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Can Weather Modification Technologies Aid Greenhouse Gas Emission Reduction Efforts?

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Abstract— ***The most common Weather Modification Technology (WMT) application is cloud seeding, which aims to enhance precipitation rates. Previous studies showed that implementing WMT has successfully suppressed peatland fires in Indonesia as an engineering solution for reducing wildfire disasters. Data acquired from the Indonesian Ministry of Environment and Forestry (2023) revealed that Sambas Regency, West Kalimantan Province, Indonesia experienced the most significant forest and peatland fires on record. This study examines the influence of WMT in reducing Greenhouse gas emissions in the Sambas Regency caused by these fires. This study employed a target-only method to assess whether WMT implementation can increase precipitation, decrease hot spots, minimize wildfire areas, and reduce greenhouse gas emissions. The INCAS method is then used to estimate the greenhouse gas emissions caused by wildfires. The findings demonstrated that WMT positively impacts increasing precipitation rates (PCH of 1.04 >1), reducing hot spots ((PHS of -1 <1), and size of wildfire areas (PLS) of 0.23<1), and consequently, mitigating greenhouse gas emissions (CHS of 0.77<1). This study provided real data for the effectiveness of WMT in a specific context. It proposed its use as a strategy for mitigating wildfire disasters and reducing greenhouse gas emissions in Indonesia, which aligns with the UN's Sustainable Development Goals (SDGs).***

Index Terms: weather modification technology, precipitation, mitigation, forest fires, Greenhouse gas emissions, target-only method.

I. INTRODUCTION

In 2023, West Kalimantan Province was recorded as one of the provinces that experienced serious challenges due to forest and peatland fires. Based on data from the Ministry of Environment and Forestry of the Republic of Indonesia, this province ranked third in the provinces with the largest forest and peatland fires or wildfires in Indonesia. In this case, East Nusa Tenggara and West Nusa Tenggara Provinces ranked first and second (Sandhyavitri et al., 2023). The regency with the largest wildfire areas in West Kalimantan Province recorded in 2023 was Sambas Regency (Figure 1).

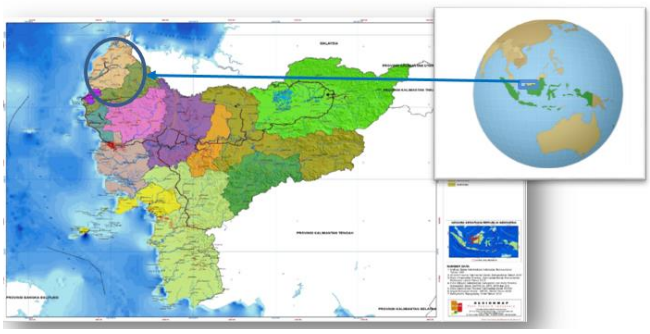

Fig. 1. Research location (in the Blue Circle area)

Forest and land fires that have been occurring frequently are very detrimental both economically and ecologically. Therefore, forest and land fires must be prevented and controlled carefully (Zubaidah & Arief, 2004, Sabiham, 2016).

Therefore, concrete efforts to prevent forest and land fires are implemented through Weather Modification Technology (WMT) (Haryanto, Untung, 2000). The method used in WMT is cloud seeding which can use airplanes, rockets, artillery, and ground-based generators (GBG). WMT activities in Indonesia have been carried out using aircraft and GBG (Seto and Mulyana, 2013; Sandhyavitri et al, 2020). This technology has been proven to be able to increase precipitation in water catchment areas, prevent floods, and for fire disaster mitigation (Sandhyavitri et al., 2020; Sandhyavitri et al., 2023).

The objectives of this study are to investigate the potential of WMT as a strategy for mitigating peatland disasters and reducing greenhouse gas emissions by increasing precipitation rates, reducing hotspots number, reducing wildfire areas, and reducing greenhouse gas emissions in Sambas Regency, West Kalimantan Province, Indonesia over five years, from 2019 to 2023. This study highlighted the application of the target-only for mitigating wildfires. This study also applied the Indonesian National Carbon Accounting System (INCAS) method in the context of calculating wildfire-related greenhouse gas emissions. This study provides a specific case study for future researchers employing similar methodologies.

Overall, the paper contributes to the body of knowledge by providing real-world evidence for the effectiveness of WMT in a specific environment. This aligns with the United Nations' Sustainable Development Goals (SDGs).

II. RESEARCH METHOD

There are several methods applied in this paper for obtaining precipitation data, hotspots amount, size of land fires, and Greenhouse gas emissions.

Precipitation. Precipitation refers to the total amount of rainwater that falls on an area or location over a specific period (which is usually measured in millimeters, mm). One of the main sources of precipitation data is the Meteorology, Climatology, and Geophysics Agency (BMKG), which routinely collects information from various weather monitoring stations throughout Indonesia. The Meteorology, Climatology, and Geophysics Agency (BMKG) is the Indonesian government agency responsible for providing weather and climate information. This data is available to the public through the official BMKG website, which can be accessed at https://dataonline.bmkg.go.id.

Hotspots. Hotspots generally serve as indicators of land fire risks. Thus, the more hotspots there are, the greater the potential for fires. Hotspots may play a role in early detection of the potential for forest and land fires. To detect forest and land fires, remote sensing data can be used, namely the Aqua, Terra, SNPP, NOAA 20, and Landsat 8 satellites in the Moderate Resolution Imaging Spectroradiometer (MODIS) catalog (LAPAN, 2020). A reliable source of data is the official website of the Ministry of Environment and Forestry (MenLHK) through its platform known as SIPONGI (Indonesian Peatland and Forest Fire Monitoring Information System). The required hotspot data can be accessed through the SIPONGI website which can be accessed via the website https://sipongi.menlhk.go.id.

Normalized Burn Ratio (NBR). Normalized Burn Ratio (NBR) is a metric used to identify and evaluate the extent of forest and peatland fire or wildfire disasters in the affected areas. This is also used to estimate the severity of wildfire in a geographic region. The basic concept of NBR is to utilize the difference in reflectance at two wavelengths of light, namely near-infrared (NIR) and shortwave infrared (SWIR), which can provide information about the level of vegetation damage caused by wildfires. NBR values range from -1 to 1, with higher values indicating healthy vegetation and lower values indicating burned areas. (García, & Caselles, 1991, a and Que, et al (2019).

Greenhouse gas emissions. Tropical peatland fires can release 10 times more methane than fires in other land types so do carbon gas emissions. In total, the impact of peatland fires on global warming can be more than 10-200 times greater than fires in other land types (Sandhyavitri, 2022).

Greenhouse gas emission Calculation. The calculation of Greenhouse gas emissions in this study uses the Indonesian National Carbon Accounting System (INCAS) method, which was developed by the Ministry of Environment and Forestry of the Republic of Indonesia together with international institutions such as AusAID, CIFOR, and REDD since 2008 for forest areas in Kalimantan. This INCAS method became the Standard Method for estimating greenhouse gas emissions, especially carbon emissions gas from the Forestry Sector in Indonesia (Krisnawati et al., 2015).

In this standard method, peatland is defined as land containing organic soil. This land is an area with an accumulation of partially decomposed organic matter, ash content equal to or less than 35%, peat depth equal to or more than 50 cm, and organic carbon content (by weight) of at least 12% (Krisnawati et al., 2015).

Evaluating Weather Modification Technology using the Target Only-Method. Weather modification technology (WMT) aims to enhance precipitation rates and mitigate the impacts of droughts and wildfires. Evaluating the effectiveness of WMT requires robust data processing methods that accurately quantify the resulting changes in precipitation, hotspot reduction, and wildfire area reduction. The target-only method offers a straightforward approach for this evaluation, employing straightforward formulas without the need for randomized designs. This paper focused on the utilization of the target-only method for assessing WMT effectiveness.

2.1 Precipitation rates Calculation (PCH)

The calculation of precipitation rates is expressed by the following equation (Sandhyavitri, 2020).

$$PCH = [(RT)p/(RT)h] \times 100\% \qquad (1)$$

with :
PCH = Precipitation rates (increase or decrease)
(RT)p = Precipitation rates in the target area during the weather modification period
(RT)h = Historical precipitation rates in the target area during the corresponding period.
If PCH > 1, WMT has been demonstrated to effectively enhance precipitation rates.
If PCH < 1, WMT does not exert an impact on the enhancement of precipitation.

2.2 Hotspots cases Calculation (PHS)

The following equation expresses the calculation of hotspot cases (Sandhyavitri, 2020).

$$PHS = [(HS)p - (HS)h] / (HS)h \times 100\% \qquad (2)$$

with :
PHS= Hotspot cases (reduction or increase)
(HS)p = Hotspot cases in the target region during the WMT period
(HS)h = Historical hotspot cases in the target region in the similar period as the WMT period
If PHS > 1, WMT has no impact on hotspot reduction.

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If PHS < 1, WMT is successful in reducing hotspots.

2.3 Calculation of Fire Area.

The calculation of the size of fire areas is expressed by the following equation (Sandhyavitri, 2020).

$$PLS = [(LS)p - (LS)h] / (LS)h \times 100\% \quad (3)$$

with :
PLS = Fire area reduction.
(LS)p = Fire area in the target area during the WMT period
(LS)h = Historical fire extent in the target area in the same period
as the WMT period
If PLS > 1, WMT has no impact on reducing wildfire area.
If PLS < 1, WMT is successful in reducing wildfire area.

2.4 Calculation of Total Carbon Gas Emissions INCAS Method

After the calculation of the area of forest and peatland fires has been identified, the greenhouse gas emissions resulting from the forest and peatland fires can be calculated. Based on Krisnawati et al, 2015, the calculation of greenhouse gas emissions (in this context we calculated the carbon gas emissions) based on the INCAS method, can be calculated in the following equation 4 below.

$$Lfire = A . MB.Cf.Gef (10)^{(-3)} \quad (4)$$

where:
Lfire = Total CO2 or non-CO2 emissions from fires (tons)
A = Area burned each year (ha)
MB = Mass of fuel available for burning (tons/ha)
= area (m2) x depth of fire (m) x content weight (t/m^3), Content weight = 0.121 g/cm^3.
Cf = Fire factor = 1 (for organic soil forest fires all fuels burn) material/fuel burns)
Gef= Emission factor for each gas, dry material burned (for CO 2 = 464, for CH4 = 21).

III. RESULTS AND DISCUSSION

3.1. Effect of WMT on Increased Precipitation

Based on processed precipitation data which were obtained from the Indonesian Agency for Meteorological, Climatological and Geophysics (Badan Meteorologi, Klimatologi, dan Geofisika or simply BMKG), it was calculated that the accumulated annual precipitation rates in Sambas during 2019-2023 were as follows: in 2019 = 2716 mm, 2020 = 3094 mm, 2021 = 3281 mm, 2022 = 3105 mm and 2023 = 2090 mm (Table 1).

There are fluctuations in the amount of annual precipitation rates. The highest of which occurred in 2021 at 3281 mm.

Precipitation rates in the WMT implementation period from June 28 to July 10 (13 days) in Sambas were as follows: 2019 = 25.9 mm, 2020 = 303 mm, 2021 = 15.9 mm, 2022 = 13.3 mm, and 2023 = 92.9 mm.

Evaluation of WMT performance in Sambas Regency based on the target-only method is as follows:

PCH = [(RT)p/(RT)h] × 100%
PCH = {92.9 / [(25.9+303+15.9+13.3) / 4]} × 100%
PCH = (92.9 / 89.5)
PCH = 1.04 > 1 (effective)

Table 1. Precipitation Rates Calculation in Sambas Regency

Period	2019 (mm)	2020 (mm)	2021 (mm)	2022 (mm)	2023 (mm)	PCH	Notes
28 June – 10 July	25,900	303,000	15,900	13,300	92,900	1,04	The implementation of WMT in Sambas 2023 was effective in increasing precipitation rates (PCH = 1.04 > 1).

Hence, the above calculations based on the target-only method, the implementation of WMT in Sambas from June 28 to July 10 was considered effective in increasing precipitation rates (PCH = 1.04 > 1).

3.2 Effect of WMT on Hotspot Cases Reduction in Sambas Regency.

The number of hotspots that occurred in 2019 was 2 events. and from 2020 to 2023 in the WMT period, there were no hotspot events occurred (Table 2). From June 1 to 27, 2023 (before the implementation of WMT) there were 25 hotspot events were detected, and after the implementation of WMT, the number of hotspot events dropped to 0. Hence it was considered that the implementation of WMT was effective in reducing the number of hotspots during this period of WMT (Table 2).

Table 2. PHS Calculation Sambas Regency

Period	2019 (events)	2020 (events)	2021 (events)	2022 (events)	2023 (events)	PHS	Notes
28 June – 10 July	2	0	0	0	0	-1	The implementation of WMT was effective in reducing the number of hotspots during this period of WMT

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Evaluation of hotspot reduction performance based on target-only

(HS)p = 0

(HS)h = (2 + 0 + 0 + 0) / 4 = 0.5

PHS = [(HS)p - (HS)h] / (HS)h × 100%

PHS = [0 – 0.5] / 0.5 × 100%

PHS = -1 < 1 (effective).

The increase in precipitation rates (blue lines) and the number of hotspot events (red lines) are presented in Figure 2.

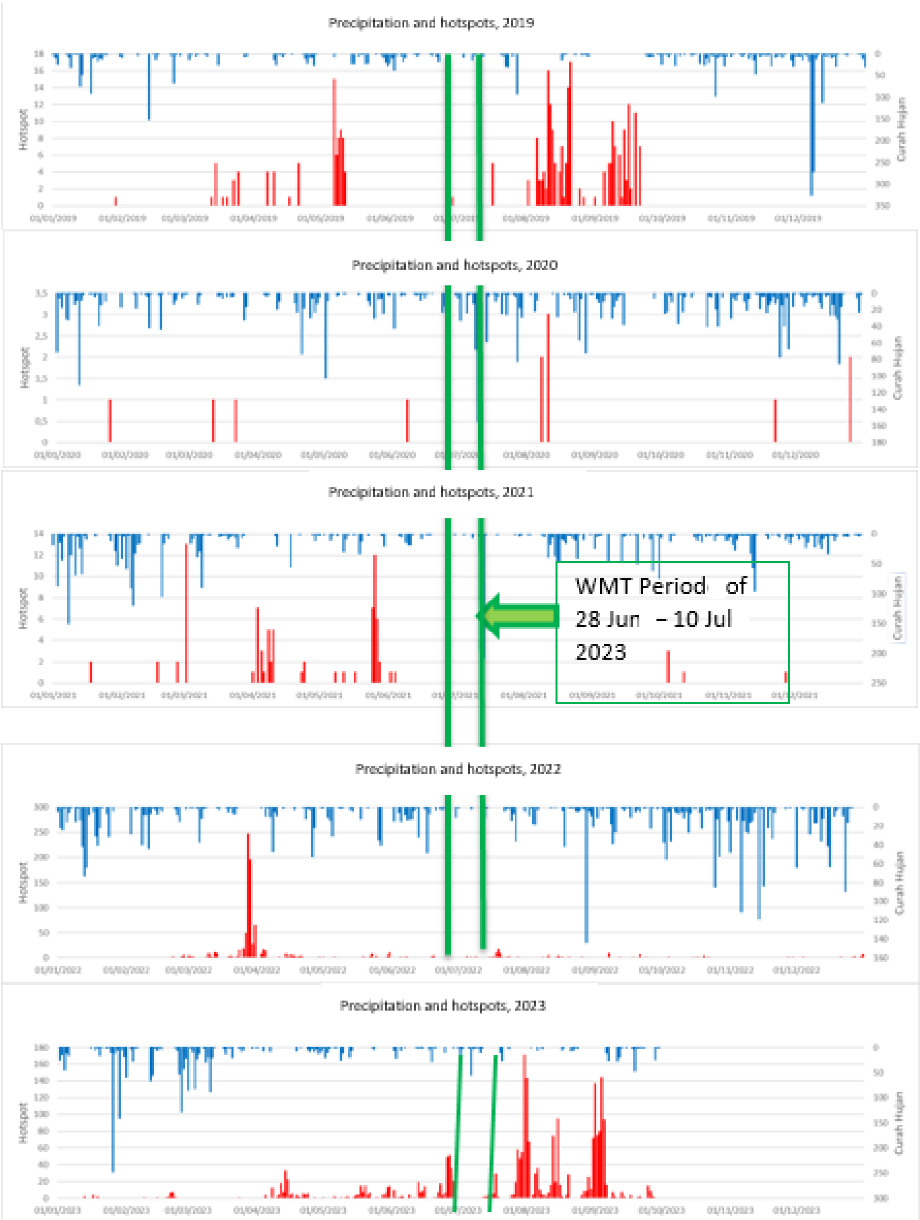

Fig. 2. Trend of precipitation rates against hotspots (2019-2023) in Sambas, West Kalimantan.

Fluctuations in the number of annual hotspot events that occurred from 2 hotspots in 2019 to become 1 hotspot in 2023 were considered effective (PHS = 0 < 1).

3.3 Influence of WMT on the Reduction of Wildfire Areas in West Kalimantan Province

The area of wildfires that occurred in Sambas Regency from June 28 - July 10, 2019 - 2023 were obtained from Google Earth Engine (Table 3).

Table 3. Size of wildfire areas in Sambas Regency in 2019 – 2023

Year	Wildfire Area (Ha)
2019	151.774
2020	178.889
2021	293.118
2022	808.316
2023	439.900

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(Source: Processed data from Google Earth Engine, 2023)

It can be seen from Table 3 above that the 2019 wildfire areas were 151,774 ha. This figure increased by 18% in 2020 to become 178,889 ha. These cases increased again to 293,118 ha in 2021 (increased by 64 compared to 2020). In 2022 the wildfire areas increased significantly up to 808,316 ha (more than 250%). Fortunately in 2023, the wildfire areas decreased to 439,900 ha (decreased up to 50% from those areas in 2022) (Figure 3).

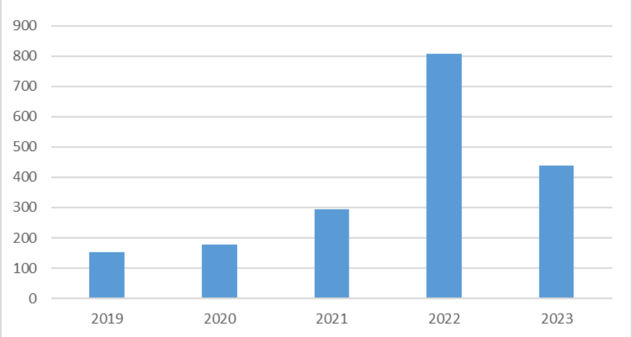

Fig. 3. The size of the wildfire areas in Sambas Regency 2019 - 2023

It is illustrated that an increase in the precipitation rates reduced the size of the wildfire area (Figure 3). The performance of wildfire area reduction based on the target-only can be evaluated as follows (Table 4).

(LS)p= 439.90 Ha

(LS)h= (151,774 + 178,889 + 293,118 + 808,316) / 4 = 358.02 Ha

PLS = [(LS)p - (LS)h] / (LS)h × 100%

PLS = [439.90 - 358.02] / 358.02 × 100%

PLS = 0.23 < 1 (effective).

Table 4. PLS calculation of Sambas Regency

Period TMC	2019 (ha)	2020 (ha)	2021 (ha)	2022 (ha)	2023 (ha)	PHS	Notes
28 June – 10 July	151,77	178,89	293,12	808,32	439,90	0,23	The implementation of WMT was effective in reducing the size of wildfire areas during this period of WMT

Based on the target-only method, it was calculated that WMT implementation from July 28 to July 10 was considered to reduce the wildfire areas effectively.

3.4. Effect of WMT in Reducing Carbon Dioxide Emissions from Forest and Land Fires in Sambas Regency.

Once the area of forest and land fires is known, carbon dioxide (CO2) emissions resulting from forest and land fires can be calculated. For example, in 2019, the fire area in Sambas Regency was 151.774 ha. This study used an assumption that the depth of the water table within this study area is 50 cm 9which is the limit of the depth of burnt land) and the weight of the burnt mass content is 0.121 g/cm3 (Krisnawati et al, 2015).

Thus MB = 151.774 Ha × 0.5 m × 0.121 g/cm3

MB = 9,182 tons/Ha

Hence, the annual MB value is presented as follows (Table 5).

Table 5. Mass of Material Burned Sambas Regency

MB (Ton/Ha)				
2019	2020	2021	2022	2023
9,182	10,823	17,734	48,903	26,614

With a CO2 gas emission factor of 464 g/kg and a wildfire factor of 1 (for forest fires on organic soil materials burned (Yokelson et al., 1997), the following greenhouse gas carbon emission values were obtained using the INCAS method as follows:

Lfire = $A \ldots G_{ef} . 10^{-3}$

Lfire = 151.774 x 9,182 x 1 x 464 x 10^{-3}

Lfire = 646,648 ton

Lfire = 0,647 Megatons (Mtons)

The Lfire (carbon gas emission) value for each year per regency is as follows (Table 6).

Table 6. Greenhouse carbon gas emission by INCAS method

No	Regency	Carbon dioxide emission (Mtons)				
		2019	2020	2021	2022	2023
1.	Sambas	0,647	0,898	2,412	18,342	5,432

Based on Table 6, shows that the larger the mass of burned material, the more carbon dioxide gas emissions are produced. The level of carbon gas emission reduction (CHS) is calculated as follows:

CHS = an average carbon gas emissions released to the atmosphere in 4 years = (0.647+0.898+2.412+18.342) Mton divided by 4 = 6.999 Mton. Then 5.432 Mton (carbon gas emissions occurred in 2023) divided by 6.999 Mton = 0.77. Thus the effectiveness of WMT performance based on the target-only method is considered successful in reducing carbon gas emissions (CHS of 0.77<1).

This study confirmed a previous study conducted by a similar author in the area of Riau, Sumatra Island Indonesia, 2020 concerning the evaluation implementation of weather modification technology (WMT). This study stated that the application of WMT in 2020 was considered successful in suppressing carbon gas emissions in Riau (CHS=0.0008<1) (Sandhyavitri et al., 2022, 2023, Viandry, 2022). However, it is not necessary for this success could be directly applicable to other locations. Various factors such as differing weather patterns and cloud formations that could affect WMT effectiveness should be further investigated.

IV. CONCLUSION

The implementation of WMT in Sambas, West Kalimantan, Indonesia succeeded in increasing precipitation rates in the period June - July 2023; reducing hotspot cases, and reducing the size of wildfire areas. This WMT also aided in reducing greenhouse gas emission efforts in 2023 (CHS of 0.77<1). These efforts offer the opportunity to be implemented elsewhere in the light of wildfire disaster mitigation and control. Further research in various locations and detailed explanations of limitations would strengthen the argument for broader WMT implementation in the future.

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