Prisma Sains: Jurnal Pengkajian Ilmu dan
Pembelajaran Matematika dan IPA IKIP Mataram
https://e-journal.undikma.ac.id/index.php/prismasains/index
e-mail: prismasains.pkpsm@gmail.com

April 2023. Vol. 11, No. 2
p-ISSN: 2338-4530
e-ISSN: 2540-7899
pp. 476-484

Analysis of Spearman Rank Correlation & Linear Regression of Atmospheric Stability and Cloud Tops Temperature of Himawari-8 IR Satellite Images (Case Study of Hail on May 22, 2022)

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Received: March 2022; Revised: March 2023; Published: April 2023

Abstract

This research is based on cases of hail that caused flooding in Binjai City on May 22, 2022. This study aims to see the correlation and regression of the Atmospheric Stability index value on cloud top temperature data from the Himawari-8 satellite imagery. So that the ERA-5 reanalysis data can be used to obtain cloud top temperatures in predicting hail events. The indices used in this study are CAPE, KI and TTI. The data used is located in Binjai City with correlation testing from 00UTC – 24UTC on May 22, 2022. Supported data is used in the form of sea surface temperature and wind conditions and looks at the causes of hail at the research location. The method used is Spearman's rank correlation with the results obtained in the form of a correlation value at the K index of -0.651, a correlation of the TT index of -0.563, and a correlation of the CAPE index of -0.348. The simple linear regression results also show a negative gradient line. This shows that the increase in the value of the stability index is in line with the decrease in cloud top temperature. So that the stability index data can be used as a benchmark in estimating cloud top temperatures in the case of convective cloud formation which causes hail.

Keywords: Atmosphere Stability, Hail, Analysis of Spearman, Correlation, Himawari-8, Linear Regression.

How to Cite: Purba, L., Humaidi, S., & Darmawan, Y., Zahedi., Nasution, T.I. (2023). Analysis Of Spearman Rank Correlation & Linear Regression Of Atmospheric Stability And Cloud Tops Temperature Of Himawari-8 IR Satellite Images (Case Study Of Hail On May 22, 2022). *Prisma Sains : Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram, 11*(2), 476-484. doi:https://doi.org/10.33394/j-ps.v11i2.7818

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INTRODUCTION

Indonesia, which is in the tropics, has a surplus of solar radiation through out the year, thereby increasing the potential for convective cloud growth. Cb clouds are thick convective clouds (deep convective) that can grow up to the tropopause layer which shows clouds that grow due to strong convection, deep convective, thunderstorm, or the like and have the potential to cause disasters that can cause economic losses and environmental damage. The transition period from the dry season to the rainy season or vice versa (September-October-November and March-April-May) has a significant potential for the growth of Cb clouds.

Hail is an extreme weather event because it is caused by anomalous conditions (weather anomalies), namely the fall of crystal grains or ice that has a small diameter to the earth's surface. Unlike normal rain, this hail is very dangerous, which can cause damage to property (roofs), aviation and even agriculture. Hail phenomenon is caused by the activity of convection clouds or the growth of convection cloud types (Cumulonimbus clouds).

Hail is defined as one of the extreme weather events, based on BMKG Head Regulation Number 9 of 2010 concerning Procedures for Implementing Early Warning. Hail or hail is a type of precipitation in the form of irregular ice cubes with a diameter of 5 mm originating from convective clouds, usually from cumulonimbus clouds (Tjasyono, 2004). According to Fadholi (2012), hail originates from single-layered or layered cumulonimbus clouds near the earth's surface, or multicellular cumulonimbus clouds with an area of about 3-5 km, growing vertically, and a height of 30,000 feet or more.

The SATAID application is an application developed by the Japan Meteorological Agency (JMA) Satellite Meteorological Center (SMC) to analyze satellite imagery to obtain cloud top temperatures. While the GRADS application is used to process data to find the atmospheric stability index CAPE, K and TT.

Research on the analysis of hail events has been carried out several times for the Indonesian region, including Aries Kristianto (2018) who concluded that in determining the freezing level and altitude at -20 ºC to detect the potential for hail, the best data source to use is weather satellites.

This research was conducted to determine the relationship between correlation and regression of cloud top temperature on atmospheric stability values at the CAPE, K and TT indices. So that it can be used in estimating predictions of the possibility of bad weather by looking at the trend of changes in cloud top temperature values.

Theory and Calculation

Hail

Hail is a form of precipitation in the form of balls, pieces, or ice flakes caused by a very strong convective system with a diameter of 5-55 mm or larger in extreme conditions (Fadholi, 2012). Hail will only form in Cumulonimbus (Cb) clouds whose cloud height is past the freezing level (the altitude where the air temperature is 0°C or around 16,000 feet in Indonesian territory) (Karmini, 2000).

Satellite Animation and Interactive Diagnosis

The Satellite Animation and Interactive Diagnosis (SATAID) application is an application with remote sensing techniques used to analyze satellite images with some of the tools provided and developed by the Satellite Meteorological Center (SMC) Japan Meteorological Agency (JMA) which can also be used to monitor an events or situations in real-time. (Prasetyo, et al. 2018)

Grid Analysis and Display System

The Grid Analysis and Display System (GRADS) is an interactive software used for easily manipulating and visualizing earth science data, displaying it in graphical form such as line graphs, bar graphs, contour graphs, shaded contour graphs, wind vectors, or streamlines, grid-shaped data and data from observation stations. To process GRD files with the GRADS application, a control file is needed that explains the format and layout of the binary file so that GRADS can recognize and read it. The control file contains information about the address (path) of the binary file, the binary format type, the horizontal size of the file (latitude, longitude, start, interval), the vertical size of the file (what is the height level), the temporal size of the file (time interval and when the start time), variable number and variable name.

METHOD

The case study chosen in this research is the the City of Binjai on May 22, 2022. The study area is limited by the coordinates 3.31°N-3.40°N and 98.27°E-98.32°E.The data used in this study are as follows:

1) CAPE, KI and TT data on 22 May 2023 at 00.00-24.00 UTC downloaded on the Copernicus ECMWF website (https://cds.climate.copernicus.eu/);
2) Image data for the Himawari-8 Satellite from 00.00 UTC to 23.50 UTC on 22 May 2022 through limited access to the BMKG server via the filezilla software; and
3) The supporting data is in the form of sea surface temperature and wind data which are also downloaded on the BMKG website (https:bmkg.go.id) and B.O.M website (http://www.bom.gov.au) used as a basic analysis of meteorological conditions at the location and time of occurrence.

The research step begins with collecting all the data used. The 5th era reanalysis model data downloaded in binary data format is then extracted into txt format data using Grid Analysis and Display System (GRADS) for further pre-processing using excell by sorting the data according to the specified time. Then for the JMA model data with the gs format, the lability index data extraction process is carried out through the NWP scheme. The data that is processed later is a general atmospheric lability index value in the process of analyzing air stability for the causes of heavy rain events. These indices are the CAPE, KI and TTI indices.

CAPE index is an index that indicates the amount of buoyant energy available for an air parcel rising due to convective events (Skew-T Mastery, n.d.).

Table 1. CAPE index classification value

CAPE Value	Stability Condition
0	Stabil
0-1000	Slightly unstable
1000-2500	Pretty unstable
2500-3500	Very unstable
3500 or greater	Extremely unstable

K index is used to identify convective events and the potential for heavy rain. The K index uses air humidity and temperature parameters at pressure levels of 850, 700 and 500 mb. Then also use the dew point temperature parameter at the pressure level of 850 and 700 mb (Skew-T Mastery, n.d.).

Table 2. K index classification value

K	Storm Potential
< 20	Low Potential
> 35	High Potential

TT index is used to identify bad weather using temperature and dew point parameters at an altitude of 850 mb and temperature parameters at an altitude of 500 mb (Skew-T Mastery, n.d.).

Table 3. TT index classification value

TT	Stability Condition
44	Thunderstorm
50	Possible bad storm
>55	Bad storm

The index data obtained was regressed and correlated to time series cloud top temperature data with the SPSS Statistics software to see the relationship between the index values of the two products. Spearman's rank correlation is used to find relationships or test the level of associative significance when the variables used are non-parameter type data (Suharto, 2016). Spearman rank correlation uses the equation of Sugiyono (2019) with the interpretation as presented in Table 4.

Table 4. Spearman Rank Correlation Interpretation

Spearman Rank	Correlation
>0.70	Very Strong
0.40-0.69	Strong
0.30-0.39	Intermediate
0.20-0.29	Weak
0.01-0.19	No Correlation

The simple regression model equation is only possible if the influence is only from the independent variable (independent variable) on the dependent variable (independent variable). So the value of b is a function of the correlation coefficient. If the correlation coefficient is high, then the price of b is also large, conversely if the correlation coefficient is negative then the price of b is also negative, and vice versa if the correlation coefficient is positive then the price of b is also positive

RESULTS AND DISCUSSION

Analysis of General Conditions of the Atmospheric Sea Surface Temperature

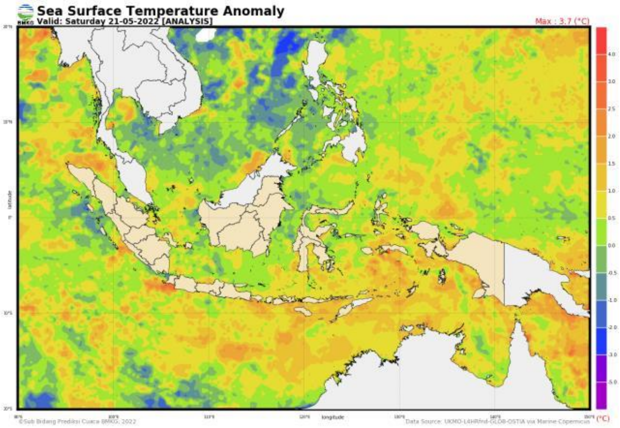

Figure 1. Map of West Indonesia's Sea Surface Temperature
(source: http://web.meteo.bmkg.go.id/id/pengamatan/sea-surface-temperature-analysis)

In Figure 1 it can be seen SST Anomaly values between – 0.5 to 2.0 °C in the region the waters west of Sumatra and the Straits of Malacca. That matter indicates the presence of a fairly high intake of water vapor from the territorial waters in particular that support growth of rain clouds.

Wind Conditions

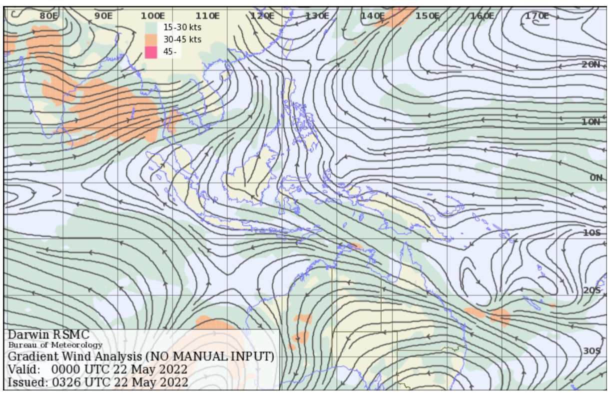

Figure 2. Wind Analysis on May 22, 2022 at 07.00 WIB (source: http://www.bom.gov.au/australia/charts/glw_00z.shtml)

In Figure 2 it is explained that there are weather disturbances in the form of wind bends and convergence in the East Coast region of North Sumatra, which trigger the formation of air convergence on the surface which accelerates the formation of convective clouds.

Cloud Top Temperature Analysis

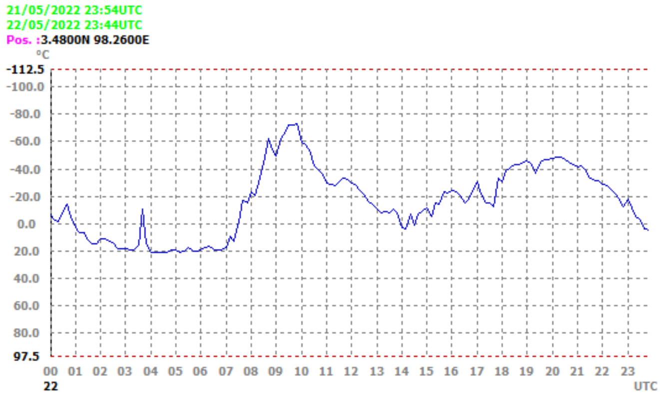

Figure 3. Cloud Top Temperature Analysis

Figure 3 shows the cloud top temperature during the hours 00-23 UTC. There are two phases with the lowest temperature. However, this discussion will focus in more detail on 08.00-10.00 UTC. During that time it has shows the phases of clouds growing, ripening, until they decay. At 08.00 UTC the temperature cloud top -22 ^{O}C. Then at 09.00 UTC it dropped dramatically to -50 ^{O}C. Low cloud top temperatures indicate that there are convective clouds or high clouds in the location. Furthermore, the lowest temperature was reached at 09.40 UTC which is -72 ^{O}C. At 10.00 UTC, the cloud top temperature starts to rise slowly but is still on the verge of being less than 0 degrees at 11 UTC to 14 UTC. The sudden decrease in cloud top temperature occurs at 17.40 UTC to 20.40 UTC and then increases again to 24 UTC.

Stability Index

CAPE Index

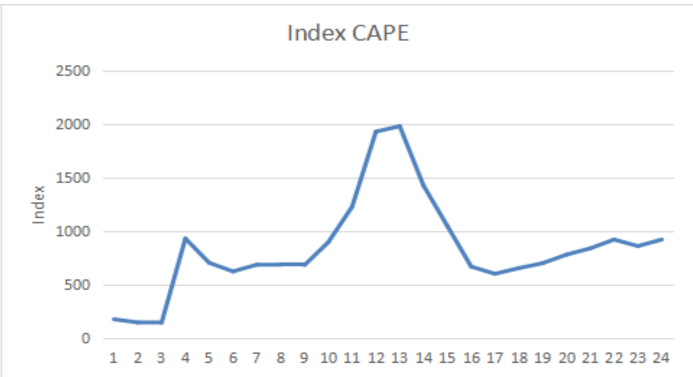

Figure 4. CAPE Index chart

In Figure 4, the CAPE value pattern shows a significant increase in value at 09 UTC to 13 UTC and a decrease at 21 UTC to 24 UTC. The interpretation of the CAPE index values according to table 1 shows that conditions were quite unstable from 11 UTC with a value of around 1231 J/kg and quite stable at more than 1000 J/kg up to 15Z.

K Index

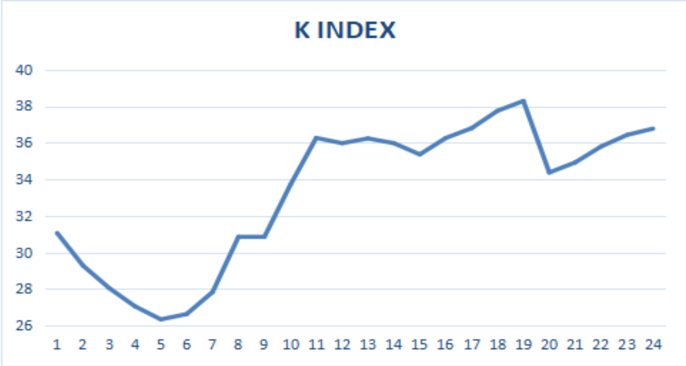

Figure 5. K Index chart

In Figure 5 shows that the value of the K index varies more with an increase at 08Z then decreases at 19Z and rises again at 22Z ending with a decrease in the value of the K index at 24Z.

TT Index

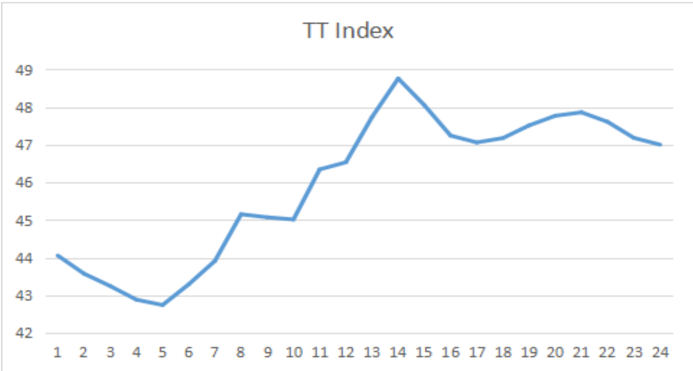

Figure 6. TT Index chart

In Figure 6 shows the TT index value varying from 42.7 to 48.7 and is interpreted according to table 3 with a threshold value of more than 44 which indicates the potential for an unstable thunderstorm event.

Cloud Tops Temperature and CAPE Regression

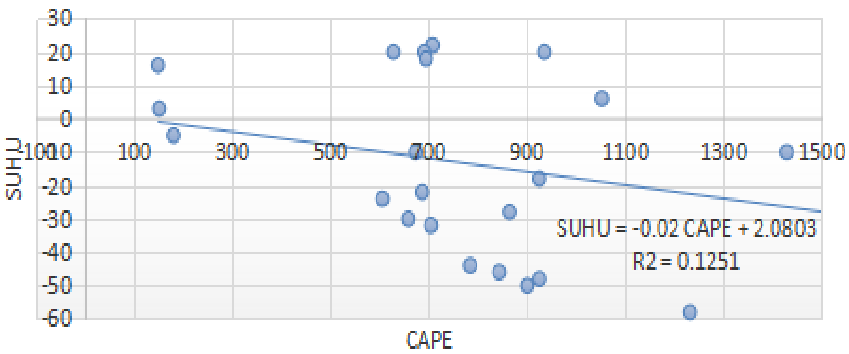

Figure 7. Cloud Tops Temperature and CAPE Regression

Table 5. Correlation of Cloud Tops Temperature and CAPE

Model		Unstand. Coeff.		Stand. Coeff.		
		B	Std. Error	Beta	t	Sig.
1	(constant)	2.080	10.772		.193	.849
	CAPE	-.020	.011	-.354	-1.773	.090

Table 6. Model Summary

Model	R	R Sqr.	Adj. R Sqr.	Std. Error of Estimate	Change statistic				
					R Sqr. change	F change	Df1	Df2	Sig
1	.354	.125	.085	24.53257	.125	3.145	1	22	.090

In Figure 7 show cloud top temperature data is regressed with the first stability index data, namely the CAPE Index. The equation obtained at the time of the incident is Cloud Tops Temperature = (-0.20) CAPE + 2.0803 with the regression line having a negative gradient pattern. The R-sq results are also shown to be at a fairly high number of up to 12.5 % which indicates changes in cloud top temperature are affected by up to 12.5 % by changes in the CAPE index and the rest by other unexpected factors.

Cloud Tops Temperature and K Index Regression

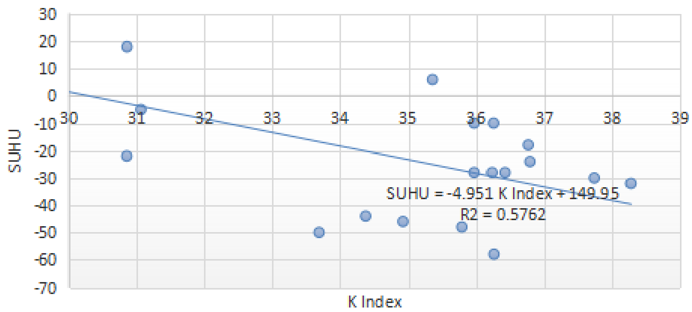

Figure 8. Cloud Tops Temperature and K Index Regression

Table 7. Correlation of Cloud Tops Temperature and K Index

	Model	Unstand. Coeff.		Stand. Coeff.		
		B	Std. Error	Beta	t	Sig.
1	(constant)	149.95	30.329		4.944	.000
	K index	-4.951	.905	-.759	-5.469	.000

Table 8. Model Summary

Model	R	R Sqr.	Adj. R Sqr.	Std. Error of Estimate	Change statistic				
					R Sqr. change	F change	Df1	Df2	Sig
1	.759	.576	.557	17.07361	.576	29.914	1	22	.000

In Figure 8 show cloud top temperature data is regressed with K Index. The equation obtained at the time of the incident is Cloud Tops Temperature = (-4.95) K Index + 149.950 with the regression line having a negative gradient pattern. The R-sq results are also shown to be at a fairly high number of up to 57.6 % which indicates changes in cloud top temperature are affected by up to 57.6 % by changes in the K Index and the rest by other unexpected factors.

Cloud Tops Temperature and TT Index Regression

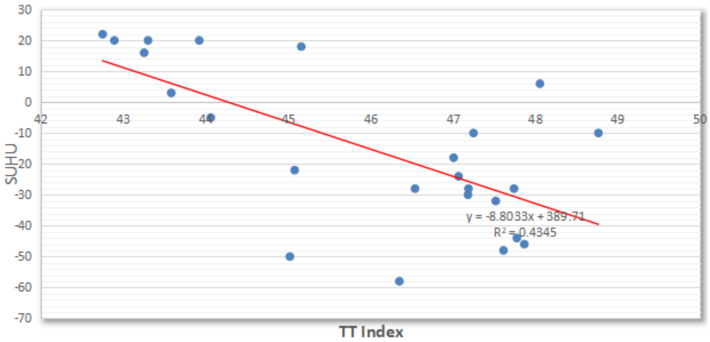

Figure 9. Cloud Tops Temperature and TT Index Regression

Table 9. Correlation of Cloud Tops Temperature and TT Index

	Model	Unstand. Coeff.		Stand. Coeff.		
		B	Std. Error	Beta	t	Sig.
1	(constant)	389.707	98.467		3.958	.001
	TT index	-8.803	2.141	-.659	-4.112	.000

Table 10. Model Summary

Model	R	R Sqr.	Adj. R Sqr.	Std. Error of Estimate	Change statistic				
					R Sqr. change	F change	Df1	Df2	Sig
1	.659	.435	.409	19.72214	.435	16.907	1	22	.000

In Figure 9 show cloud top temperature data is regressed with TT Index. The equation obtained at the time of the incident is Cloud Tops Temperature = (-8.803) K Index + 389.707with the regression line having a negative gradient pattern. The R-sq results are also shown to be at a fairly high number of up to 43.5 % which indicates changes in cloud top temperature are affected by up to 43.5 % by changes in the TT Index and the rest by other unexpected factors.

Stability Index Correlation

Table 11. The results of Spearman's rank correlation analysis on cloud top temperature and CAPE, KI and TTI Atmospheric Stability Index data

			CAPE index	cloud top temp.
Spearman's rho	CAPE index	Correlation Coeff.	1.000	-.348
		Sig. (2-tailed)	.000	.096
		N	24	24
	cloud top temp.	Correlation Coeff.	-.348	1.000
		Sig. (2-tailed)	.096	.000
		N	24	24
			K index	cloud top temp.
Spearman's rho	K index	Correlation Coeff.	1.000	-.651
		Sig. (2-tailed)	.000	.001
		N	24	24
	cloud top temp.	Correlation Coeff.	-.651	1.000
		Sig. (2-tailed)	.001	.000
		N	24	24
			TT index	cloud top temp.
Spearman's rho	TT index	Correlation Coeff.	1.000	-.563
		Sig. (2-tailed)	.000	.004
		N	24	24
	cloud top temp.	Correlation Coeff.	-.563	1.000
		Sig. (2-tailed)	.004	.000
		N	24	24

After the regression test, Spearman's rank correlation analysis was carried out on all research data variables, namely cloud top temperature and CAPE, KI and TTI Atmospheric Stability Index data. The correlation result is negative, meaning that the increase in the stability index is in line with the decrease in cloud top temperature. In particular, the best correlation values are the K index and the TT index. The result of the correlation between the K index and the cloud top temperature is -0.651 and the result of the correlation between the TT index and the cloud top temperature is -0.563. Both can be interpreted as a result with a very strong relationship. The lowest correlation results are found in the CAPE index with a result of -0.348 although it still shows the interpretation of the value of a strong relationship between cloud top temperature and changes in the CAPE index.

CONCLUSION

Spearman's rank correlation method and simple linear regression method were used to analyze the relationship between cloud top temperature and atmospheric stability index with the results showing individually, the K Index explains changes in cloud top temperature better than the TT index & CAPE index as well as changes in the increase in the aligned stability index value. with decreasing cloud top temperature. So that the stability index data can be used as a reference in estimating cloud top temperature in the case of a positive data trend or the growth stage of cumulonimbus clouds.

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