Analysis of the rainfall event in 2018-2019 using the air stability index method at the Meteorological Station of Sultan Iskandar Muda Banda Aceh

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Abstract. The purpose of the present research is to determine the forecast of rain events with good results and can provide information on rain events to be right on target. In this study, an analysis of rainfall events in 2018 and 2019 was carried out using rainfall and radiosonde data at the Meteorological Station of Sultan Iskandar Muda Banda Aceh. The analysis used with the atmospheric stability index method, which was taken by Radiosonde data, obtained information on atmospheric parameters such as temperature, dew point, pressure, and wind. This parameter can be used to predict rain events using the air stability index, where the indices used are Showalter Index (SI), Lifted Index (LI), CAPE, Total-Total Index (TT), K-Index, Severe Weather Threat Index (SWEAT). From the results of the stability indices verified by rainfall data observed by the Meteorological Station of Sultan Iskandar Muda. The results showed that the LI, SI, TT, and KI indices were good enough to predict rainfall, while the CAPE and SWEAT indices were still not good at predicting rainfall events. This information can then be used as a basic reference which is quite good to use through the upper air stability index approach in develop the rainfall forecast value.

1. Introduction
Rain is liquid precipitation that falls from the atmosphere to the earth's surface. Rain events originate from water vapor in the atmosphere, so that their shape and quantity is influenced by climatological factors such as wind, temperature and atmospheric pressure. The process of the occurrence of rain requires condensation points and it can occur when the ambient temperature is almost the same as the dew point temperature. According to Ref. [1], condensation points are formed when warm and humid air rises in conditionally unstable environmental conditions, namely where cold and dry air overlaps warm and humid surface air. One way to predict rain events is through analysis of upper air conditions from the results of sounding data. From recorded sounding data, it can produce atmospheric lability indices, one of which is to predict rain events. An understanding of atmospheric stability makes it possible to see the tendency of the vertical motion of an air mass in the atmosphere. Unstable air allows clouds to form. Especially for clouds that have a striking vertical size and which usually cause bad weather but sunny weather without clouds is a result of stable air. The main factor for atmospheric stability is the relationship between temperature and altitude. The degree to which the temperature varies with altitude is called the time-lapse rate. The level of the hose has a significant effect on the vertical motion of air [2]. According to Ref. [3] explains that the processes that take place in the Atmospheric...
Boundary Layer such as the exchange of momentum, heat, water and the rest of the chemical processes between the earth's surface and the free troposphere are often used as parameters in atmospheric models. Understanding the atmosphere dynamics in the Indonesian region is needed to better understand weather and climate processes. So that atmospheric stability plays an important role in atmospheric dynamics for building and producing complex weather systems [4]. Stability index has been used for cases of heavy rain events in several studies as conducted [5–8]. Analysis of atmospheric conditions before the occurrence of rain can be seen by observing the upper air conditions [8]. The indices used for predicting rain include Showalter Index (SI), Lifted Index (LI), CAPE, Total Index (TT), K-Index, Severe Weather Threat Index (SWEAT). The index values can be directly determined by processing the sounding data using RAOB (Rawinsonde Observation) software. Atmospheric stability refers to the ability of turbulence in the atmosphere which can be determined from radiosonde observation data, namely the parameters of temperature, pressure, humidity, and wind [9].

The impact of rain events can have negative things such as floods, landslides and can disrupt flight activities at airports, but it can also have a positive impact if we can use the rainfall information itself properly. When providing good and precise weather forecast information, we can minimize the incidence of floods and landslides and smooth flight activities at the airport. Therefore, the purpose of this research is to determine the probability value of forecasting rain events with good results and can provide an overview of rain event information so that the forecast becomes right on target using the air stability index value.

2. Methodology

The data used in this study came from intensive observations of the meteorological station of Sultan Iskandar Muda Banda Aceh (BMKG) during 2018 to 2019. The data consists of upper air observation data from the Radiosonde results of daily rainfall observation data. From the data above, the relationship is then searched based on the atmospheric stability index from the sounding data with the incidence of daily rainfall. The analysis used with the atmospheric stability index method, which was taken by Radiosonde data, obtained information on atmospheric parameters such as temperature, dew point, and wind speed. This parameter can be used to predict rain events using the air stability index. The stability index method is an algorithm designed to evaluate the atmospheric stability properties of sounding observations. This index describes the real state of stability and the limit value of the chance of convection, the chance and frequency of thunderstorms and bad weather in an area [10]. The stability index can have different effects for each region due to its geographic and topographic location. There are various types of indexes that can express atmospheric stability [6]. The stability index method used is Showalter Index (SI), Lifted Index (LI), CAPE, Total-Total Index (TT), K-Index, Severe Weather Threat Index (SWEAT).

2.1. Showalter Index (SI)

Showalter Index is an index used to characterize the instability of air in the middle troposphere, which is between the levels of 850 and 500 mb. The value of the index value is based on the amount of water vapor and energy contained in the 850 and 500 mb layers. The SI index is written in equation (1) [11].

\[ SI = T_{500} - T_x \]  

Where \( T_{500} \) is the ambient air temperature in the 500 hPa layer (in °C), and \( T_x \) is the temperature of the air parcel at the 500 hPa layer which undergoes a saturated adiabatic process (in °C). A negative index value indicates stability and a positive index value indicates instability.

2.2. Lifted Index (LI)

Lifted Index is a value obtained from the difference between the temperature of the air parcel which is raised adiabatically and the ambient air temperature in the 500 mb layer at a pressure height \( p \) in the troposphere. LI can be calculated by equation (2) [11].
\[ LI = T_{lp} - T_{gp} \]  

(2)

Where \( T_{lp} \) is the ambient air temperature in the 500 hPa layer (in °C) and \( T_{gp} \) is the temperature of the air parcel at the 500 hPa layer which undergoes a saturated adiabatic process (in °C).

2.3. Convective Available Potential Energy (CAPE)

CAPE is the total energy from the buoyancy force in the air column available to lift the air package. CAPE is directly related to the maximum potential vertical velocity in an updraft. So CAPE is good enough to mark the potential lability of the atmosphere. CAPE value is calculated by equation (3) [11].

\[ \text{CAPE} = \int_{z_f}^{z_n} g \left( \frac{T_{\text{parcel}} - T_{\text{env}}}{T_{\text{env}}} \right) dz \]  

(3)

Where \( z_f \) is the Level of Free Convection (LFC) layer in meters (m) and \( z_n \) is the equilibrium level in meters (m). \( T_{\text{parcel}} \) is the parcel air temperature (°C) and \( T_{\text{env}} \) is the ambient air temperature (°C). \( g \) is the earth’s gravity (m/s²) and \( dz \) is the difference in height (m).

2.4. Indeks K (KI)

The K index (KI) is a measure to predict the potential for thunderstorm clouds or Cumulonimbus clouds [12]. The K index measures the potential for thunderstorm events based on the shrinkage of the vertical temperature of the environment, the water vapor content contained in the lower layer, and the water vapor content that extends vertically. The KI value is calculated based on the layer temperature values of 850, 700, and 500 mb, and the dew point for layers of 850 and 700 mb. The higher the humidity and the greater the temperature difference from 850 - 500, the higher the KI and the potential for convection. In addition to predicting potential thunderstorm events, the K index value is also important for predicting heavy rain events [11]. The K index value is expressed by equation (4).

\[ KI = (T_{850} - T_{500}) + (T_{d850} - \Delta_{700}) \]  

(4)

Where \( T_{850} \) is the temperature at the level of 850 mb (°C) ; \( T_{d850} \) is the dew point temperature at the level of 850 mb (°C) ; \( \Delta_{700} \) is the difference between air temperature and dew point temperature at the level of 700 mb (°C).

2.5. Indeks Total-Totals (TT)

The Total-Totals Index is used to identify potential areas of thunderstorm development. Total Total is the sum of Vertical Total (VT) and Cross Total (CT). VT describes the rate of temperature shrinkage between two constant pressure surfaces, that is, the difference between the temperature at the layer of 850 and 500 mb. CT describes a combination of calculations between humidity in the lower layer and temperature, namely the difference between the dew point temperature of the layer 850 mb and the temperature in the layer 500 mb [11]. Equation TT index can be determined as in equation (5).

\[ TT = (T_{850} - T_{500}) + (T_{d850} - T_{500}) \]  

(5)

Where \( T_{850} \) is the air temperature measured by radiosonde at a height of 850 mb (°C) ; \( T_{500} \) is the air temperature measured by radiosonde at an altitude of 500 mb (°C); \( T_{d850} \) is the dew point temperature at an altitude of 850 mb (°C);
US Air Force as a combination of inconsistency, wind shear and wind speed. Equation of the SWEAT index is \[11\] in equation (6).

\[
SWEAT = 12(Td_{850}) + 20(TT - 49) + 2(f_{850}) + f_{500} + 125(sin\varphi + 0.2)
\]

(6)

Where \(Td_{850}\) is a dew point temperature at an altitude of 850 hPa; \(TT\) is the total value of the index; \(f_{850}\) is the wind speed in knots at an altitude of 850 hPa; \(f_{500}\) is the wind speed in knots at an altitude of 500 hPa; \(\varphi\) is the angle between the wind vector projection at the 500 hPa level and the 850 hPa level (\(dd_{500} - dd_{850}\)), which represents the wind shear value in the seam between 850 and 500 hPa. Studies on the air stability index have been done a lot of research, the new classification related to the index limit of rainfall events has also been widely studied. While the Stability Index Classification used in this study uses a basic index boundary using the source Aws/Tr-79/006 (1990). From the results of the boundary stability indices then validated and verified with the observed rainfall data. The evaluation step of data validation and verification is to assess how much accuracy it produces. Storm strength level criteria are used to validate the stability index against rainfall events \[13\]. The validation method used is the contingency/dichotomy method using a two-category contingency table. An example of a two-category contingency table is shown in Table 1.

| Prediction | Observation |
|------------|-------------|
|            | Yes | No | Total |
| Yes        | a   | b  | a + b |
| No         | c   | d  | c + d |
| Total      | a + c| b + d| a + b + c + d = n |

Information:
- a is hits (predicted to happen, and did happen)
- b is false alarm (predicted to happen, but it did not)
- c is misses (thought it didn’t happen, but it did)
- d is correct negative (presumably did not happen, and did not happen)

The results from the contingency table are used to calculate the accuracy level of the stability index in predicting rain events with equation (7).

\[
\text{Accuracy} = \frac{(a+d)}{n}
\]

(7)

Calculate the percentage of the lability index for rainy and non-rainy events using POD (Probability of Detection) for each number of columns with equation (8).

\[
\text{POD} = \frac{a}{(a+c)} \times 100\%
\]

(8)

Furthermore, analyzing the accuracy of the index value regarding the conditions of atmospheric stability, based on the results of the calculation of the accuracy of the atmospheric stability index associated with daily rainfall data.

3. Results

The analysis obtained includes analysis of the conditions of the characteristics of the rain event during 2018 - 2019 and analysis of the radiosonde index parameters to show the value of the stability index. Radiosonde index parameters that have been analysed include Showalter Index (SI), Lifted Index (LI), CAPE, Total-Total Index (TT), K-Index, Severe Weather Threat Index (SWEAT) related to rain events. Then each index value is analysed based on the accuracy of the rain event.
3.1. Rainfall Event
Figure 1 shows the conditions of rainfall in 2018 – 2019, for analysis rainfall showing the equatorial rain pattern. The results of this study for rainfall conditions at the study site showed an equatorial pattern. The equatorial rain pattern, whose territory has a bimodal monthly rainfall distribution with two maximum rainy season peaks and most of the year is included in the wet season criteria. The equatorial pattern is characterized by the type of rainfall with a bimodal form (two rain peaks) which usually occurs around beginning and end year or when there is an equinox. This concludes that rainy events throughout the year can be important things to observe so they are important to predict. Furthermore, it will show a how the relationship between atmospheric stability and the phenomenon of equatorial rain patterns.

![Figure 1. Rainfall Event 2018-2019](image)

3.2. Stability Index
The results of the study using the Stability Index method are summarized in valid and non-valid percentage values in a table. These results are shown in Table 2.

| Accuracy | SI | LI | KI | TT | CAPE | SWEAT |
|----------|----|----|----|----|------|-------|
| Valid    | 63%| 66%| 73%| 70%| 50%  | 52%   |
Table 2 shows the index stability value generated by radiosonde data during 2018 - 2019 that the percentage values of the KI and TT indices are the highest values in detecting rain events of 73% and 70%. For the percentage value of the CAPE and SWEAT indices it shows the lowest value of the index used to detect rain events by 50% and 52%. The percentage of valid values of approximately 50% is very poorly used in rainfall forecasts and the percentage of yellowish can be used more than 60%. The values for the LI, SI, TT and KI indices show valid values above 60% which can be said to be good enough to be used in predicting rainfall, while CAPE and SWEAT indices which show values below 60% are considered less good in predicting rainfall events.

In particular, the results of the percentage index value are valid in detecting rain events, it can be broken down into light rainfall forecasts and heavy rainfall. Figure 2 shows that the SI index displays the highest valid value for heavy rain events of 40%, while the CAPE index is the lowest percentage for heavy rain events of 3%. The SI index shows a fairly high percentage of rain forecasts compared to others while other indices are much lower in detecting heavy rainfall. In contrast to the case of heavy rain events, the forecast value for heavy rain conditions is very low in the forecast. This can be seen in the percentage values in dark blue in the pie chart for each stability index in Figure 2. This value is quite far when compared to the predicted value of rain events as a whole, namely the percentage of the number of potential rain events in blue and dark blue.
Figure 2. Percentage of valid values for rainfall forecasts with heavy rainfall forecasts and non valid for not raining forecasts during the events of 2018 - 2019.

Conclusions
The results of radiosonde sounding shows that the SI, LI, KI and TT indices are good enough to predict rainfall, while the CAPE and SWEAT indices are still not good at predicting rainfall events. In the case of extreme rainfall forecasts, each of them shows a fairly low probability value, so that in predicting extreme rainfall, further research can be carried out which can provide a better picture of extreme rainfall in the future. From the two information above, it can be seen that the stability index can have different effects for each region due to geographic location and topography. Atmospheric stability index at the boundary of each area also varies based on time. The diurnal index value over time of day and night also greatly affects changes in the stability of the atmosphere of a location due to the warming of the air temperature by the sun. Radiosonde measurements are strongly influenced by weather parameters, namely air pressure, ambient temperature, relative humidity (RH), wind direction and speed. The rate at which temperature varies with altitude is called the lapse rate which has a significant effect on the vertical motion of air [3]. The Lapse rate value then affects the atmospheric stability conditions so that various types of atmospheric stability index parameters are obtained in the weather forecast. Weather parameter information can be used as a basic reference which is quite good to use through the upper air
stability index approach in strengthening the value of rainfall forecasts. Particularly for the possibility of extreme rain, for future research, we can focus closer to the rainfall in a shorter period of time in a matter of hours or expand the area spatially by comparing the stability values and rainfall index of each location.

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