Impact of Winds of Various Layers upon Thunderstorms and Rainfall over Vidarbha

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ABSTRACT

The meteorological data of Nagpur for forty years (1965-2004) are considered to conduct this study. It has been observed from this study that the frequency of occurrence of thunderstorms is the highest in the month of July and lowest in January during the year. There is positive and significant correlation between the number of thunderstorms occurred and the amount of rainfall. It is observed that there is decreasing trend in the days of occurrence of thunderstorms and rainfall. It is also found that winds are changing in southerly direction at the surface, 850 hPa and 200 hPa levels. It is pointed out that the maximum chances of formation of squalls is observed in the transition period of onset of southwest monsoon and its withdrawal. The wind shear between 850 hPa level & the surface and the differences in wind directions between 200 hPa & 850 hPa levels are found to be more related to the formation of thunderstorms. Winter season is observed to be most safe period for aviation purposes due to lesser frequency of occurrences of thunderstorms over Nagpur. This study has relevance to the forecasters, aviation sector and farmers.

Keywords: *Thunderstorms, Squall, Surface and Upper Winds (850 hPa & 200 hPa levels) and Rainfall.*

1. Introduction

Thunderstorms are familiar events in the atmosphere. These phenomena produce thunder, turbulence, icing, dust-storms, updraft or downdraft of air resulting into squally winds, gusty winds, downbursts, microburst, cloud burst, hailstorms, lightning, heavy to very heavy rains and tornadoes. Thunderstorms hammer and disturb aviation, navigators and ground services. These weather events sometimes destroy crops due to flood and strong wind, losses of lives, economy and property. Present study is focused on Vidarbha region. Vidarbha is on its path on industrial development and this place has its importance for aviation sector in the central region of India. There are two functional national level flying clubs at Nagpur and in NIATAM, Gondia 100 Km away towards east of Nagpur. Therefore, this study has wide implications as far as aviation sector and related operations are concerned. Secondly, Nagpur in Vidarbha is an important city in central part of India and is also known as orange city due to growing of oranges in large quantity. It has an international airport and cargo terminal. The city in its periphery has Butibori and Hingna MIDC (Maharashtra industrial development Corporation) industrial area and an ambitious Multimodal International Hub and Airport (MIHAN) project, which has earned fame in Asia and abroad. Nagpur is the "Tiger capital in India" and it is well connected to world's tiger project. Therefore, air traffic safety in this city has gained vital importance. For the above operations to be smooth enough and for the safety of air traffic, there is a need to have the knowledge of thunderstorm activity in this region since the thunderstorms are the most hazardous of all clouds affecting the safety of passengers and other operations. Furthermore, farming is main occupation in Vidarbha. Hence, any advance information of rainfall such as whether it is due to prevailing weather systems or due to developing thunderstorms or occasional hail can help the farmers to protect their agricultural products from the losses subsequent to the adverse weather situation. Therefore, in this study, an attempt has been made to find out impact of winds of various layers upon thunderstorms and rainfall over Vidarbha.

The formation and development of thunderstorms vary from place to place and also with time. The knowledge of thunderstorm at a particular station with respect to its frequency of occurrence, duration, time during year, climatology and synoptic situation(s) need to be known for good planning and developmental works. Stephen et al. (2000) pointed out that essential conditions for the formation of a severe thunderstorm are (i) Conditional instability, (ii) Availability of moist air at lower levels, (iii) Insolation and Orography for initial lifting of moist air at higher levels, (iv) Presence of high lapse rate of temperature, due to dry westerly at upper levels and moist southerly/southwesterly air at lower levels and (v) Presence of trough or cyclonic circulation in lower levels over the region. In addition, strong vertical wind shear is found to be one of the important factors for the occurrence of severe thunderstorm as the release of latent energy in an environment of strong vertical wind shear often leads to the development of severe convective storms. Several researchers have studied the climatological aspects of thunderstorms for various stations particularly at airports. Krishnamurthy (1965), Viswanathan and Faria (1962) studied the climatology of thunderstorms over Bombay and Pune respectively. Rao et al. (1971) studied the diurnal frequency of incidence and duration of thunderstorms at international aerodromes of Bombay, Kolkata, Chennai and Delhi. Philip et al. (1974) have conducted a similar work on the thunderstorms at the aieport stations of Ahmedabad, Bangalore, Agartala and Hyderabad. Freier (1978) showed that in general the low precipitation regimes matched with lower frequencies of thunderstorms. Kumar (1992) has given various statistical aspects of occurrence of thunderstorms at Lucknow airport. Moid (1996) conducted similar study of thunderstorms at Mohanbari airport. Santosh et al. (2001) considered thunderstorm climatology of Thiruvananthapuram, Kochi and Kozhikode airports in Kerala. Norris (1998) reported the highest frequency of occurrence for Cb (Cumulonimbus) cloud with anvil in the tropical regions with maximum surface convergence. Basu and Mondal (2002) made the forecasting aspect of thunder squall over Kolkata and its parameterization. Mohapatra et al. (2004) have analyzed the data for a period of 10 years from 1985-1994 and studied the climatological characteristics of thunderstorm activity during pre and post monsoon seasons over Bangalore. Manohar and Kesarkar (2004) opined that most parts of India except southern portion of East coast and extreme South India are free from thunderstorm activity during October and November of post monsoon season. Biswas (2005) studied the thunderstorms over Mumbai analytically. Kumar and Mohapatra (2006) have studied the climatology of thunder and squall at the Guwahati Airport. Tyagi (2007) has studied the frequency of thunderstorms over the central parts of the country between 30 and 50 days and has reported the lowest frequency over the extreme western and northwestern parts of the country. Chakraborty et al. (2007) described the positive aspects of thunderstorm over West Bengal. Pattanaik (2008) pointed that the difference of seasonal OLR anomalies in winter season between the period (1992-2004) and (1979-1991) indicated increase in convective activity during recent period (1979-1991) over the south Arabian Sea & south Bay of Bengal and just the opposite occurred over the rest of the region associated with a significant decreasing trend of convective activity over the north and central Arabian Sea (at 99.9% level and 99% level) respectively. Das et al. (2010) described the climatological and synoptic aspects of hail storm and squall over Guwahati airport during pre-monsoon season. Singh et al. (2011) pointed out how the climatological information of thunderstorms over a particular station is useful in forecasting and aviation purpose. Study of Biswas and Dukare (2012) shows month-wise and year-wise number of thunderstorm days during the study period 1990-2009. Laskar and Kotal (2013) concluded that fine network of surface and upper air observing systems are needed to understand the mesoscale systems such as thunderstorms on a micro level and they have discussed as to how such observing systems augment our prediction capability. Singh (1985) concluded that easterly wind maxima at 200 mb level over the Bay of Bengal and Arabian Sea are mostly observed southwest of well organized cloud systems associated with the well marked lows or depressions during monsoon season .The formation of wind maxima through this mechanism cause further enhancement of the upper air divergence and therefore the process of self-amplification. Koteswaram and Srinivasam (1958) concluded that the simultaneous presence of low level convergence and upper air divergence contributes significantly in the development of thunderstorms over Gangetic West Bengal. Nowcasting Unit, IMD (2014) opined that a jet at 200hPa is generally associated with more number of thunderstorms due to a westerly trough at 500hPa level. Choudhury (1961) concluded that presence of low level convergence and orographic lifting are the two factors responsible for thunderstorm development over north-eastern region of India. Rao and Raman (1961) showed that the frequency of thunderstorms over NE-region is higher during the pre-monsoon season, Mohanty et al. (2008) pointed that the frequency of occurrence of thunderstorm is dependant not only on the topography but also on the prevailing synoptic conditions and land heating, where as Mukharjee (1964) concluded that the frequency of thunderstorm activity at Guwahati airport is the maximum during the nights of pre-monsoon season. Wunderground (2014) inferred that in case of hurricanes, wind shear is important primarily in the vertical direction from the surface to the top of the troposphere. The troposphere is the region of the atmosphere to which our weather activities are confined to, and it extends up to about 40,000 feet altitude (200hPa) in the tropics in the summer. More the differences in the wind shear between 850hPa and 200hPa level, stronger is the thunderstorm activity. Das et al. (2014) pointed out that moisture incursion in the lower level due to the presence of anticyclone over the Bay of Bengal in the presence of instability in the atmosphere, as revealed by different stability indices, is responsible for the occurrence of thunderstorms. Emrah et al. (2017) found that the duration of TS in autumn season is the highest during the study period. 42.16% of thunderstorm events are between 1700 UTC and 2400 UTC and 17.48% are between 0900 UTC and 1300 UTC. Laskar et al. (2016) pointed out that the understanding of the dynamical/physical mechanisms of these thunderstorms is essential for improving the forecast of such mesoscale systems. Singh et al. (2011) primarily classified thunderstorms on the basis of (i) Climatological (ii) Thermodynamical (iii) Radars and satellites (iv) Mesoscale modeling and (v) Synoptic situations.

As per the above studies of researches on thunderstorms, it has been seen that several aspects of thunderstorms in various parts of India has been examined so far. However, there has been no study undertaken regarding the thunderstorm activity over Vidarbha. In India, thunderstorms reach severity when continental air meets warm moist air from ocean and this is one of the favorable conditions for the formation of thunderstorm, Laskar and Kotal (2013), Singh (1985) also concluded the same finding as above. Therefore, in the present study, investigations have been carried out to find relationship between rainfall amount and number of thunderstorms and trends of surface & upper air winds at different specific levels which are of paramount importance for thunderstorm activity over Vidarbha.

Further, this study will cover effective and successful planning in the aviation sector, especially forecasting and other related operations and understanding climatology of the region. It involves aspects which render the farmers helpless due to the heavy rains and hailstorms associated with the thunderstorms. If useful information can be provided to the concerned stake holders in advance, heavy losses can be prevented.

2. Meteorological Terminologies

Single Cell Storm: It typically lasts 20-30 minutes. Pulse storms can produce severe weather elements such as downburst, hail, some heavy rainfall and occasionally weak tornadoes. It is of low to moderately dangerous to the public and aviation sector.

Multi-cell Cluster Storms: A group of cells moving as a single unit, with each cell in different stage of thunderstorm life cycle. It can produce moderate size hail, flash floods and weak tornadoes.

Multi-cell Line Storms: It consists of a line of storms with a continuous, well developed gust front at the leading edge of the line. Also known as squall lines, these storms can produce small to moderate size hail, occasional flash floods and weak tornadoes.

Supercells: Defined as a thunderstorm with a rotating updraft, these storms can produce strong down bursts, large hail, occasional flash floods and weak to violent tornadoes. It can often be isolated from other thunderstorms, and can dominate the local weather up to 32 km away and last for 2-4 hours. It is extremely dangerous to the public and aviation sector.

Vertical Wind Shear: It is the second critical factor in the determination of thunderstorm type and potential storm severity. Vertical shear or the change of horizontal wind direction and/or speed with height interacts dynamically with thunderstorm to either enhance or diminish vertical draft strengths.

Squall: A sudden increase of wind speed by at least 3 stages on the Beaufort scale, the speed rising to force 6 or more and lasting one minute.

3. Data and Methodology

In the present paper, investigators have considered meteorological data recorded at Nagpur (21.15° N/ 79.09° E) as a representative of Vidarbha. Nagpur is the only station in Vidarbha that is recording/ reporting upper air wind data and has twenty four hours meteorological observations. The available meteorological data of forty years for the period 1965-2004 have been obtained from Climatological section, RMC, Nagpur and National Data Centre, ADGM (R), Pune. Data are arranged as means of months, seasons and years in tabular and graphical format for further interpretation and analysis. In the present work, attention is focused on conducting a study of frequency and trends of occurrence of thunderstorms, correlation with rainfall and thunderstorm activities at various levels. Impact of differences in wind shears and differences in wind directions at separate levels between 200hPa & 850 hPa and between 850hPa & surface levels upon formation of thunderstorms are studied. The types of thunderstorms i.e. single cell, multi-cell & super cell are not counted and the analysis is done based on its thermodynamic instability due to several thunderstorms recorded during 40 years over Nagpur. Other meteorological parameters and winds at 500hPa, and 700hPa levels are dropped from inclusion in this study due to limitation of the manuscript size. However, these are proposed for further research.

4. Results and Discussion

Table 1 depicts the monthly average winds at the surface, 850hPa and 200hPa levels rainfall, number of thunderstorms and squalls recorded at Nagpur. It is seen that highest monthly average rainfall 293.0 mm recorded in month of July and the lowest monthly average rainfall 11.2 mm recorded in April at Nagpur. The highest number days of thunderstorm 10.7 reported in July, whereas, lowest number of days of thunderstorm 0.4 reported in January. Average wind direction recorded at surface level is 256 degrees in July and at 200hPa it is 84 degrees. In January, average wind direction is 71 degrees at the surface and at 200hPa it is 260 degrees. This means, in July there is westerly wind at the surface and easterly wind at 200hPa level favourable for formation of maximum number of thunderstorms. But in January, there is easterly wind at the surface and westerly wind at 200hPa favoring the formation of thunderstorms.

There exists positive and significance correlation (r = 0.87) between monthly mean values of frequency of occurrence of thunderstorms and rainfall. It is also observed that number of occurrence of thunderstorms are more during the months of July to October and the highest in July (10.7). It is pointed out that the activity of squalls is maximum in the transition periods of onset and withdrawal of Southwest monsoon. Good number of thunderstorm days are also observed during this period. It indicates that the chances of development of multi-cell line storms are more in the month of June and October. Table 2 reveals the seasonal average values of direction & speed of winds at the surface, 850hPa and 200 hPa levels; rainfall; number of days of thunderstorms and squalls.

During winter season (Jan–Feb), average wind direction and speed are 144 degrees & 1.8 m/s at the surface, 243 degrees & 4.9 m/s at 850hPa level and 27 degrees & 33.6 m/s at 200hPa. Average

Table 1. Month wise average data of various parameters recorded at Nagpur.

Winds / months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Surface dire. Deg.	71	216	153	276	289	265	256	268	280	133	73	108
Average Wind Speed mps at surface level	1.6	2	2	2.4	3.1	3.3	2.8	2.9	2.2	1.8	1.7	1.4
850 hPa-dire. deg.	244	242	279	293	312	298	289	301	274	48	72	191
Average Wind Speed mps at 850hPa level	4.7	5	5.2	5.6	6.8	7.8	9.2	9	6.4	5	4.5	4.2
200 hPa-dir. deg.	260	263	262	262	249	109	84	86	102	232	250	201
Average wind speed mps at 200hPa level	33.6	32.4	30.5	26.5	13.9	10.2	17.4	16.6	10.5	12.7	23.4	31.5
R /F in mm	15.9	22.6	17.9	11.2	18.9	163.0	293.0	260.0	164.0	57.3	14.8	17.2
Average no. of days of TS	0.4	1.2	1.8	3.1	4.6	5.8	10.7	8.9	7.2	7.9	2.7	0.6
Average no. of days of squall	0.1	0.3	0.3	0.3	0.8	2.3	0.7	0.4	0.5	2.8	0.3	0.1
Correlation	*(r=0.87) between monthly mean values of frequency of occurrence of thunderstorms and rainfall.*											

rainfall is 38.5 mm and the average number of days of thunderstorms and squalls are 0.8 and 0.2 respectively.

Pre-monsoon season (Mar-May) average wind direction and speed are 239 degrees & 2.5 m/s at the surface, 295 degrees & 5.9 m/s at 850hPa level and 258 degrees & 23.6 m/s at 200hPa respectively. Average rainfall is 48.7 mm, average number of days of thunderstorms and squalls are 3.1 and 0.46 respectively.

Monsoon season (Jun-Sept) average wind direction and speed are 267 degrees & 2.8 m/s at the surface, 291 degrees & 8.1 m/s at 850hPa level and 95 degrees & 13.7 m/s at 200hPa. Average rainfall is 880 mm, average number of days of thunderstorms and squalls are 8.2 and 0.91 respectively.

Post-monsoon season (Oct-Dec) average wind direction and speed are 105 degrees & 1.6 m/s at the surface, 104 degrees & 4.6 m/s at 850hPa

Table 2. Representation of the average values in Season wise of various Met. Parameters recorded at Nagpur.

Met. Parameters / Seasons	Winter	Pre-monsoon	Monsoon	Post-monsoon
Average wind direction in deg. at surface	144	239	267	105
Average wind speed in mps at surface	1.8	2.5	2.8	1.6
Average wind direction in deg. at 850 hPa	243	295	291	104
Average wind speed in mps at 850 hPa	4.9	5.9	8.1	4.6
Average wind direction in deg. at 200 hPa	27	258	95	228
Average wind speed in mps at 200 hPa	33.6	23.6	13.7	22.5
Rainfall in mm	38.5	48.7	880.0	89.3
Average no. of days of thunderstorms	0.8	3.1	8.2	3.7
Average no. of squalls	0.2	.46	.91	1.1

level and 228 degrees & 22.5 m/s at 200 hPa. Average rainfall is 89.3 mm, average number of days of thunderstorms and squalls are 3.7 and 1.1 respectively.

Table3 represents the yearly average meteorological data at the surface and 850 hPa and 200 hPa levels which include wind direction, rainfall amount and number of days of thunderstorms for 40 years recorded at Nagpur. During the period, Nagpur experienced highest rainfall of 1748.6 mm in the year 1994 and lowest of 606.0 mm in the year 1972. The average number of days of thunderstorms recorded is the highest at 7.6 in 1975 and lowest at 0.5 in 2000. The wind directions are found varying between 267 and 151 degrees at the surface, 271 to 197 degrees at 850 hPa level and 241 to 186 degrees at 200 hPa.

Table 4 reveals the month wise wind shears between 850hPa & surface and average number of days of thunderstorms. Large differences in wind shears between 850hPa & surface are found during the months of May to September. During this period, maximum days of thunderstorms are observed. It indicates that large wind shears between 850hPa & surface favors formation of thunder clouds. Positive and strong correlation (r=0.74) is noted between number of thunderstorms and wind shears between 850hPa & surface. It indicates that large wind shears between 850hPa & the surface are favorable for formation of thunderstorms.

Table 5 reveals the month wise wind shears between 200hPa & 850hPa levels and average number of days of thunderstorms. It is observed that differences in wind shears between 200hPa & 850 hPa levels are more in the months of November & December and January to April. It is also observed that thunderstorm activities are minimum during this period. There exists negative correlation (r = -0.86) between average number of days of thunderstorms and wind shears between 200hPa & 850hPa levels. It indicates that large wind shears between 200hPa & 850hPa levels do not favor formation of thunderstorms.

Table 3. Representation of yearly average weather parameters recorded/reported at Nagpur.

YEAR	1965	1966	1967	1968	1969	1970	1971
Surface wind direction (deg.)	170	232	199	213	199	193	196
850hPa	224	242	266	235	234	212	241
200hPa	206	201	207	215	196	196	195
R/F in mm	1017.8	1043.6	1104.2	962.1	892.8	1513.7	1114.5
No. of TS	4.8	4.3	4.2	5.3	5.8	6.6	6.0
YEAR	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**
Surface wind direction (deg.)	175	170	200	258	228	254	168
850hPa	259	224	256	226	250	246	249
200hPa	202	194	186	189	195	202	201
R/F in mm	606.0	1224.8	973.3	1348.3	1061.7	947.2	1130.4
No. of TS	3.3	4.7	5.5	7.6	5.2	4.8	4.8
YEAR	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**
Surface wind direction (deg.)	267	251	240	205	225	**151**	198
850hPa	214	242	212	265	225	247	251
200hPa	191	191	200	191	210	198	201
R/F in mm	1307.1	1212.0	1340.3	854.9	855.2	759.2	1318.2
No. of TS	4.8	3.9	5.1	5.1	3.8	2.3	4.8
YEAR	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
Surface wind direction (deg.)	208	162	174	213	208	198	176
850hPa	227	223	209	246	248	249	228
200hPa	206	207	196	201	199	204	206
R/F in mm	989.5	954.5	861.3	643.9	1159.5	912.0	788.5
No. of TS	3.6	7.5	4.9	4.0	4.5	4.0	3.6
YEAR	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Surface wind direction (deg.)	202	153	178	161	207	192	227
850hPa	232	251	237	**197**	**271**	219	234
200hPa	197	193	192	199	222	205	195
R/F in mm	1312.3	1748.6	1227.1	734.4	1058.6	1087.3	992.0
No. of TS	3.7	4.3	6.2	4.8	4.7	6.3	4.7
YEAR	**2000**	**2001**	**2002**	**2003**	**2004**		
Surface wind direction (deg.)	254	203	252	200	199		
850hPa	233	224	248	251	229		
200hPa	205	203	220	241	199		
R/F in mm	936.2	1129.6	963.5	1207.7	749.2		
Average no. of days of TS	0.5	5.3	1.9	4.8	2.2		

Table 4. Month wise wind shear between 850hPa level & surface and average number of thunderstorms.

Winds / months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
850hPa Wind Speed mps	4.7	5	5.2	5.6	6.8	7.8	9.2	9	6.4	5	4.5	4.2
Surface speed mps	1.6	2	2	2.4	3.1	3.3	2.8	2.9	2.2	1.8	1.7	1.4
Wind shear (between 850hPa & surface)	3.1	3	3.2	3.2	5.7	4.5	6.4	7.9	4.2	3.2	3.8	2.8
Average no. of days of TS	0.4	1.2	1.8	3.1	4.6	5.8	10.7	8.9	7.2	7.9	2.7	0.6
Correlation between wind shear of 850 hPa level & surface and TS, r = 0.74												

Table 5. Month wise wind shears between 200hPa & 850hPa levels and average number of thunderstorms.

Winds / months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
200hPa speed m/s	33.6	32.4	30.5	26.5	13.9	10.2	17.4	16.6	10.5	12.7	23.4	31.5
850hPa Speed mps	4.7	5	5.2	5.6	6.8	7.8	9.2	9	6.4	5	4.5	4.2
Wind shear (between 200 & 850 hPa levels)	29.9	27.4	25.3	20.9	7.1	2.4	8.2	6.6	4.1	7.7	18.9	27.3
Average no. of days of TS	0.4	1.2	1.8	3.1	4.6	5.8	10.7	8.9	7.2	7.9	2.7	0.6
Correlation between wind shears of 200 hPa & 850 hPa levels and number of TS r = -0.86												

Table 6. Differences in directions between 850hPa level & the surface and average number of thunderstorms.

Winds / months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Surface dir. Deg.	71	216	153	276	289	265	256	268	280	133	73	108
850 hPa-dir. deg.	244	242	279	293	312	298	289	301	274	48	72	191
Differences in direction (850 hPa & surface)	173	26	126	17	23	33	33	33	6	85	01	83
Average no. of days of TS	0.4	1.2	1.8	3.1	4.6	5.8	10.7	8.9	7.2	7.9	2.7	0.6
Correlation between differences in wind directions of 850 hPa level & surface and TS r = -0.41												

Table 7. Differences in directions between 200hPa & 850 hPa levels and average number of thunderstorms.

Winds / months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
850 hPa-dir deg.	244	242	279	293	312	298	289	301	274	48	72	191
200 hPa-dir. deg.	260	263	262	262	249	109	84	86	102	232	250	201
Differences in direction (200 hPa & 850 hPa)	16	21	17	31	63	189	205	215	172	184	178	10
Average no. of days of TS	0.4	1.2	1.8	3.1	4.6	5.8	10.7	8.9	7.2	7.9	2.7	0.6
Correlation between differences in wind directions of 200hPa & 850hPa levels and TS r = 0.85												

Table 6 reveals month wise wind directions between 850hPa & the surface and average number of days of thunderstorms. It is observed that differences in wind directions between 850hPa level & the surface are maximum in the months of November & December and from January to April.
During this period, less number of thunderstorms are experienced. Negative correlation (r= - 0.41) is established between number days of thunderstorms and differences in wind directions at 850 hPa & surface levels. It indicates that large differences in wind direction between 850hPa & surface do not favor formation of thunder clouds.

Table 7 reveals the month wise differences in wind directions between 200hPa &850hPa levels and average number of days of thunderstorms. It is observed that differences in wind directions between 200hPa & 850hPa levels are maximum in the months from May to November. During this period, it is also observed that thunderstorm activities are maximum except in the month of

November. Positive and strong correlation (r = 0.85) is established between the number of days of thunderstorms and the differences in wind directions between 200hPa & 850hPa levels. It indicates that large differences in wind directions between 200hPa & 850hPa levels favor formation of thunder clouds.

Figure 1 depicts month wise average number of thunderstorm days and the amount of rainfall. It shows that month wise average number of thunderstorm days and the amount of rainfall vary in the same way. It is seen that the number of thunderstorm days and the amount of rainfall both start increasing from the month of May and decreases from July. Freier (1978) and Norris (1998) have also inferred similar results. From the figyre, it is concluded that there exists a positive relationship between the number of thunderstorm days and the amount of rainfall in Nagpur.

Figure 2 depicts monthly average winds at 850hPa, 200hPa and surface, and their trends in Nagpur. It is seen that during monsoon season of June to September, winds are easterlies at 200hPa, whereas these are westerly at the surface. At 850hPa level, winds are from northwest direction. The wind shear between the surface and the 200hPa level results in the formation of extensive thunderstorms because of favorable vorticity and also results in greater amounts of rainfall during the monsoon months. In other seasons of the year, no such significant patterns of wind are observed thus reducing the number of formation of thunderstorms over Nagpur and thereby lesser amounts of rainfall. Stephen et al. (2000) also opined similarly.

It is seen that the trends of winds vary from northwest to south at 850hPa, southwest to south at 200hPa and southwest to south at the surface. Also the difference in wind directions between the surface and 200hPa level is always opposite but it is significant only during the monsoonal months. Results indicate that the trends of wind at all these three levels change to southerly direction at Nagpur.

Figure 3 represents winds at the surface reported during forty years of study at Nagpur. It is found that wind directions change from 267 to 151 degrees. It indicates that winds have large scale variation from westerly to southeast direction at Nagpur.

Figure 4 represents winds at 850hPa level reported during forty years of study at Nagpur. Winds are found to vary from 271 to 197 degrees in direction. It indicates that winds change from westerly to southerly direction at Nagpur.

Figure 5 represents winds at 200hPa level reported during forty years of study at Nagpur. Winds are found to change from 186 to 241 degrees in direction. Results indicate that winds at 200hPa change from southerly to southwesterly in direction over the years of study at Nagpur.

Figure 6 represents year wise rainfall recorded during 40 years at Nagpur with the highest rainfall at 1748.6 mm in the year 1994 and the lowest of 606.0 mm in the year 1972. The decreasing trend in rainfall is confirmed over the years.

Figure 7 shows number of days of thunderstorms during the forty years of study at Nagpur. The highest number of thunderstorm days at 7.6 in the year 2005 and the lowest of 0.5 in the year 2000 are reported at Nagpur. The decreasing trend of thunderstorm days is quite significant and it results in decreasing trend in annual rainfall at Nagpur.

Figure 8 shows average wind speeds at the surface, 850hPa and 200hPa levels in various seasons. At the surface, the highest average wind speed of 2.8 m/s is found in monsoon months and the lowest of 1.9 m/s is in the post monsoon season. Highest average wind speed of 8.1 m/s is reported at 850hPa level in the monsoon season and the lowest of 4.6 m/s in the post monsoon season.

5. Conclusions

On the basis of the results obtained, discussion, interpretation and analysis of various meteorological parameters of Vidarbha, the following conclusions are drawn.

1. There exists significant co-relationship between amount of rainfall and number of occurrence of thunderstorms.

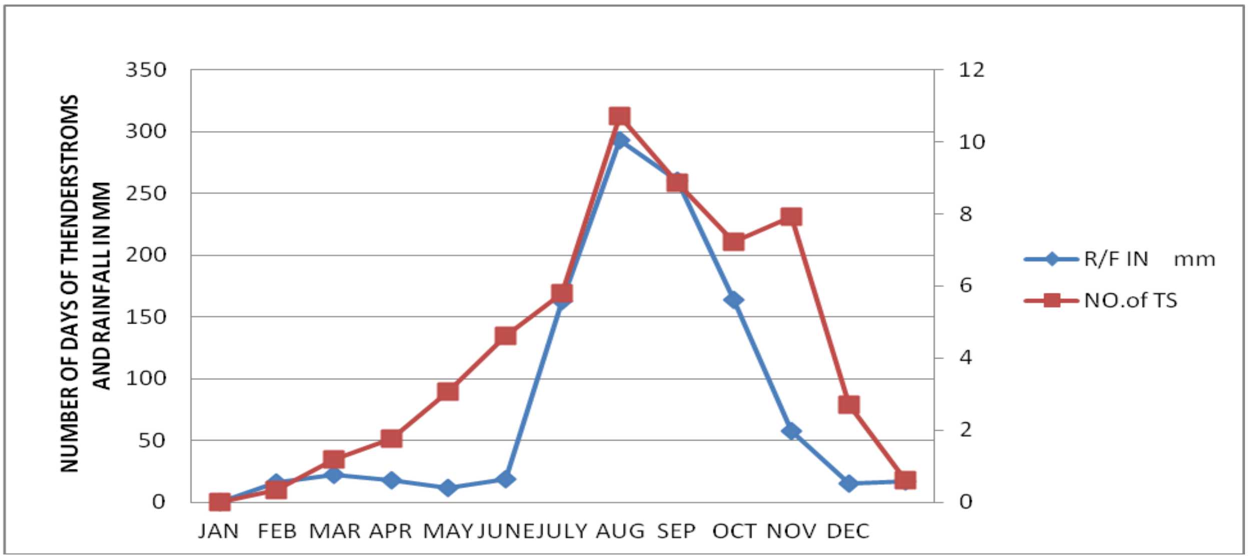

Figure 1: Graphical representation of number of days of Thunderstorms and Rainfall at Nagpur.

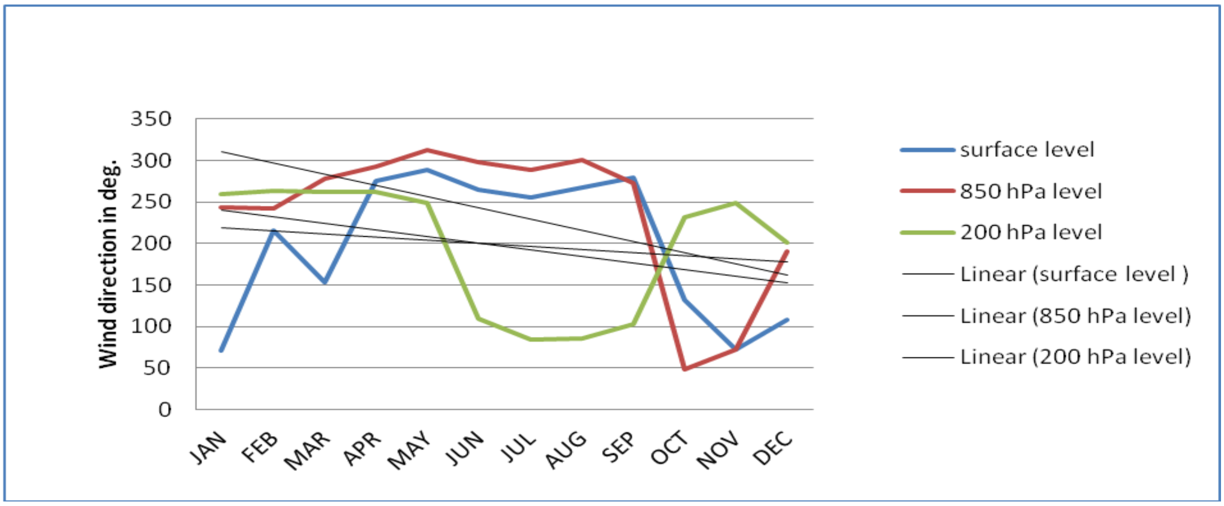

Figure 2: Graphical representation of monthly average wind directions at the surface, 850hPa & 200hPa levels.

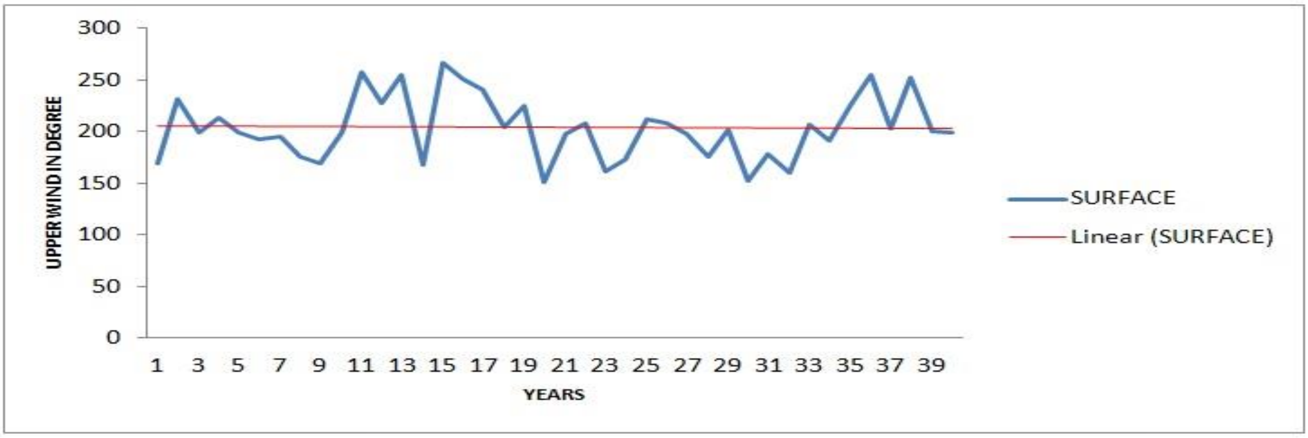

Figure 3: Graphical representation of Wind directions of the levels at surface level in year wise over Nagpur.

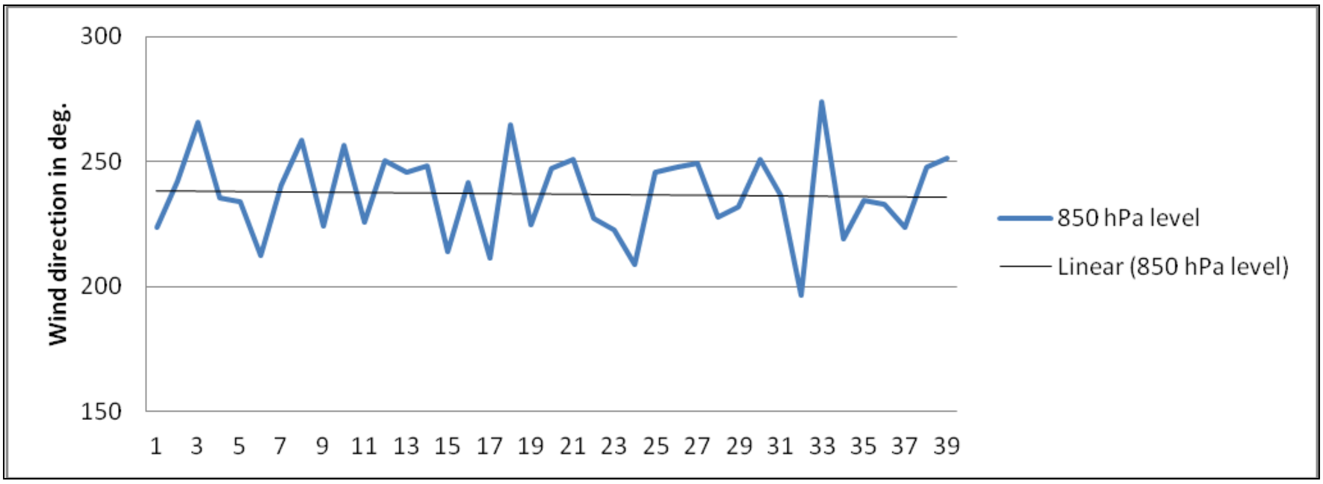

Figure 4: Graphical representation of year wise average wind direction in degrees at 850hPa level.

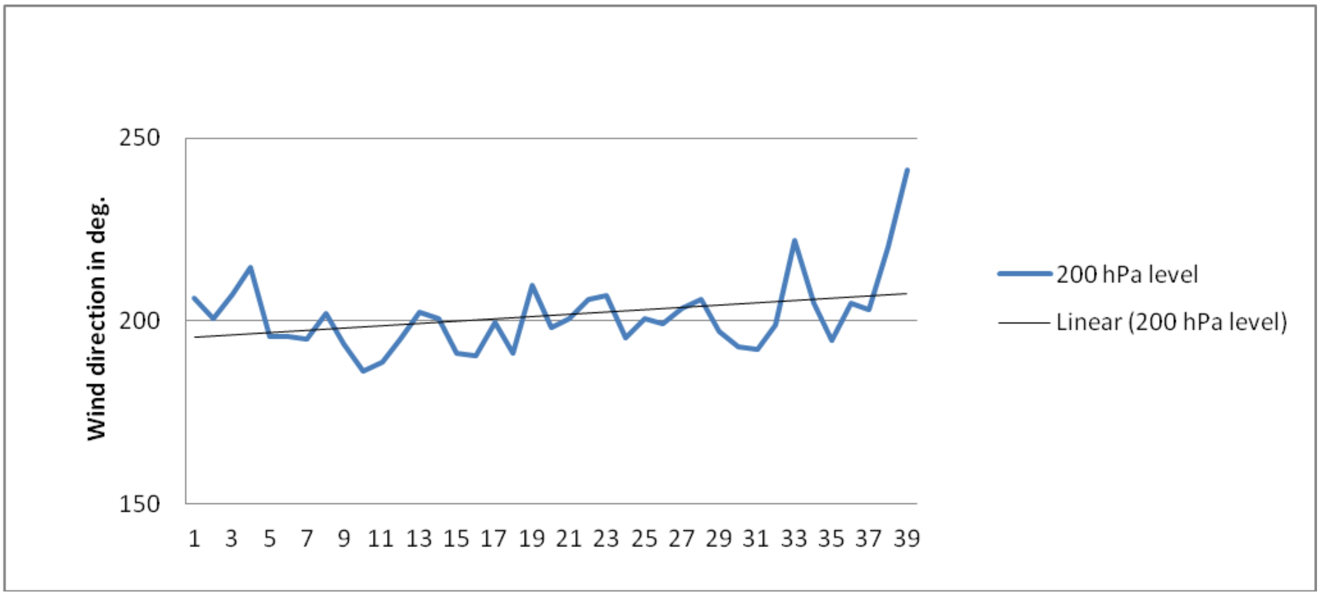

Figure 5: Graphical representation of year wise average wind direction in degrees at 200hPa level.

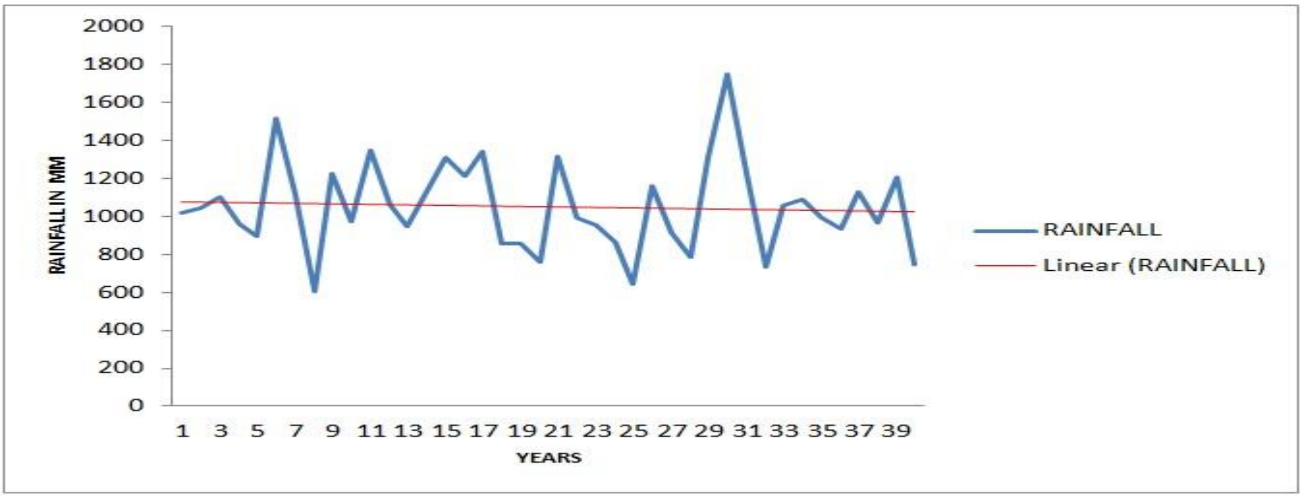

Figure 6: Year wise average amounts of rainfall (mm) recorded at Nagpur.

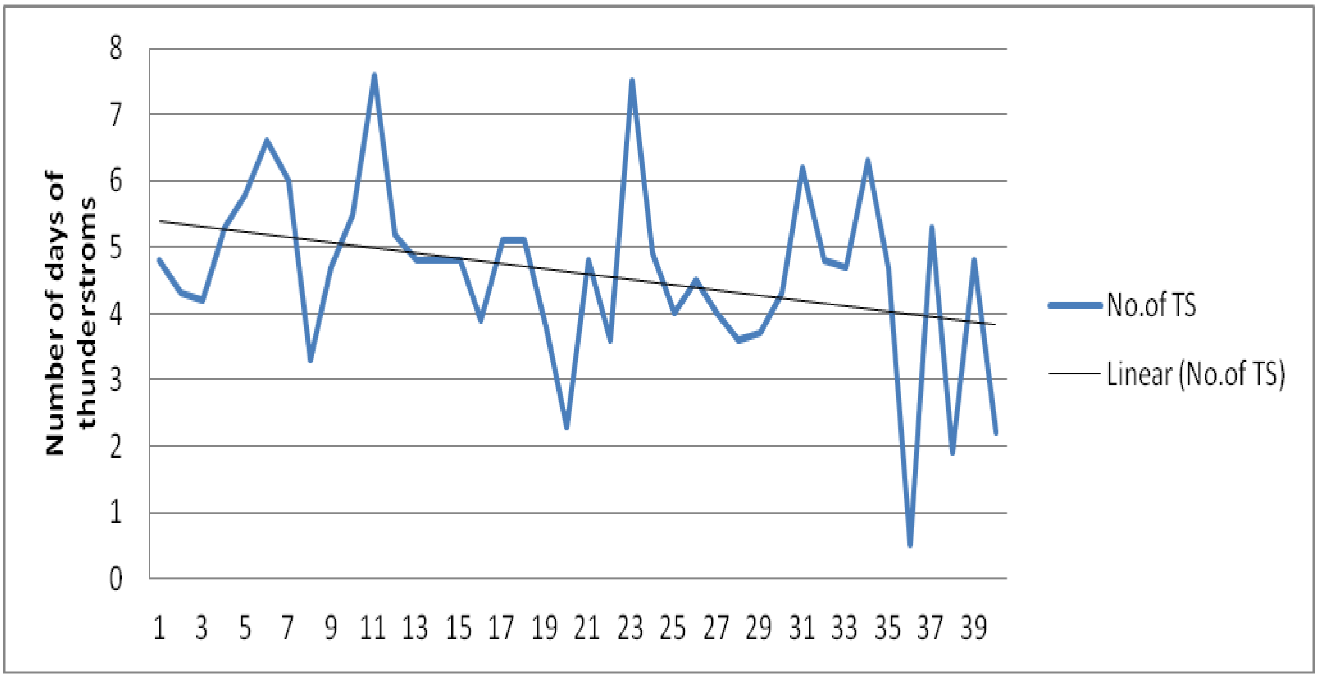

Figure 7: Year wise average number of thunderstorms recorded at Nagpur.

2. Decreasing trends are found in the amount of rainfall and the number of occurrences of thunderstorms.

3. At Nagpur, monsoon season experiences good amount of rainfall and more number of thunderstorms as compared to other seasons during the year.

4. It is pointed out that July has the highest monthly average rainfall and number of thunderstorms and January has the lowest occurrence of thunderstorms.

5. In a year, June to October period indicates more number of thunderstorms whereas more number of squalls are recorded in the months of June and October.

6. It is found that low level convergence due to incursion of moisture from westerly wind and upper air divergence of dry air from easterly wind are favorable conditions for the formation of thunderstorms.

7. It is pointed out that winter season is the safest season for any aircraft operations over the skies of Nagpur.

8. It is found that direction of upper level wind at 200hPa level would be most useful in aviation and forecasting purposes.

9. It is noted that trends of winds at the surface, 850hPa and 200hPa levels are changing in southerly direction over Nagpur.

10. Maximum chances of formation of squalls are in the transition periods of onset and withdrawal of southwest monsoon.

11. Wind shears between 850hPa & the surface and difference in wind directions between 200hPa & 850hPa levels are highly correlated to the formation of thunderstorm activity. On the other hand large wind shears between 200hPa & 850hPa levels do not favor formation of thunderstorms.

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