ANALYSIS OF STORM CATEGORY AND COALESCENCE ACTIVITY : RELATIONSHIP TO THE DAILY MEAN CATCHMENT RAINFALL (CASES CLOUD SEEDING OPERATIONAL IN LARONA AND CITARUM CATCHMENT AREA)

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Abstract

Cloud seeding operational has been conducted in Indonesia. In this study, the two cases operational were analysis, ie Larona (2005) and Citarum Catchment Area (2011). The coalescence activity during operational were analysed using archives of NOAA-GFS model sounding and it also used to determined storm category and ICA. For this purpose, the number parameters for moderate threshold range on Raob-55 software were reduced and modified with more suitable range for Indonesia region. Result indicated that in Larona Catchment Area, the most of the storm having category weak to moderate with mean of storm category 67% and 21% respectively, the mean ICA value was -5.7. Relative larger weight of Weak and Medium category of storm were shown in Citarum ie 72% for weak and 18%, with the mean of ICA was -2.7%. As consequences, proportion of Medium together with Strong category for Larona is larger than Citarum, resulting larger amount mean catchment rainfall for Larona (17.1mm) compare to the Citarum (5.2 mm). The coalescence actifity in cloud during operation was effective for booth of two area, but varies due to the varies of cloud base height temperature and potential buoyancy (PB). The mean of CCL temperature in Larona was 20.3^{0}C since PB was 3.8^{0}C. This study also found that mean 500mb temperature (T) and mean rising parcel (TP) in Larona catchments was more warmer comparing to the Citarum ie -4.0^{0}C and -0.15^{0}C for Larona , and -5.3^{0}C and -1.5^{0}C for Citarum. Base of the result it has been concluded that ICA has inverse correlation to the mean daily catchments rainfall, since together of Medium and Strong Storm Category has positive correlation.

Intisari

Modifikasi awan sudah operasional . Pada studi ini dilakukan analisis dua kasus operasional , yaitu operasional di DAS (Daerah Aliran Sungai) Larona (2005) dan DAS Citarum (2011). Aktifitas koalesensi selama operasional dianalisis menggunakan arsip data sounding NOAA-GFS yang digunakan untuk menentukan ICA (Index Coalescence Activity – indeks aktifitas koealesensi) dan Storm Category – kategori awan hujan). Bagi keperluan ini banyaknya parameter dan rentang kategori moderat pada perangkat lunak Raob -55 di dikurangi dan dimodifikasi dengan yang paling sesuai dengan kondisi daerah di Indonesia. Hasil analisis menunjukkan sebagian besar awan hujan yang ada memiliki kategori weak hingga moderat – yaitu 67% dan 21% di DAS Larona dengan rata-rata nilai ICA besarnya -5.7, sedangkan di DAS Citarum, nilai kategori ini lebih besar yaitu 72% dan 18% dengan nilai rata rata ICA adalah -2.7. Sebagai konsekuensinya adalah porsi awan hujan dengan kategori ini lebih banyak muncul di DAS Larona dibandingkan pada DAS Citarum dengan rata rata hujan masing masing 17.1mm di DAS Larona dan 5.2mm di DAS Citarum. Aktivitas koalesensi di kedua DAS INI sama sama aktif, variasinya ditentukan oleh variasi ketinggian dasar awan konvektif (CCL) dan potensi daya apung awan (PB). Di DAS Larona CCL cukup hangat yaitu 20.3^{0}C , dengan nilai PB 3.8^{0}C. Pada sutudi ini juga di peroleh bahwa rata rata suhu dan suhu parsel paras 500mb pada DAS Larona lebih hangat (-4.0^{0}C dan -0.15^{0}C) dari pada di DAS Citarum (-5.3^{0}C dan -1.5^{0}C). Dari studi ini, disimpulkan bahwa ICA berkorelasi terbalik dengan curah hujan harian, dan berkorelasi positif dengan awan hujan berkategori " sedang" dan "kuat" secara bersama-sama.

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1. INTRODUCTION

Indonesia located spread out in tropical region, with warm surface temperature of about 25 – 28^{0}C. Variation of temperature mainly due to diurnal variation of sun insulation and due to altitude of places. This characteristic affects the local cloud formation in the whole area. Convective cloud formations mixed with orographic formation are dominated type of rainfall. In the rainy season, the westerly monsoon Asia air mass covered the the atmosphere over the country, in general occur from November until April. During this season, atmosphere usually very humid, with high water content. As consiquences, the dew point are very closed to the air temperature, specially in the surface and some times until more 500 mb vertical provile. This situation are caused formed mixed cloud with layer type as Sc, Ns, and convective as Cu and Cb with low (warm) base of cloud.

Cloud seeding operational was conducted for filling Towuti and Matanu Lake (Larona Catcment Area) in South Sulawesi since Citarum Catchment Area in West Java which is having 3 large dam for electric generation (Fig. 1). Result of observation indicates that cloud base level is about 18 – 20^{0}C. Mostly the storm caused by these type of clouds was having weak to moderate category. In some days a large amount of mean catchment rainfall occurs in Larona catchment. Its produced from moderate storm followed by light rain falling during the night day, and some times occured until early morning of the next day. In Citarum Catcment area, in general the amount of mean daily rainfall is less than Larona catchment mean rainfall. Index Coalescence Activity ICA has been used to evaluate the effectiveness of glaciogenic seeding in Thailand (Wooley et.al., 2003). Base on physical properties in ICA formula, in this study, ICA was used to evaluate mean daily rainfall during warm cloud seeding operational in those of two target area.

Figure 1. Target Area Cloud seeding Operational. Left: Lake Towuti and Matano in Larona Catchment Area (South of Sulawesi) , and Right: Jatiluhur-Saguling-Cirata in Citarum Catchment Area (West of Java). The blue arrow indicate the dams or lakes in each of Catchment Area.

2. METHOD OF ANALYSIS

Storm category analysed using RAOB-55, with modification of weighing and threshold range of parameters. According to Storm definition rain is one marks manifested of the atmospheric disturbance. Storm with Strong category usually accompanied with heavy rainfall and strong wind The reason for modified those parameters was differences storm and rainfall processes between Indonesia region and United States region which was original parameters threshold was developed. For example, hail producing from storm is unusual in Indonesia, so hail parameter in severe weather parameters on RAOB must be zero weighing.

The other examples are surface air temperature and surface dew point temperature, include 850 mb dew point temperature. In Indonesia, precursor of ordinary storm in general characterized by warm surface temperature (25 – 28^{0}C) and warm dew point temperature 23 – 24^{0}C. In this case, it was observed that dewpoint temperature on 850 mb ranges between 17 – 19^{0}C. Wind velocity also modified. In Indonesia, high speed wind also unusual, even in high altitude (500 and 200 mb). Near the surface, precursor high wind speed usually caused drifting or breaking cloud formation and rain not occured from the cloud or shifted to down wind area. But condition too low wind speed precursor is not good for developing storm. The other parameters to be modified are Lifting Index (LI), Showalter Index (SI), and CAPE, and K-Index (KI). LI and SI are sensitive parameters due to convective and orographic processes of Indonesia precursor storm. As consequence, high updraft velocity is favorable for storm in convective cloud, so CAPE also used for precursor storm predictor. In other view, warmer lifting parcel compare to the

Table 1. Modified weight and threshold Raob parameters for Indonesia Storm.

Parameters	Weight	Threshold for moderate storm
Surface Dewpoint (^{o}C)	3	23 ~ 24
850 mb Dewpoint (^{o}C)	3	17 ~ 19
850mb Wind Speed (kt)	1	10 ~ 20
500mb Wind Speed (kt)	1	15~30
200mb Wind Speed (kt)	1	40 ~ 45
Level of Free Convection (mb)	3	990 ~ 1000
Lifted Index	4	-3 ~ -4
Showalter Index	1	-2 ~ - 4
K Index (^{o}C)	1	37 ~ 40
Total-totals (^{o}C)	1	45 ~ 50
CAPE Total (J/kg)	1	1500 ~ 2500

environment temperature in 500 mb level are most favourable for precursor storm. The large value of LI and also large negative value of SI are most favorable condition as transport high water vapor content in the atmosphere over the area to high altitude and then precipitate to producing storm or rain. The other parameters in Raob are not used and weighed as zero. Parameters weighed and threshold of moderate storm shown in Table 1. For this purposes, archives data from NOAA ARL - GFS model 3-hourly, generally data 06z are used. For operational in Citarum, sounding position located in upwind of target at -6.8 Latitude and 107.2 Longitude, since for operation in Larona Catchment, sounding located at -2.7 Latitude and 121.5 Longitude. Rainfall monitored using relative dense of raingage in Catchment area and also some in outer border of Catchment Area.

The Index Coalescence activity has been used to evaluate cloud seeding experiment in Thailand (Woodley et al., 2003), Texas (Woodley et al., 2007), and also in India (Muralli et al., 2009). The Index of Coalescence Activity (ICA) has been developed as a predictor of in-cloud collision-coalescence activity using an atmospheric upper-air sounding. The ICA is described as the summation of the collision and collection efficiency, which results in the coalescence efficiency. The ICA has been used extensively as a measure of quantifying the seed ability of a cloud (http://www.sandylandwater.com /reports.htm), which was mathematical expression consisting base of cloud temperature and differences of parcel temperature and environment temperature, ie ICA = 8.6 – TCCL + 1.72(PB) and TCCL is the temperature at the convective condensation level and PB is the potential buoyancy at 500 mb for a saturated parcel raised from the convective condensation level (CCL) to 500 mb (Woodley,2003).

In warm cloud seeding using hygroscopic substance (Sodium Chloride or Calcium Chloride) produced from flare burning or in powder form, coalescence is a part of mechanism of droplet growth in cloud via deposition of water vapor onto surface of hygroscopic substance particles, and then collect (swept) the small cloud dropllets to become raindrop. In certain condition, many cloud droplets in cloud are support to effectiveness of coalescence activity, ie on warm cloud base and enough lifting force of air and updraft speed which is corresponds to buoyance force of cloud. So the ICA can also used to evaluate favorable environment condition for warm cloud seeding. Low (warm) base of cloud, and large PB are favorable for cumulus development. If CCL warms (for example 20^{0}C) and PB value of about 5^{0}C, ICA value becomes arround -5. The ICA are shifted into 0 (zero) direction with value arround of -1 in case of unfavorable condition that was for high cloud base (17^{0}C) altitude and small of PB (3^{0}C). Significat drift of more negative the ICA value occure in favorable condition that is for large number of PB and very low warm cloud base temperature. In this case, the ICA value becomes more negative then -5. The negative component of the ICA contributes from cloud base temperature, and positive component contribute from lifting parcel temperature, so ICA and weather condition are not linear. Cluster of the ICA arround -1 and -2 indicates the less favorable condition for collission and coalescence processes in cloud and corelated with high cloud base with less amount of mean rainfall over the area. The cluster of the ICA arround -5 indicates good condition (more favorable condition for production rainfall in cloud). In this case, high intensity of rain maybe occurred from cumulus cloud over the target area. From the physical view, its mean that - if seeding carry out with correct and proper procedures -, the operational will have positive effects and resulting additional water.

3. RESULTS

During cloud seeding in Larona catchment area, daily catchment rainfall varies from 0.7 – 52.2 mm, with mean daily rainfall was 17,1 mm. The mean of daily rainfall are correspond to the dominant of mean weight of weak and medium storm category ie 67% and 21%. On some days, amount of mean daily rainfall for catchment area was large enough, but no indication the strong storm category from Raob display. These large amount of mean daily catchment rainfall maybe comes from stratiform cloud occurred with longtime duration during the

night day, and also from short duration of medium rainfall in some place in the catchment area. That is why some times looks inconsistent between storm category and amount of daily rainfall. But in general daily catchment rainfall having relationship to the storm category, in term of correlation. Figure 2 show the sample of Raob display storm category for 06Z 9 April 2005 from sounding at Timampu, near coast of Towuti lake, after parameters be modified. The amount of mean daily Catchment Area for this day was 37.6mm.

Dominant combination of two category that is weight together of Weak and Moderate category and also weight together of Moderate and Strong Category looks more suitable as precursor rainfall in catchment area. Larona Catchment with large body of Water Lake maybe affects the storm formation through warmer temperature of water body comparing the land surround the lake after sunset (Haryanto, 2006). Need mo accurate re rainfall data which can explore peak and tail on rainfall distribution. The relationship between storm category looks more strong and clearly in Citarum.

In Citarum area, storm category has different with Larona which has 72% and 18% of Weak and Moderate Category respectively. Much smaller of mean rainfall (5.2 mm) caught during cloud seeding operational in Citarum area, February 2011 with more less variation of daily rainfall (0.30 – 14.5 mm). Much larger mean daily Larona Catchment rainfall may be comes from occurrence combination of booth Moderate and Strong Category which has total 33% of weight, camparing with 28% weight of Citarum Catchment. The summary of Storm category together of booth Larona and Citarum catchment area are shown in Table 2.

There are significant difference of mean ICA during Cloud seeding operational conducted in Larona and Citarum. The mean ICA for Larona Catchment Area was -5.7, since for Citarum was -2.7 or about two times larger than ICA in Larona Catcment Area. It's mean that atmospheric environment of cloud seeding in Larona Catchment Area conducted on March – May 2005 was more favorable due too more effective of coalescence activity in cloud compare to the cloud seeding conducted on February 2011 in Citarum. It was agree with observation that if event weak storm occur and dominant (or little weight category of Moderate and Strong), it is mean that on average, daily rainfall tend to decrease.

As recorded of daily rainfall on those of two areas, mean daily rainfall Larona Catchment area was more than three times (17.1 mm) compare to Citarum Catchment (5.2 mm). Actually, ICA was calculated base on 2 parameters from sounding data (Tccl and PB) on 500 mb level but actualy PB strongly depends on T (ambient temperature) and TP (parcel lifting parcel temperature), so exactly there were 3 parameters related to the ICA. All of these parameters that was processed for Larona looks more warmer than Citarum and as consequences ICA for Larona have more negative value even though slight difference on PB. Its mean that more warmer booth of environment and parcel temperature resulting more favourable condition comparing to less warmer condition, related to the more water vapour content on the atmosphere. The summary of the ICA and related parameters for booth Larona and Citarum included the mean daily catchment rainfall are shown in Table 2.

Furthermore, statistical technics has been used to explore relationship between daily catchment rainfall to the storm category and also to the ICA. It was found that storm with category weak having negative correlation and consisten for mean catchment rainfall booth of Larona and Citarum Area. The other category (Moderate and Strong)

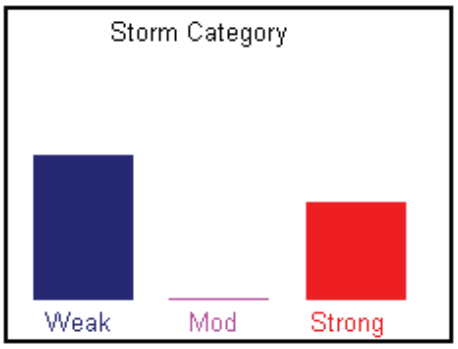

Figure 2. Display of Storm Category for 06Z sounding at Timampu (near coast of Towuti Lake), 9 April 2005. The amount of mean Catchment Area for the day was 37.6mm correspond to dominant of weak and strong category.

Table 2. Summerized of storm category (% weight), ICA and related parameters for determining of ICA for Larona and Citarum Catchment Area.

Storm Category and Parameters	Larona Catchment Area	Citarum Catchment Area
Weak storm	67	72
Moderate storm	21	18
Strong storm	12	10
T(°C)	-4.00	-5.30
TP(°C)	-0.15	-1.50
TCCL(°C)	20.30	17.7
PB(°C)	3.80	3.7
ICA	-5.70	-2.7
Mean Daily Rainfall (mm)	17.1	5.2

were same correlation ie positive. Correlation of the ICA and mean dailly rainfall looks also consistent for Larona and Citarum. If ICA tends to be large negative (litle value of ICA), mean daily rainfall tends to be large (Figure 3).

4. CONCLUDING REMARKS

Storm Category and the ICA during cloud seeding operational that conducted in Larona Catchment Area (South of Sulawesi) and Citarum Catchment Area (West of Java) has been analysis. It was founded that booth of dominant storm and ICA has relationship to the mean daily catchment rainfall in term of correlation. Storm with weak and medium category are frequently (dominant) occurred booth in Larona and Citarum Catchment Area with proportion occurrence of weight are 67 and 72% respectively. As consequence, total proportion of Medium and Strong category together for Larona Catchment Area are more frequently occurs comparing to the Citarum Catchment Area (ie 34% and 28%) respectively, resulting mean daily rainfall in Larona much larger (17.2 mm) compare to the Citarum (5.2 mm). This result support and agree to the ICA analyisis, which was – 5.7 and -2.7 for Larona and Citarum respectively. It was indicated that coalescence activity more active in Larona Catchment Area comparing to the Citarum, resulting received larger amount of rainfall in Larona. Negative correlation found for both weak storm criteria and also for ICA, positive correlation found for Medium and Strong criteria of storm

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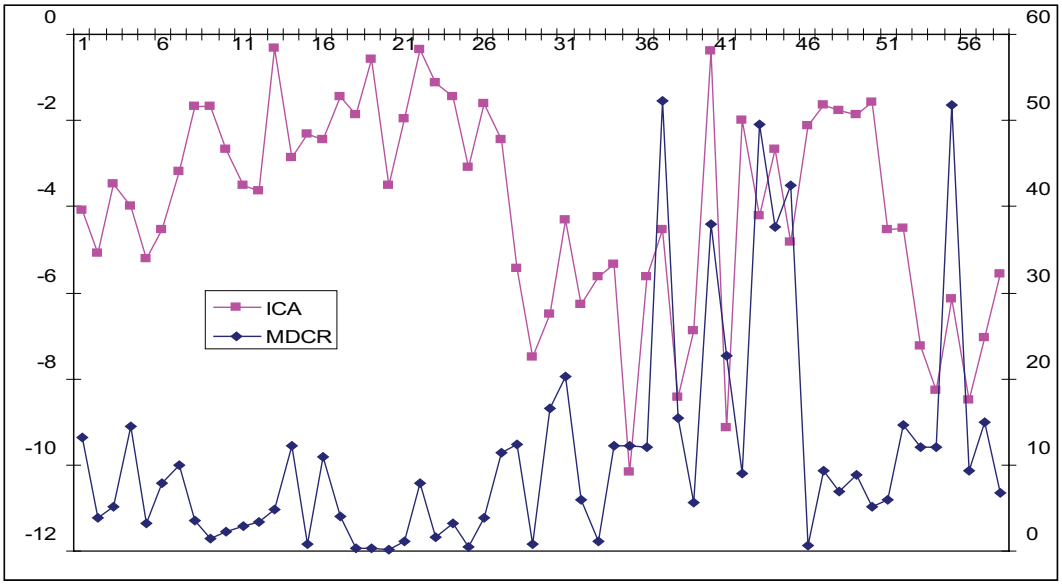

Figure 3. Relationship of Index Coalescence Activity (ICA) and Mean Daily Catchment Rainfall (MDCR). Plot using all data : Citarum, followed by data Larona. Relationship of ICA (left vertical axis) and MDCR (right vertical axis) looks as inverse correlation.