

Predicting the formation of tornadoes using association rule mining by studying a real life tornado event : Georgia, USA January, 2013

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सार – निचले वातावरण में मौजूद अस्थिरता और विंड शीयर के कारण हिंसक गरज के साथ बवंडर बनते हैं। एक बवंडर की कटाई अस्थिर हवा के कारण होने वाले अपड्राफ्ट और डोंवड्राफ्ट का परिणाम है। बवंडर कैसे और क्यों बनते हैं, इसका रहस्य संतोषजनक व्याख्या से कोसों दूर है। इस पत्र में, जनवरी, 2013 में जॉर्जिया, संयुक्त राज्य अमेरिका में हुई वास्तविक समय बवंडर घटना से डेटा निकाला गया है। फिर बवंडर लाने के लिए जिम्मेदार प्रत्येक चर पर गहन विश्लेषण किया गया है और अंत में एसोसिएशन नियम खनन को सभी के बीच सहयोग खोजने के लिए लागू किया गया है। वे मौसम चर। हमारे अध्ययन ने गैर-तूफान और तूफानी मौसम की स्थिति की भविष्यवाणी करने के लिए दिलचस्प नियम तैयार किए।

ABSTRACT. Tornadoes form in violent thunderstorms due to instability and wind shear present in the lower atmosphere. The spinning of a tornado is the result of the updrafts and downdrafts caused due to unstable air. The mystery that how and why tornadoes are formed are far away from a satisfactory explanation. In this paper, data is extracted from real time tornado event occurred at Georgia, USA in January, 2013. Then in-depth analysis has been done on each variable responsible to bring tornado and finally association rule mining has been applied to find association among all those weather variables. Our study produced interesting rules to predict non tornadic and tornadic weather conditions.

Key words – Association rule mining, Apriori algorithm, Downdraft, Fuzzy logic, Vorticity, Updraft, Wind Shear.

1. Introduction

Formation of Tornado is so complex that scientists have yet to understand it. So, in this paper an attempt has made to understand the formation of tornado by first analyzing each weather attribute and then applying data mining to find association among all those attributes. For this purpose, only important weather elements are analyzed and processed. A real time tornado event is analyzed and experimental results are shown. In Georgia, USA from 29 January to 30 January 2013, a total of 65 tornadoes was confirmed making it the fourth largest winter outbreak.

Confirmed tornadoes by Enhanced Fujita rating retrieved from NOAA (2003, Jan)

EFU	EF0	EF1	EF2	EF3	EF4	EF5	Total
0	28	26	10	1	0	0	65

Wind speed, windshear (Vorticity), instability and lifting are the most important ingredients for a tornado to occur. In this paper, each ingredient is covered separately and in-depth analysis is performed. After analyzing these ingredients, association has been found among them by applying association rule mining. For association rule mining from the given dataset, we use predictive Apriori algorithm for finding the hidden relationship between various atmospheric parameters. By using predictive Apriori algorithm the association rules are generated on weather data set with support and confidence threshold values.

2. Literature review

Association rule mining had been applied in different research areas like prediction in stock market by V. Argiddi and S. Apte, 2013, analysis of the customer behaviour in retail or super store by Raj and Gupta, 2012, correlation among diseases for patients in health care by

Rashid *et al.*, 2010, video semantic concept detection framework by Hu and Yang, 2010, crime detection by Ubon Thongsatpornwatana 2014, the spatial autocorrelation by Chen, 2008 and weather forecasting by Pappula and Javvaji, 2014.

Harun, *et al.*, 2017, have applied apriori algorithm in predicting flood areas. The results of the apriori algorithm produced best results and created associations among flood areas. The rules are generated with 100% confidence and 1.5 lift values.

Ranjan and Pani, 2015, have done a comparative study on association rule mining algorithm using weather dataset. They have compared apriori algorithm and filter association to produce association rules. The results have shown the apriori algorithm produced same number of rules as filter association but in less number of cycles.

Jin, 2015 has proved that fuzzy classification rules can be treated as a subset of fuzzy association rules. By applying the fuzzy association rule mining technique one can construct a fuzzy classifier from large datasets by choosing high quality rules from among all possible rules. In order to select high quality rules, a rule weight is needed to attach to each rule to indicate the significance of each rule.

S. Nandagopal *et al.*, 2010, have proposed modified apriori algorithm and applied the algorithm to single and multiple stations weather data. The test results show that with the extended inter-transactional association rules, more comprehensive and interesting association relationships can be found in meteorological data sets.

Dhanya and Kumar, 2009, applied fuzzy association rule mining to predict the summer monsoon rainfall of All-India. Fuzzy association rule helps in extracting the relation between the variables by overcoming the sharp boundary problem when mining association rules from quantitative data.

In Calargun and Yazici, 2008, fuzzy association rule mining is performed with spatial temporal data cubes using two different methods, namely association rule mining through data cubes and association rule mining through Apriori algorithm. Real meteorological data for Turkey recorded between 1970 and 2007 is analyzed using data cube and Apriori algorithm in order to generate fuzzy association rules. The association rules discovered using these algorithms are analyzed based on predefined metrics for association rules to guide data mining researches in this respect.

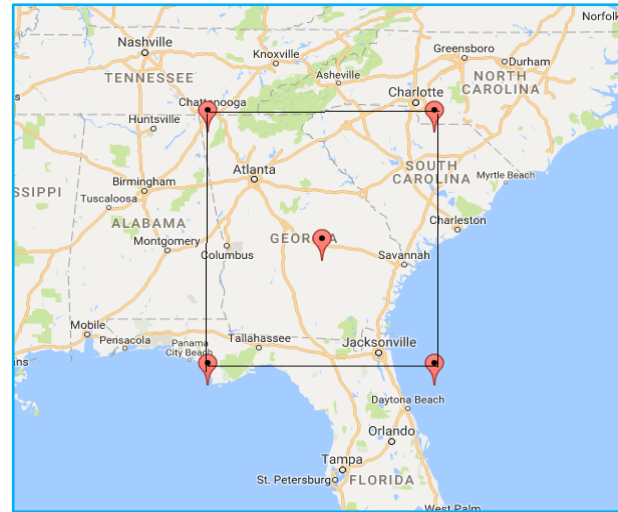


Fig. 1. Location Georgia, USA Grid Size 0.25×0.25 From 29.66° N , -85.40° W to 34.66° N , -80.40° W

3. Data extraction

With the courtesy of Indian Meteorological Department (IMD), forecasts made by NWP model for variables u wind component, v wind component and temperature have been considered for analysis. The Forecasts taken for analysis is as follows:

- (i) Forecast made on 0000 GMT 27th January, 2013 to 30th January 2013, valid for 0600 GMT 29th January to 30th January.
- (ii) Forecast made on 0000 GMT 27th January, 2013 to 30th January 2013, valid for 1200 GMT 29th January to 30th January.

In this paper a computational grid of 0.25×0.25 (latitude \times longitude) has been selected around Georgia, USA which is at 32.1656° N , 82.9001° W as shown in Fig. 1. Fundamental quantities of tornado formation like u wind component, v wind component, vertical velocity and temperature are extracted at 500 hPa, 600 hPa, 700 hPa, 800 hPa, 925 hPa and 1000 hPa levels. Derived attributes are wind speed, wind shear, temperature gradient, divergence and convergence, the important ingredients of Tornado formation McGovern *et al.*, 2007. By selecting these quantities at specific grid points has significantly reduced the dataset so that each variable can be examined at each grid point with great proficiency. All the fundamental quantities responsible for formation of tornado are analyzed. Datasets are analyzed for the development of temperature and wind flow patterns in the atmosphere that can cause instability, lift, and wind shear for tornadic thunderstorms.

TABLE 1

Sample data to show wind speed in the given dataset. From the following data its evident that wind speed has significantly increased at 500 hPa level and is of intensity of EF0, EF1 and EF2 scale

Enhanced Fujita Scale		Wind Speed m/s									
Scale		Wind Speed m/s									
EF0		29-37 m/s									
EF1		38-49 m/s									
EF2		60-60 m/s									
ISRL Level	LAT\ \LON	30	30.5	31	31.5	32	32.5	33	33.5	34	34.5
500	-85	35	35	35	40	40	50	50	50	40	40
	-84.5	30	35	35	35	40	50	50	50	50	40
	-84	30	30	35	35	35	40	50	50	50	50
	-83.5	30	30	35	35	35	35	40	40	50	50
	-83	25	30	30	35	35	35	35	40	40	50
	-82.5	25	25	30	30	35	35	35	35	40	40
	-82	25	25	30	30	30	35	35	35	35	35
	-81.5	25	25	25	30	30	35	35	35	35	35
	-81	20	25	25	25	30	30	35	35	35	35
	-80.5	20	25	25	25	30	30	30	30	35	35
600	-85	25	30	30	30	35	35	35	36	40	40
	-84.5	25	30	30	30	35	35	35	35	35	36
	-84	25	30	30	30	30	35	35	35	35	36
	-83.5	25	30	30	30	30	30	35	35	35	36
	-83	25	30	30	30	30	30	30	35	35	35
	-82.5	25	25	30	30	30	30	30	30	35	35
	-82	25	25	25	30	30	30	30	30	32	35
	-81.5	25	25	25	25	30	30	30	30	31	35
	-81	20	25	25	25	25	30	30	30	30	35
	-80.5	20	20	25	25	25	25	30	30	30	35

4. Technique applied

Wind Speed, wind shear, velocity and temperature are analyzed and instability in the atmosphere is calculated based on these attributes. For Association Rule mining from the data sets Apriori algorithm is used for finding hidden relationship among weather attributes. By using Apriori algorithm the association rules are generated with support and confidence threshold values. Finally, Fuzzy rules are generated to estimate the weather conditions favorable for tornadoes.

4.1. Analysis of wind speed and wind shear

The important ingredient in the formation of a tornado is the speed of the wind over a given distance. For tornadoes to develop significant increase in wind with height is important. Wind speed and damage caused by the wind is measured by Enhanced Fujita Scale. The Enhanced Fujita scale (EF-Scale) rates the intensity of tornadoes based on the damage they cause. Implemented in place of the Fujita scale introduced in 1971 by Tetsuya Theodore Fujita, it began operational use in the United States on February 1, 2007, followed by Canada on April 1, 2013, as explained online on Tornado Facts and Information. The sample from given dataset is shown in Table 1, which clearly shows that wind speed has increased significantly at 500 hPa level.

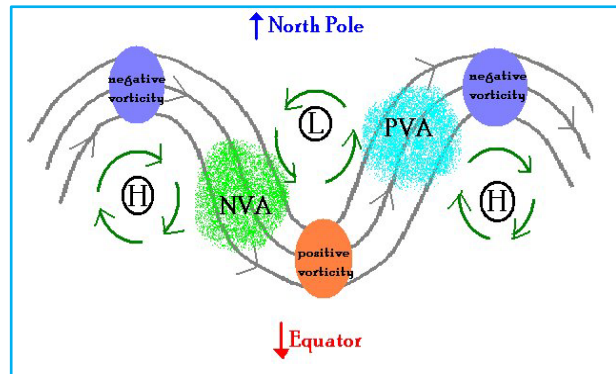


Fig. 2. positive vorticity advection and negative vorticity advection

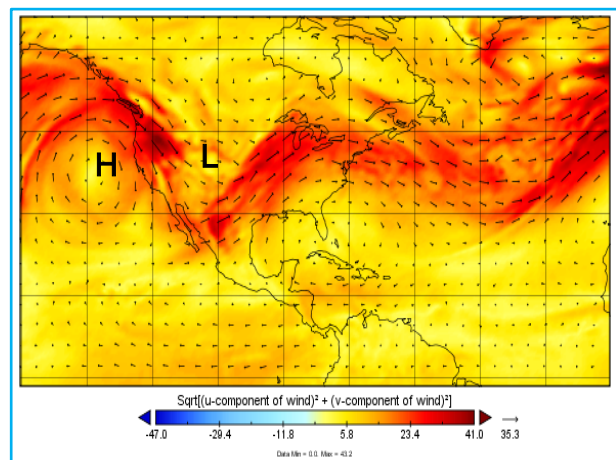


Fig.3. The winds at 500 hPa level on 30 January 2013 at 1200GMT. The winds in the northern hemisphere becomes cyclonic forming convergence and low pressure and high-pressure areas are developed, denoted by H and L

The next important ingredient of tornado formation is wind shear which is the change in wind speed with height. In the graph above, the wind is increasing with height. Such increase in wind speed tends to create a rolling affect to the atmosphere and is the key component in the formation of mesocyclones which can lead to tornadoes. This results in positive vorticity advection (PVA) and negative vorticity advection (NVA) as shown in Fig. 2. When there is positive vorticity advection the air spins fast and divergence occurs. When there is negative vorticity advection, the air spins slowly and convergence ensues. Almost similar pattern is visible from the forecast data taken for analysis as shown in Fig. 3. Figure clearly indicates strong directional wind shear over the lower atmosphere, an important component for tornado development.

4.2. Analysis of convergence or divergence patterns

The concept of convergence and divergence is very important in forecasting tornadoes. With the wind shear in

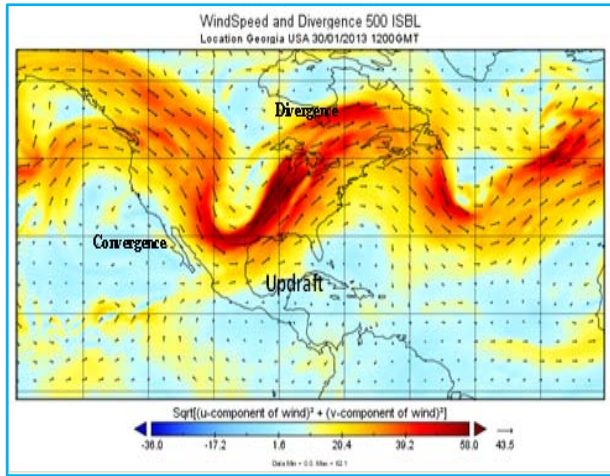


Fig. 4. Clear indication of divergence/convergence and a strong updraft

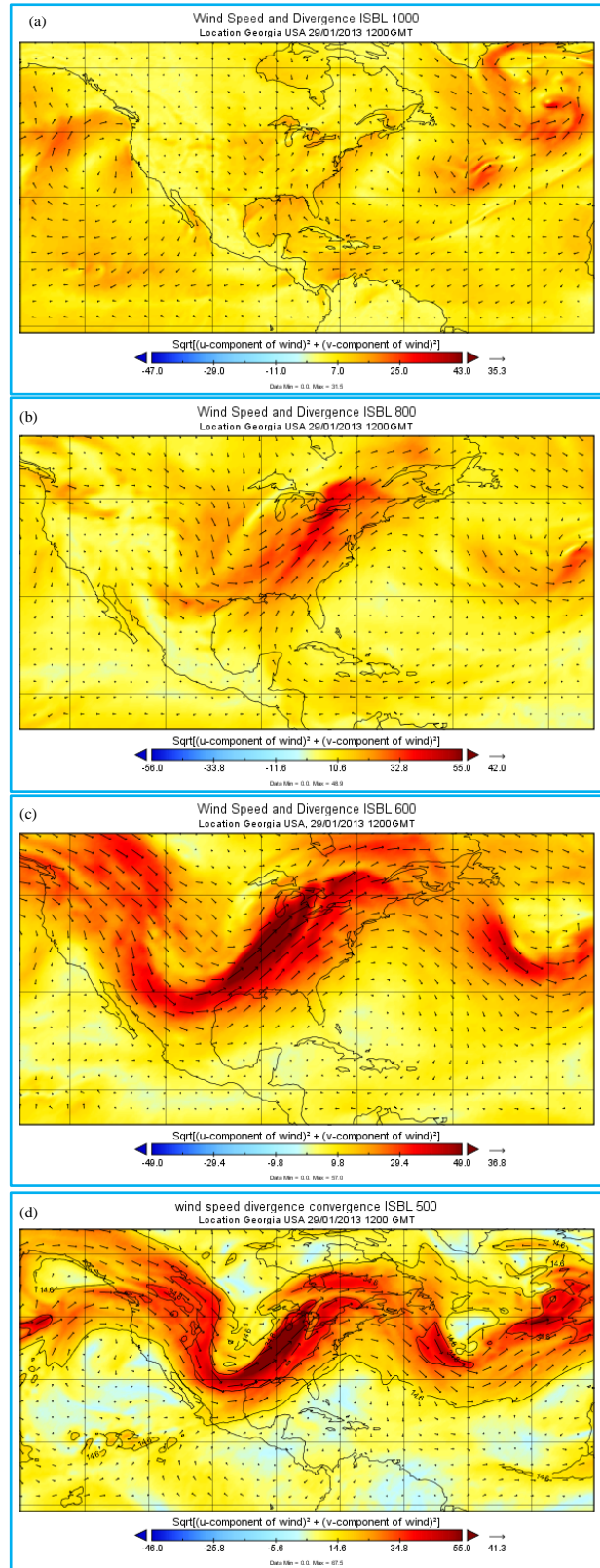
TABLE 2

Summary of convergence/divergence on all the four days from 27th of January, 2013 to 30th January, 2013 at different hPa levels. Values in red are convergence and green is divergence

ISBL Level	1/27/2013	1/28/2013	1/29/2013	1/30/2013
500	-3.825E-07	-0.000000355	-0.00000027	-6.26667E-07
600	-0.0000003	-0.000000305	-0.000000285	-0.00000048
700	-2.025E-07	-2.425E-07	-0.000000225	-0.0000005
800	-2.925E-07	-2.375E-07	-0.000000175	-0.00000051
925	-0.00000014	-1.225E-07	-0.000000145	-3.23333E-07
1000	0.000000235	0.00000021	0.000000222	2.5E-08

place there has to be a force which cause the wind to move towards the upward direction to develop a supercell. For this forecast variables are analyzed to find convergence and divergence at different levels of the atmosphere near the selected region.

Convergence is sinking of the air and is associated with clouds and precipitation therefore it indicates bad weather. Divergence is rising air and is associated with clear, calm conditions and indicates good weather. Fig. 4 gives a sample of gridded data output using NCL. (The NCAR Command Language (NCL), a product of the Computational & Information Systems Laboratory at the National Center for Atmospheric Research (NCAR) and sponsored by the National Science Foundation, is a free interpreted language designed specifically for scientific data processing and visualization. The top panels which show both convergence and divergence at different



Figs. 5(a-d). Location Georgia, USA, 29 January, 2013. 1200 GMT Wind Speed and Divergence ISBL (a) 1000, (b) 800 (c) 600 and (d) 500

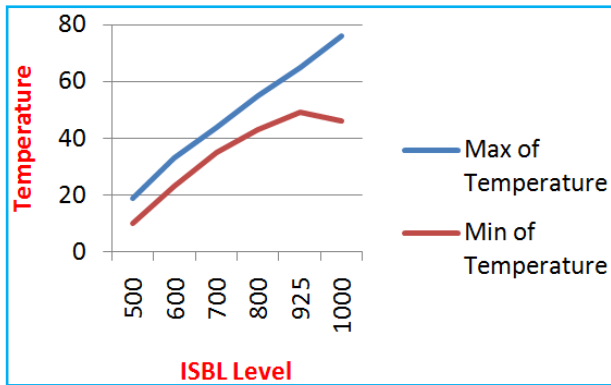


Fig. 6. Maximum and minimum of temperature Georgia from 27-30 January, 2013

atmosphere levels are selected as samples. The opposite of divergence in normal conversation is convergence. Mathematically, there is no separate definition for convergence, we call it “convergence” if the value of the divergence is negative as explained in R. Holton, 2004. Table 2 shows the sample data output for convergence and divergence of the wind at different atmospheric levels.

The comparison of wind speed and convergence at different atmospheric levels are shown in the following panels [Figs. 5(a-d)]. It is clear that wind speed increases as we move up from 1000 hPa to 500 hPa.

4.3. Analysis of temperature

Thunderstorms develop when warm, humid air near the surface lies beneath a thick layer of air in which the temperature decreases rapidly with height. We call this type of atmosphere “unstable”, meaning that when air is nudged upward, the water vapor that it contains condenses. The weather data shows that In Atlanta, Georgia the month of January is characterized by essentially constant daily high temperatures, with daily highs around 53° F throughout the month, rarely exceeding 66° F and low temperatures are around 36° F, rarely falling below 22° F as specified in Weather spark. But the forecast datasets have shown different picture of the atmosphere from 27th January to 30th January, 2013. The temperature data shows minimum temperature as 10° F and maximum as 76° F as shown in the Fig. 6.

4.4. Calculating instability in the atmosphere

Instability refers to unusually warm and humid conditions in the lower atmosphere and possibly cooler than usual conditions in the upper atmosphere. This instability can be responsible for severe weather events, such as tornadoes and tropical cyclones as proved in

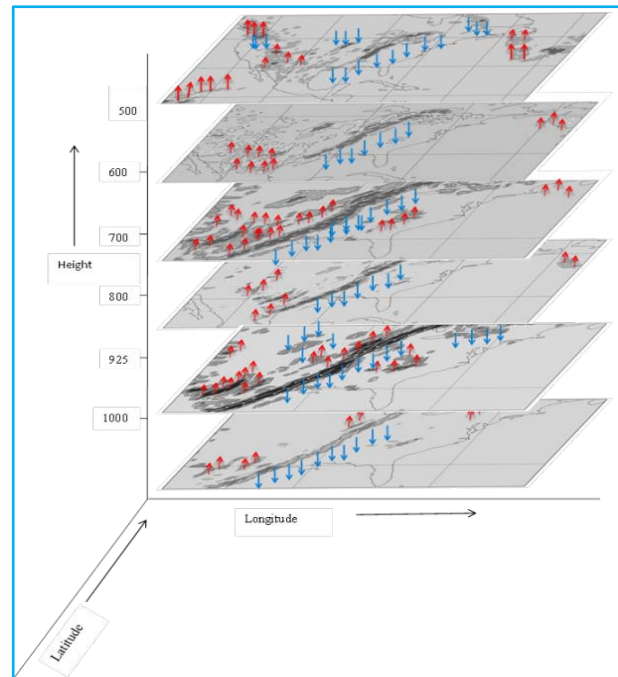


Fig.7. Forecast on 30 January, 2013 for Updraft and Downdraft Location Georgia 32.1656° N, 82.9001° W
Blue : negative velocity (Updraft)
Red : Positive velocity (Downdraft)

Edwards, R., 2012. The forecast dataset shows that temperature increases significantly in the lower atmosphere and decreases to its minimum in upper atmosphere thus causing severe instability in the atmosphere. Temperature decreases as we move up in the atmosphere minimum temperature noted is at 500 hPa and Maximum at 1000 hPa.

Another important component to find instability in the atmosphere is vertical velocity. Vertical velocity is the rate of change of pressure with time. A negative value implies ascending air (updraft) and a positive value implies descending air (downdraft). A classic supercell in its mature stage consists of a rotating updraft (mid-altitude mesocyclone) and a downdraft that coexists symbiotically with the updraft in an almost steady state as defined in Davies and Jones, 2015. The comparison of vertical velocity is shown in Fig. 7 at different atmospheric levels. It is evident from the panels that at higher levels vertical velocity becomes negative and there is clear updraft from 1000 to 500 ISBL level. The atmosphere instability thus calculated as shown in the Table 3.

Thus, the analysis of all the components have shown that the temperature instability, vertical velocity and wind speed observed during the given period, are favourable for tornado occurrences at Gerogia, USA.

TABLE 3

Atmoshere Instability

#Rule	Condition	ISBL Level	Instability
1	If temperature <20 and vertical velocity <0	500-600	Severe
2	If temperature >20 & <39 and vertical Velocity <0	500-600	High
3.	If temperature >66 and vertical velocity >0	925-1000	High
4.	If temperature >66 and vertical velocity <0	925-1000	Severe

TABLE 4

Rules generated by applying association rule mining

#	Rule	Conf.
1	WindSpeedm/s='(>45.9)' ISBL Level='(500-550)' ==> Atmosphere Instability= Severe	1
2	WindSpeed m/s='(>45.9)' Vertical Velocity='(-1.1)' ISBL Level='(500-550)' ==> Atmosphere Instability= Severe	1
3	WindSpeedm/s='(>45.9)' ISBL Level='(500-550)' Temperature='(0-13.7)' ==> Atmosphere Instability= Severe	1
4	WindSpeed m/s='(>45.9)' Temperature='(0-13.7)' Vertical Velocity='(-1.1)' ISBL Level='(500-550)' ==> Atmosphere Instability= Severe	1
5	WindSpeedm/s='(>45.9)' ISBL Level='(500-550)' Temperature='(0-13.7)' Vertical Velocity='(-1.1)' ==> Atmosphere Instability= Severe	1
6	Temperature='(0-13.7)' Vertical Velocity='(-1.1)' ==> Atmosphere Instability= Severe	1
7	ISBL Level='(500-550)' Temperature='(0-13.7)' ==> Atmosphere Instability= Severe	1
8	WindSpeed m/s='(29.5-33.6)' ISBL Level='(550-600)' ==> Atmosphere Instability= High	1
9	WindSpeed m/s='(29.5-33.6)' ISBL Level='(550-600)' Vertical Velocity='(-1.1)' ==> Atmosphere Instability= High	1
10	ISBL Level='(550-600)' Temperature='(27.2-29.9)' ==> Atmosphere Instability= High	1
11	ISBL Level='(550-600)' Temperature='(27.2-29.9)' Vertical Velocity='(-1.1)' ==> Atmosphere Instability= High	1
12	WindSpeed m/s='(33.6-37.7)' ISBL Level='(550-600)' ==> Atmosphere Instability= High	1

TABLE 5

Fuzzy IF-Then Rules

IF	Then Tornado Occurrence	Confidence [0-10] Lowest to Highest
Instability is Stable and Wind_Speed is Low and Divergence is Smooth	No	10
Instability is High and Wind_Speed is Medium and Divergence is Divergence	May Be	10
Instability is Severe and Wind_Speed is High and Divergence is Convergence	Yes	10
Instability is Severe and Wind_Speed is High and Divergence is Divergence	No	6
Instability is Stable and Wind_Speed is High and Divergence is Convergence	May be	6
Instability is Severe and Wind_Speed is Medium and Divergence is Convergence	May Be	7

4.5. Association rule mining

After analyzing each output in depth, apriori algorithm of Association Rule Mining has been applied to find association among all these variables. The apriori algorithm is very effective to find frequent patterns and their relationships. The interestingness of the rules is based on minimum support and confidence specified by the user. Only those association rules are considered as interesting if their support and confidence are greater than the minimum support and confidence threshold values. For finding interesting rules, threshold for support is set at 0.2 and confidence is 0.9 at the scale of 0 to 10. Association Rule Mining has generated interesting rules among all the variables as shown in Table 4. Only rules for maximum confidence and instability as 'Severe' or 'High' are selected for illustration purpose.

From the above table, Fuzzy rules algorithm has been applied and following rules have been generated. A fuzzy IF-THEN rule associates a condition described using linguistic variables and fuzzy sets to an output or a conclusion. The Analysis shows that wind speed, instability and divergence play a major role in formation

of Tornadoes. It is also evident that percentage and range of these attributes define the occurrence of tornadoes. Based on association among all attributes, rules have been generated as shown in Table 5. Although several different conditions are required for the tornado formation but these rules are generated for this particular event and can be tested on other real-life events.

5. Conclusions and future work

The objective of the research work is to develop better prediction of the formation of tornadoes by applying association rule mining and fuzzy association rules. We have applied Association Rule Mining to find association among various weather variables responsible for the tornado formation. For association rules mining from the given dataset, we use predictive Apriori algorithm for finding the hidden relationship between various atmospheric parameters. By using predictive Apriori algorithm the association rules are generated on weather data set with support and confidence threshold values. The research has produced interesting rules to predict tornadic and non-tornadic weather conditions. It has been noticed that probability of Tornado is maximum when wind speed is high, divergence is convergence and instability is severe. We further conclude that there are no chances of tornadoes when wind speed is low, divergence is divergence and instability is stable. Association rules are generated and tested on real life tornadoes in Georgia, USA. In future, this work may be extended to analyze severe weather conditions in India.

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