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Rainfall Estimation with Convective Stratiform Technique (CST) Model

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Keywords

Convective, Stratiform, Satellite Imagery, Rainfall

Abstract. Pontianak City is geographically located on the equator. Based on its location, the atmospheric dynamics in this region fluctuate greatly, the equatorial region throughout the year is exposed to solar radiation so that the potential for convective clouds is very high. This research aims to estimate rainfall based on the characteristics of convective and stratiform rain during extreme weather that causes flooding in Pontianak City. The data used is HIMAWARI 8 satellite image data with a duration of December 22-23, 2023. The method used is Convective Stratiform Technique (CST). The results showed that the atmospheric dynamics on December 22 and 23, 2023 were very high, this was characterized by the formation of high clouds with very low cloud top temperatures below -70°C around Pontianak City. Then the estimation of rainfall based on the CST model can be done during heavy rains that cause flooding in Pontianak City. The model rainfall value overestimates the observation data, on December 22 the difference is very large, while on December 23 the model rainfall is able to approach the obeservation rainfall with a very small difference of 1.2 mm.

1. INTRODUCTION

Climatic phenomena in the equatorial region including Pontianak City are very complex which are influenced by natural phenomena in the form of monsoon, equinox, el-nino and la-nina events and dipole mode [1]-[5]. The complexity of the atmosphere causes high rainfall variability which can trigger natural disasters, if there is a wet extreme it will have an impact on flooding, and vice versa if there is a dry extreme it causes drought and can trigger land and forest fires [6], [7]. To anticipate natural phenomena and their impacts, it is necessary to improve the quality and quantity of weather information. Weather and climate estimates are needed which can later be utilized for disaster mitigation in the form of rainfall predictions both spatially and temporally.

Studying rainfall variability can use observational data on the earth's surface in the form of rain gauge data can also be done by utilizing meteorological satellite data. Rainfall estimation using satellite data is needed to fulfill accurate global rainfall, in order to improve weather and climate estimates in the short, medium and long term [8], [9]. Meteorological satellites are one of the high-tech measuring instruments that can provide and present information about the state of the earth's atmosphere.

One method of estimating rainfall using meteorological satellite data that has been carried out by researchers is the Convective Stratiform Technique (CST) method [10]-[12]. The CST algorithm utilizes satellite image data on the Infrared (IR) channel, by converting the temperature of the cloud tops received by the satellite into rainfall values. The meteorological satellite in the Asia Pacific region is the HIMAWARI satellite owned by the Japanese government which is a replacement for the MT-SAT satellite which has expired. Researchers were encouraged to conduct research on the estimation of Pontianak City rainfall utilizing HIMAWARI 8 satellite data, during extreme weather that caused flooding on December 22 - 23, 2023. The output of this research can be used as a disaster mitigation study to support flood management and forest fires that often occur in Indonesia.

2. METHOD

Location and Data

The research was conducted in Pontianak City, West Kalimantan (Figure 1).

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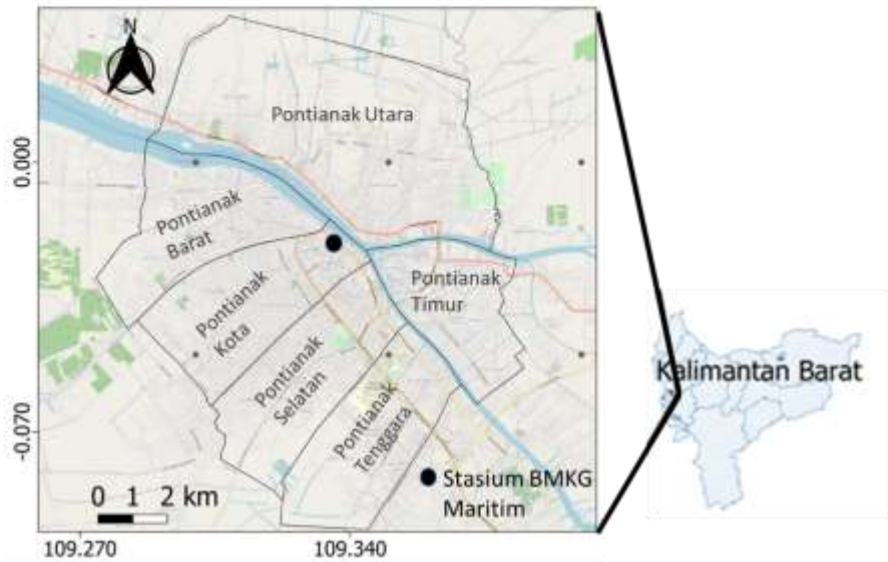

Figure 1. Research Location

HIMAWARI 8 satellite image data, infrared channel (IR1). This data is downloaded from http://www.weather.is.kochi-u.ac.jp/sat/GAME. which is 1800 x 1800 pixels in size which has a fairly high resolution of 0.05° by covering the area 70° East - 160° East and 70° North - 20° South. While the verification data uses observation data from the Pontianak Maritime Meteorology and Geophysics (BMKG) station which can be downloaded at https://dataonline.bmkg.go.id/.

Data Processing Steps

Data extraction

Satellite image data has a large observation range, namely 70° East- 160° East and 70° East - 20° South, resulting in large file sizes as well. To get the desired satellite data results, data sampling is carried out for the Pontianak City area.

Convert Infrared Data into cloud-top temperature data

Satellite image data that has been extracted in each region is then converted into equivalent blackbody temperature data known as cloud top temperature (TBB) using calibration data downloaded along with the IR image data. This calibration data contains the conversion value of certain color pixel levels into TBB in Kelvin units. The TBB data that has been obtained is then estimated rainfall using the CST Method. The data processing is done from hourly scale data then daily scale.

Convective Stratiform Technique (CST) Method

The CST method was first conducted by Adler and Negri (1988) for tropical rainfall estimation. This study uses the CST method that has been developed by previous researchers including [10], [13]-[18]. Validation and statistical analysis. Validate the results with rainfall data from BMKG and then analyze it by finding the difference between the model rainfall value and the observed rainfall. The following is a partial script of the CST model using octave software used in this study:

```
%-----------------------------------------------------------------%
%Convert satellite image index data to temperature data
[m, n]    = size(d);
for i = 1:m,
    for j = 1:n,
        idx        = double(d(i,j));
        ta(i,j) = data(idx+1);
colormap(jet);
    end
end
s=0.125*(ta(2,1)+ta(3,1)+ta(4,1)+ta(5,1)+ta(6,1)+ta(7,1)+ta(8,1)+ta(9,1)-8*ta(1,1));
CH=(ta(1,1)-207)*0.0826;
bs=exp(CH);
b=15.27 +((-0.0492)* ta(1,1));
a= exp (b);
%-----------------------------------------------------------------%
```

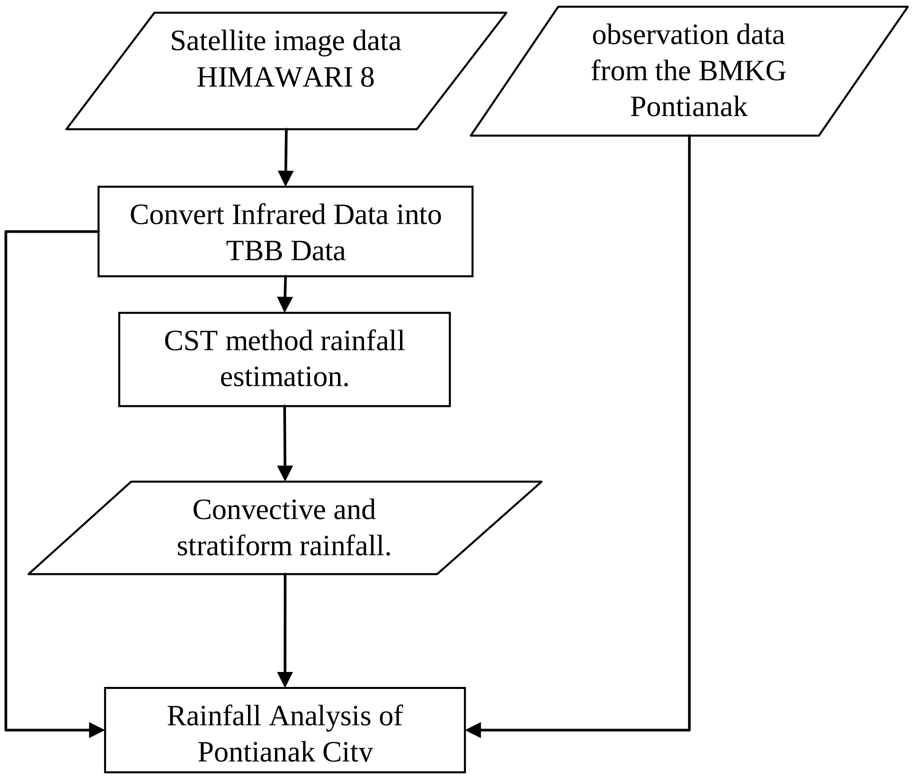

Figure 2. Research Flow Chart

3. RESULTS AND DISCUSSION

Cloud Top Temperature Analysis

Cloud top analysis is carried out based on HIMAWARI 8 satellite images, in the IR canal, on IR identification. Cloud formations with high peaks will look bright while clouds with low cloud tops look darker. Satellite images emitted in the infrared channel are directly proportional to the temperature of the object that emits/reflects them. Waves in the IR channel are generally absorbed and emitted by grains in clouds and little is absorbed by the atmosphere.

The level of color brightness based on cloud type will differ from one another, the brightest stratiform clouds, then cumulus clouds. The estimated cloud top temperature will be easily identified but for thin clouds the cloud top temperature will be obtained higher than the actual value. This will lead to errors in determining the cloud tops. Similar cloud type factors will also cause errors in the estimation of cloud top temperatures, such as Cirrus cloud types with very thick cloud layers will have cloud tops that are almost the same as Cumulonimbus clouds, making it very difficult to distinguish between the two types of clouds. Likewise, Stratus clouds are low clouds so that the peak temperature of Stratus clouds is very similar to the surface temperature, making it difficult to detect the presence of Stratus clouds if using IR channel satellite imagery alone.

Convective clouds are generally cloud clusters with a narrower coverage area. As the convective clouds develop further, the thickness of the clouds will increase and then the cluster-shaped clouds merge together causing an enlarged convective cloud area that is recorded by satellite imagery. Convective type cloud boundaries are easy to distinguish because they are clearly visible. While stratiform cloud boundaries are very difficult to distinguish because they are not clearly visible.

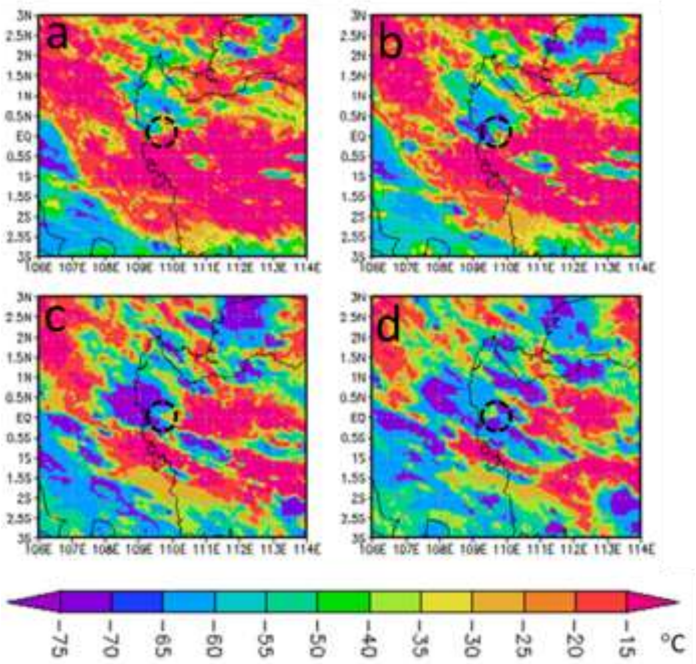

Figure 3. The growth of cumulonimbus clouds in the western Kalimantan region on December 22, 2022, a. 07.00 UTC, b. 08.00 UTC, c. 09.00 UTC, d. 10.00 UTC.

Atmospheric conditions in the Pontianak City area at the time of the flood on December 23, 2022 showed the development of cumulous clouds that grew in the area. Figure 3 shows a cloud formation that developed in the northern part of the coast of West Kalimantan recorded by satellite imagery starting on December 22, 2022 at 07.00 UTC (14.00 WIB), the peak temperature of the cloud observed was in the range of -60°C to -65°C (Figure 3.a). Then it can be seen that the cloud formation continues to develop and move up to the upper layer in the next hour (08.00 UTC/15.00 WIB), in the equatorial region (Pontianak City and its surroundings) the cloud top temperature is seen to decrease to the level of -70°C. Cloud formations with peak temperatures at that level experienced an expansion of the area in the next hour then at one hour the trend weakened, the clouds began to disappear, cloud formations with cloud peak temperatures with level -70°C were seen to begin to decrease (Figure 3.d).

Atmospheric dynamics in the Pontianak City area were again volatile in the second period, an indicator of the development of cumulous clouds that grew in the region starting at 18.00 UTC on December 22, 2022 (01.00 WIB on December 23, 2022). Figure 4, shows the cloud formations that developed in the western Natuna waters of West Kalimantan recorded by satellite imagery, the peak temperature of the clouds observed below -70°C (Figure 4.a). However, in the Pontianak City area, the temperature is still high, indicating that convective clouds have not grown in this area. Likewise, one hour later the high cloud formation was still in the water area, but at 20.00 and 21.00 UTC (03.00 and 0.400 WIB on December 23, 2022) there was visible cloud growth around the Pontianak City area. With a range of cloud top temperatures below the -40°C level (Figures 4.d and 4e).

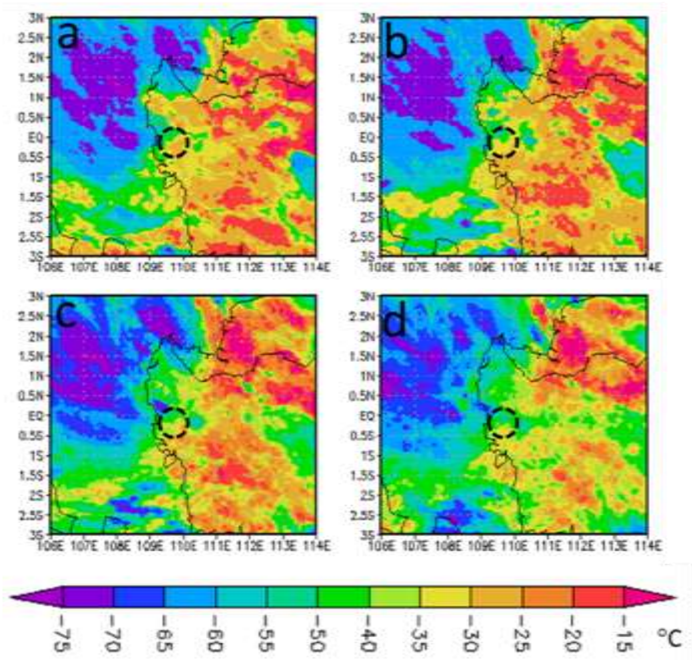

Figure 4. The growth of cumulonimbus clouds in the western Kalimantan region on December 22, 2022, a. 18.00 UTC, b. 19.00 UTC, c. 20.00 UTC, d. 21.00 UTC.

Convective and Stratiform Rainfall Analysis

Rainfall estimation of Pontianak City area has been conducted based on IR satellite image data using the CST method. Rainfall estimation is done by dividing two periods based on cumulonimbus cloud formation as discussed in the previous section. The first period from 07.00 UTC to 10.00 UTC and the second period from 18.00 UTC to 21.00 UTC on December 22, 2022.

At 07.00 UTC the first period has not seen any rain events in the Pontianak City area still categorized as not raining (Figure 5.3a). One hour later (08.00 UTC) all areas of Pontianak City experienced rain and even most areas experienced extreme rain (>20 mm/hour) covering all of North and East Pontianak and parts of Southeast Pontianak and South Pontianak, as well as a small part of Pontianak City and West Pontianak. While other areas experienced rain with heavy categories (10 - 20 mm/hour). While at 09.00 UTC the entire city of Pontianak experienced rain with the category of extreme rain. Rain in the Pontianak area still lasted for the next hour but the rain category dropped to heavy rain.

In the second period, at 18:00 UTC, it was seen that there was a rain event in a small part of Pontianak City, namely around West Pontianak and Pontianak Kota, with rain in the category of heavy rain (Figure 6a). One hour later (19.00 UTC) all areas of Pontianak City experienced rain with light rain category. Then at 20:00 UTC the rain shifted to the north Pontianak area with heavy rain category. Then at 21.00 UTC the entire Pontianak city experienced light rain with the exception of heavy rain at certain points as shown in Figure 6d.

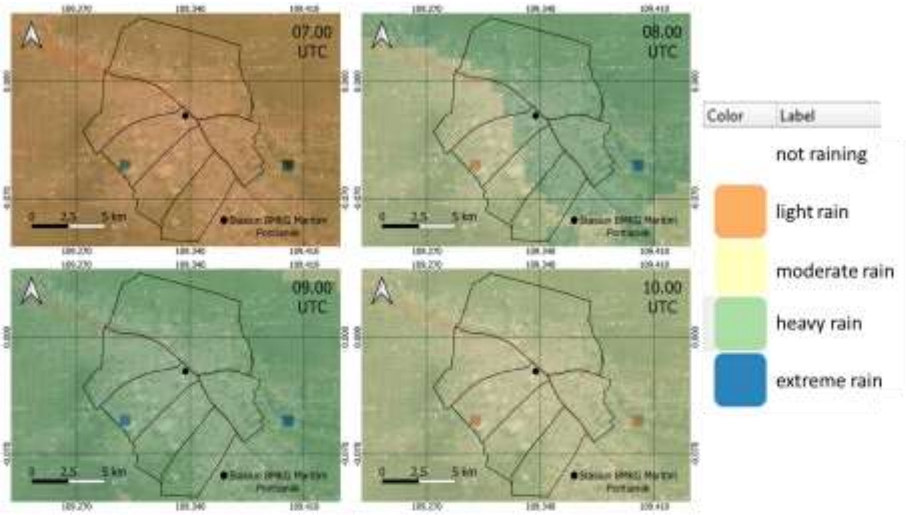

Figure 5 Precipitation levels of the CST model results in the western Kalimantan region on December 22, 2022, a. 07.00 UTC, b. 08.00 UTC, c. 09.00 UTC, d. 10.00 UTC.

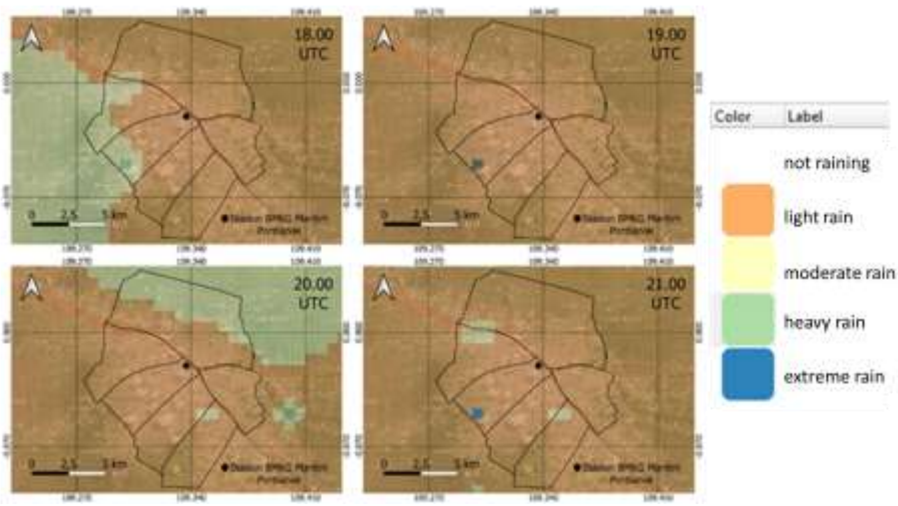

Figure 6. Precipitation levels of the CST model results in the western Kalimantan region on December 22, 2022, a. 18.00 UTC, b. 19.00 UTC, c. 20.00 UTC, d. 21.00 UTC.

Model Validation

Validation of the rainfall value of the model results is done by comparing with observation data from BMKG Maritime Pontianak. The rainfall data from the model results on an hourly scale is accumulated into daily data because the observation data obtained is in the form of daily data. The model validation period used was on December 22, 2022 and December 23, 2022 (Figure 7). Based on the validation results obtained that the CST model on December 22 is not able to simulate rainfall in the Pontianak City area, it can be seen that the difference between the model rainfall value and the observed rainfall is very large, which is above 100 mm, this shows that the rainfall model overestimates the observed rainfall. In contrast to the modeled rainfall value on December 23, the value is very close to the observed rainfall value, the difference is very small, namely 1.2 mm. The high difference in the value of modeled rainfall is because on December 22 the formation of cumulonimbus clouds was very active as seen by the low temperature of the cloud tops recorded by satellite imagery, especially at 08.00 UTC and 09.00 UTC as explained in the previous section (Figure

5), while the observation data on the surface did not record any rain at that time. Because the CST model input data only uses the cloud top temperature parameter, the results show a very high value.

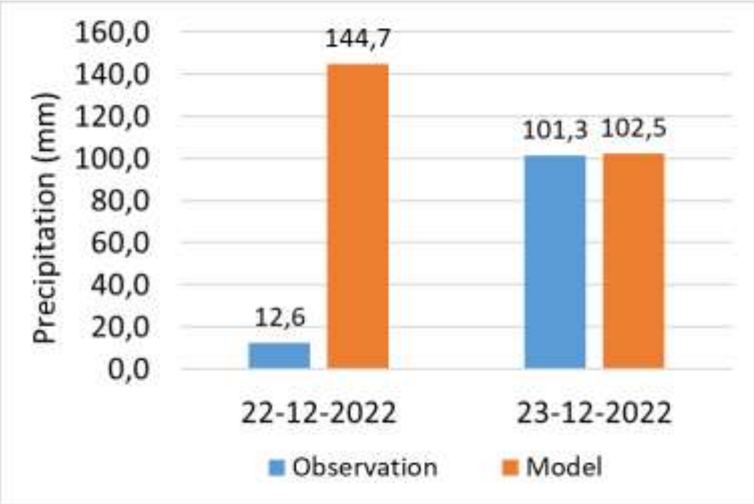

Figure 7. Comparison of CST Model rainfall values with observed rainfall values (BMKG Maritim) on December 22, 2022 and December 23, 2022.

4. CONCLUSION

Atmospheric dynamics on December 22-23, 2023, are very strong, this is characterized by the formation of cumulous clouds with very low cloud top temperatures below -70°C, which began at 08.00 UTC (15.00 WIB). Then the formation of clouds with low cloud top temperatures occurs again at 19.00 UTC (02.00 WIB on December 23, 2023). Estimated rainfall based on the CST model, showing heavy to extreme rain on December 22, 2023 then one day later (December 23, 2023). The results of the comparison of the model rainfall value with the observation data show that on the first day, it has a very large difference, while on the second day, the model rainfall is able to approach the observation rainfall with a difference of 1.2 mm. We would like to thank DIPA FMIPA UNTAN for funding this research with the contract number: SP DIPA-023.17.2.677517/2023.

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