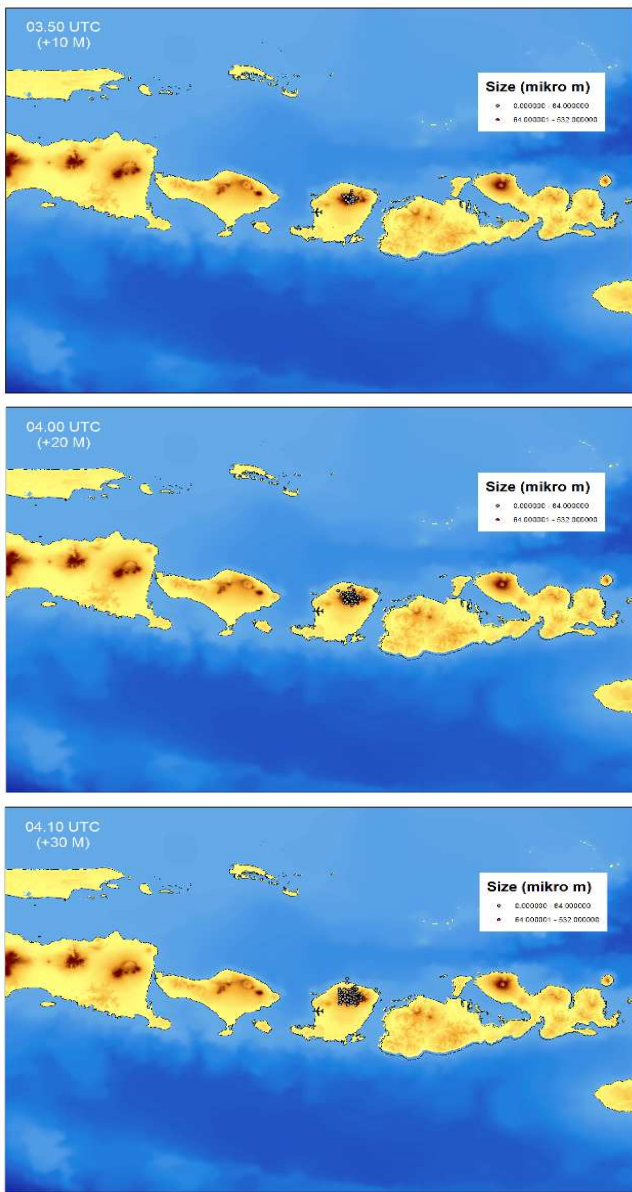


Fig. 7 Dispersion of Volcanic Ash from PUFF Model based on size in first 30 minutes

The result of PUFF model which is mapped by size will be differentiated into two kinds of ash. First, fine ash with size less than $64\mu\text{m}$, and the second, coarse ash with size 64 to $532\mu\text{m}$ [12]. In the first 30 minutes, it can be seen that the dominant particle size was less than $64\mu\text{m}$ which is fine ash particles.

TEPRHA	PARTICLE TYPE	PARTICLE SIZE	DISTANCE FROM THE VOLCANO VENT	RESIDENCE TIME IN THE ATMOSPHERE
Ash	Fine ash (FA)	$< 64\mu\text{m}$	Hundred to thousand kilometers	Day to month
	Coarse ash (CA)	$64\mu\text{m} - 532\mu\text{m}$	Ten to hundred kilometers	Day
Lapilli	Small lapilli (SL)	$0.532\text{ mm} - 2.56\text{ mm}$	Few to ten kilometers	Few minutes
	Large lapilli (LL)	$2.56\text{ mm} - 32\text{ mm}$	Hundred meters to few kilometers	Seconds to minutes
Blocks	Blocks and boms (BB)	$> 32\text{ mm}$	Ten to hundred meters	Ten of seconds

Fig. 8 Characteristic of volcano's eruption material

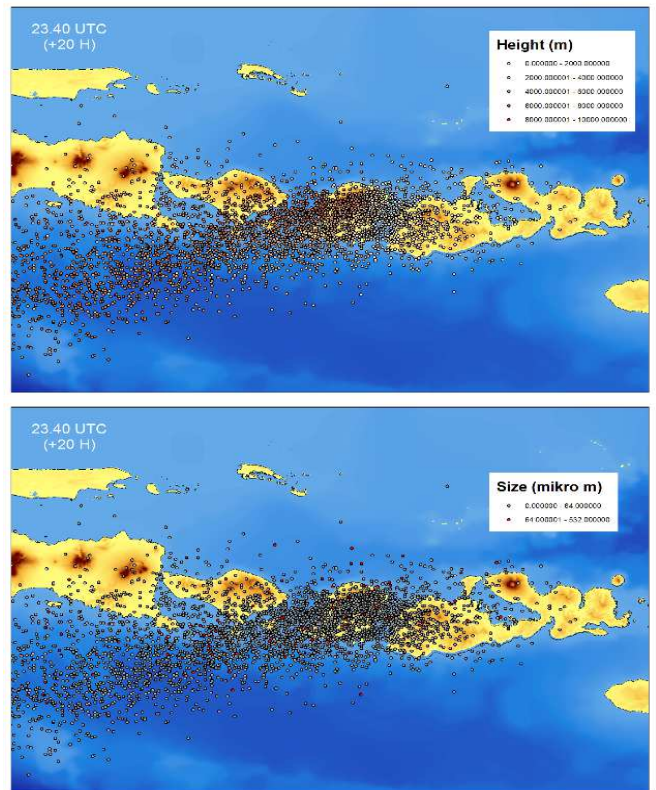


Fig. 9 Volcanic ash dispersion from PUFF model 20 hours after the eruption

From the forecast result of PUFF model, it can be seen that particles at the height of 4 to 10 km tend to move toward to southwest after 20 hours of the eruption. The type of particles was fine ash which had a size less than $64\mu\text{m}$, while particles with a height of 0 to 4 km tend to move east. The dominant volcanic ash particles were fine ash, but there were also some particles with particle sizes of $64\mu\text{m}$ to $532\mu\text{m}$ (coarse ash).

In the case of Mount Rinjani's eruption on August 1, 2016, there are two directions of volcanic ash dispersion. The lower layer was dominated by heading to the east while the upper layer was heading west. The information that delivered in this research is very useful for pilots since the information that pilot receives is the dispersion of volcanic ash has the same direction of dispersion on each layer.

C. Information of VAAC Darwin

Based on data of VAAC Darwin released at 05.15 UTC, forecasting dispersion of volcanic ash moved to the south and spread with the velocity of 15 knots on surface layer to 32000ft (9800 meters) until 17.15 UTC.

While at 10.20 UTC, volcanic ash advisory which is updated by VAAC Darwin released that volcanic ash dispersion moved to southwest with the velocity of 15 knots on surface layer to 14000 feet (4300 meters) and moved to south with the velocity of 15 knots on surface layer to 20000 feet (6100 meters), and forecasted that it is located southeast - south at 22.20 UTC.

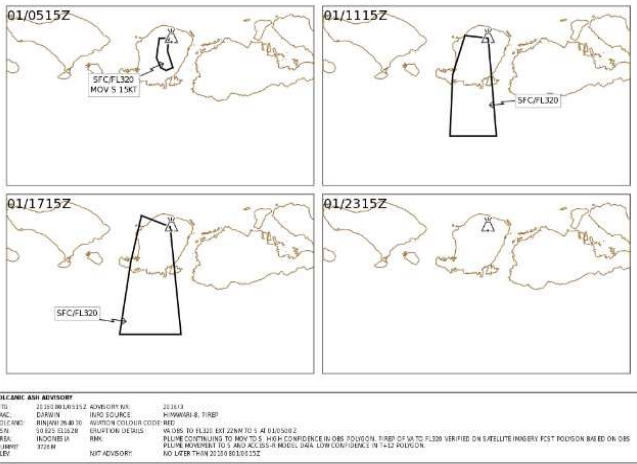


Fig. 10 Volcanic ash released at 05.15 UTC

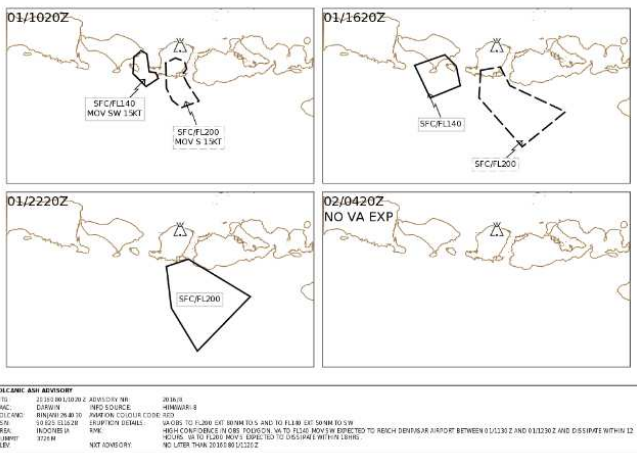


Fig. 11 Volcanic ash advisory released at 10.20 UTC

This information is compatible enough with a forecast of PUFF Model. However, from PUFF Model can inform volcanic ash dispersion each layer and can be forecasted to 20 hours ahead and can be differentiated the size or particle type that is dispersed to the atmosphere.

D. Himawari-8 Satellite's Information

Volcanic ash dispersion identification with the image of Himawari-8 using SATAID application with split window method to display RGB Composite image is combining three channel on Himawari Satellite with the composition of SP (IR1-IR2) as the colour of red, S2 (IR4-IR1) as the colour of green, and also IR4 (3.9 μm) as the colour of blue so that will show pink colour for ash cloud. Value of (IR1-IR2) will be negative and can be shown on Contour Line menu.

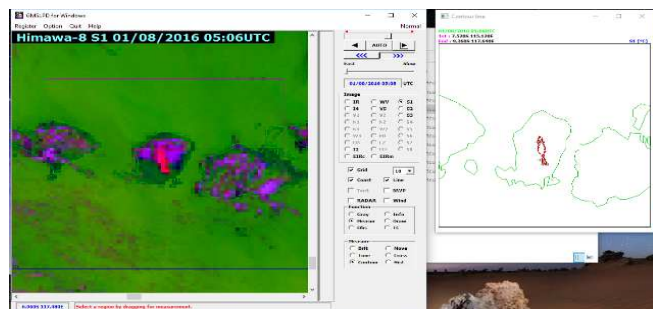


Fig. 12 Volcanic ash on Himawari-8 satellite

Volcanic ash dispersion based on Himawari-8 satellite information moved to the south. This corresponds to the information released by PUFF model. Lack of information of volcanic ash dispersion on Himawari-8 satellite describes less on how dispersion on each layer and small size particle which is dispersed also cannot be described using this Himawari-8 satellite.

In this volcanic ash dispersion information, the researcher tries to make the verification based on the observation data of pilot balloon observed at Selaparang Meteorology Station at 00, 06 and 12 UTC.

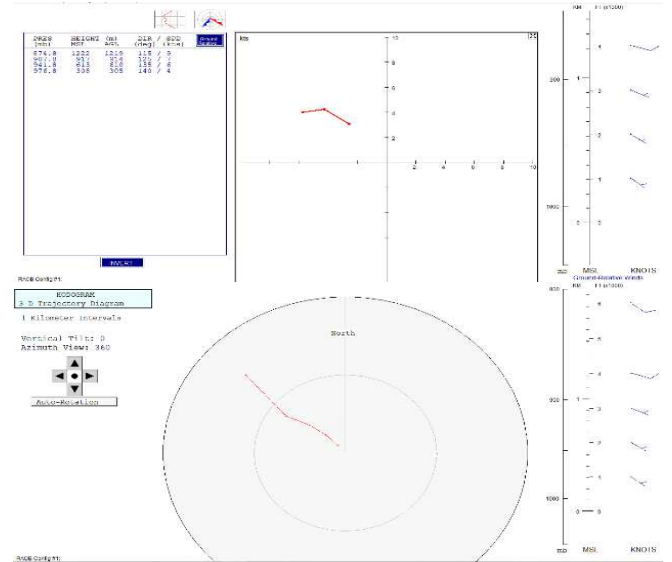


Fig. 13 Wind vertical at 00 UTC

Based on the Fig. 13 at 00 UTC, wind direction came from the southeast. At level of 308 meters, the wind degree is 140° (southeast) with the speed of 4 knots, 613 meters level wind degree is 135° (southeast) with the speed of 6 knots, 917 meters level wind degree is 125° (southeast) with the speed of 7 knots, and 1222 meter level wind degree is 115° (southeast) with the speed of 9 knots. In general, the wind moves from east to west so that corresponded with a dispersion of volcanic ash at the initial of the eruption (040 UTC) towards west.

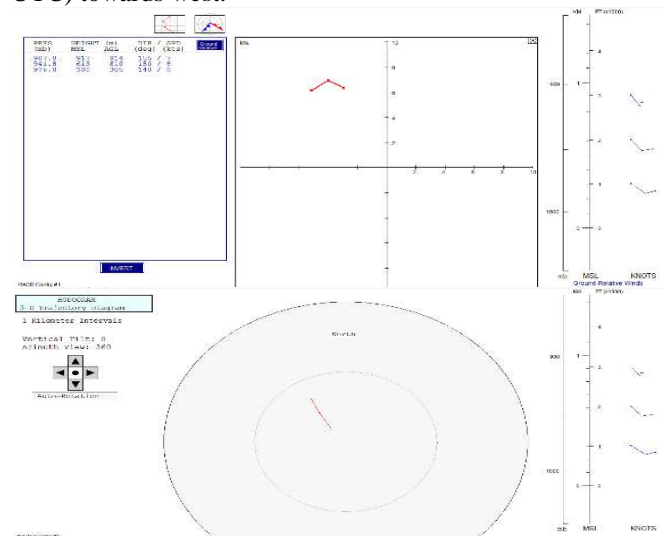


Fig. 14 Wind vertical at 06 UTC

Based on data above, at 06 UTC wind direction dominant came from the southeast. At layer 308 meters the direction of the wind is 140° (southeast) with the speed of 8 knots, layer 613 meters the direction of the wind is 150° (southeast) with the speed of 8 knots, and layer 917 meters the direction of the wind is 155° (southeast) with the speed of 7 knots. Generally, the wind moved from east to west so that corresponded with volcanic ash dispersion at 06-12 UTC to the west.

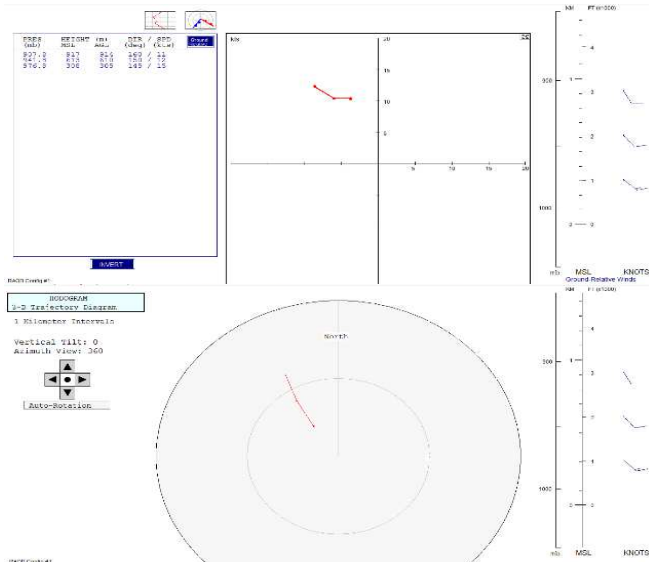


Fig. 15 Wind vertical at 12 UTC

Based on data above, at 12 UTC wind direction dominant came from the southeast. At layer 308 meters the direction of the wind is 145° (southeast) with the speed of 15 knots, layer 613 meters the direction of the wind is 150° (southeast) with the speed of 12 knots, and layer 917 meters the direction of the wind is 160° (southeast) with the speed of 11 knots. Generally, the wind moved from east to west so that corresponded with volcanic ash dispersion at 12 UTC to the west.

Can be concluded that volcanic ash dispersion PUFF model corresponded with pilot balloon observation at 00, 06, and 12 UTC which is dominated by west direction. This is also supported by VAAC Darwin information that mentioned the dispersion moved to the west.

IV. CONCLUSION

The information released by the PUFF model is more informative because it contains the dispersion of volcanic ash in each layer and the size of the dispersed particles.

PUFF model output also very corresponds with vertical wind data from pilot balloon observation data of Selaparang Meteorological Station which the dispersion is dominated to the west. Ash volcanic dispersion data from PUFF model can be used in delivering the information to pilot because it has more details and can predict up to 20 hours after the eruption better than volcanic ash advisory information issued by VAAC Darwin. Eruption or plume height information is more accurate using remote sensing of weather radar if it is compared with the observation by weather observer because it can capture small size objects.

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