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Research Article

Analysis of a Case of a Classical Supercell Storm in Bihar, India: Observation and Tracking

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Abstract

In this study, we use the S-band Doppler Weather Radar to analyze the weather of a prolonged classical supercell storm that occurred on April 7, 2018, across the Indian state of Bihar. In the early morning hours of April 7th, 2018, a supercell storm with its origins in a colliding cloud mass produced in the Himalayan foothills invaded the Himalayan foothills from the North-West of Bihar via East Uttar Pradesh. The echo top increased to over 14 kilometers as it moved through the Bihar districts of Siwan and Gopalganj. As it followed, the storm shifted direction, heading northwest. Maximum radar reflectivity reached up to 61 dBz at 11: 32 IST observation (seen from Doppler Weather Radar, Patna), which may be the highest reflectivity ever recorded at DWR (Doppler Weather Radar) Station, Patna. It stopped being a supercell at 13: 30 IST and convert into a multicellular storm. A strange hook echo could be seen off the Storm's back in the Vertical Integrated Liquid profile. The supercell had two linked outflows, one to the northeast and one to the southeast. The Supercell's inverted "V"-shaped front flank was another characteristic feature. Within a small vertical band along the echo wall, reflectance reached over 60 dB at its highest. There was significant divergence near the peak of the supercell storm, with the speed differential between the updraft and downdraft reaching around 60 m/s. The system lasted for about 7 to 8 hours, damaging hailstorms occurred often along the path. Hail stones larger than 6-7 mm in diameter were spotted (as per the observed report). This particular cell was determined to be a supercell based on its internal structure, reflectivity, duration, and ground-level weather pattern. The incidence, timing, and development of the storms were all accurately predicted by the convective outlook products 2 to 3 hours in advance.

Keywords

Supercell Storm, Vertical Integrated Liquid, Vertical Profiles of Radar Reflectivity, Doppler Weather Radar

1. Introduction

The Indian subcontinent suffers huge social and economic costs from frequent, intense thunderstorms [3]. Therefore, knowing the processes that lead to severe convective storms and their regional features is crucial for comprehension [6, 7, 9, 12-14, 17]. The likely intensity of convection in India is mostly determined by how well organized it is. Perhaps the most well-known example of organized convection is the supercell [19], which is characterized by the presence of a spinning updraft or mesocyclone [7, 8] and is typically linked with widespread outbreaks of severe convective weather. The numerical simulations [1, 4, 5, 18] show that the dynamical factors at play in the formation of supercell storms are distinct

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from those of regular thunderstorms. It is the interaction of convective updrafts with the sheared ambient environment that causes mesocyclones to form in supercells [1, 4]. For example, the development of non-hydrostatic pressure gradients can contribute to the generation of large updrafts caused by intense vertical wind shear. According to meteorologists, a supercell thunderstorm is characterized by an extremely strong and persistent rotating updraft [2, 16]. The radar echo from precipitation must be at least one-third as deep. Longer lasting than the time it takes for a parcel of air to travel from the updraft's base to its peak, this phenomenon is "persistent." Though they don't happen often, supercells can generate extremely strong convection when they do. Non-hydrostatic pressure gradients can form in response to intense vertical wind shear, which in turn can cause powerful updrafts to form [11]. However, supercell thunderstorms can occur anywhere in the world, albeit they are more common in low-lying areas near mountains. In the Indian subcontinent, supercells only appear occasionally, Supercell storms can arise due to favourable synoptic circumstances in Eastern India [15]. It is possible to gain insight into the future with the help of supercells due to their distinctive radar and lightning properties. For instance, the bounded weak echo region (BWER) signature shows the presence of a strong quasi-steady updraft with a lifetime of several hours by forming above the low-level reflectivity gradient at mid-levels.The V-notch is another distinctive radar signature created by the diverging flow surrounding the storm's updraft and is associated with a wide range of extreme weather phenomena, including large hail, high winds, and tornadoes. This study aims to accomplish two primary things. The first is a record of the most striking radar signatures and other observations from the supercell on April 7, 2018. Since remote sensing measurements have just recently been used in an operational setting, the Indian Meteorological Department's services have a vested interest in studying supercell events. The development of a comprehensive microscale thunderstorm climatology for eastern India requires. Single case studies like the one presented here as a foundational first step. Due to the magnitude of the pending supercell event, a careful analysis of its predictive feasibility is required. The paper's secondary objective is to evaluate the Nowcast services utilising Doppler Weather Radar in Patna.

Hail swathes of 110–120 km in length and 15–25 km in width were produced by the Supercell that formed over Bihar on April 7, 2018. (Source: Observation from S-band Doppler Weather Radar). Powerful winds and a hailstorm were mostly to blame for the destruction. Using Radar and other data sources (such as satellite imagery, upper air observations, surface observatories, etc.), meteorologists may track the development of a storm from its inception through the onset of catastrophic wind damage. Exploring several parameters for nowcasting the violent wind occurrences and hail connected with these storms is made possible by the database of these storms. Doppler radar observations revealed that the area of low echo strength is linked to a vortex signature, pointing to significant rotation of the midlevel air mass. It is now widely understood that the combination of the unique storm motion and the radar features of supercell storms is in large part the result of the presence of spinning updrafts. There were no reports of visible tornadoes, but the storms did cause extensive damage due to their hail and strong winds. Doppler weather radar data gathered at Patna is used to provide the Nowcasting Services. The remainder of this paper is organized as follows: In Section 2, the observed dataset and the study areas are discussed, and in Section 3, the extensive assessment and the discussion are provided. Section 4 discusses the implications of the newcasting, and finally, Section 5 wraps up the study.

2. Dataset and Observation

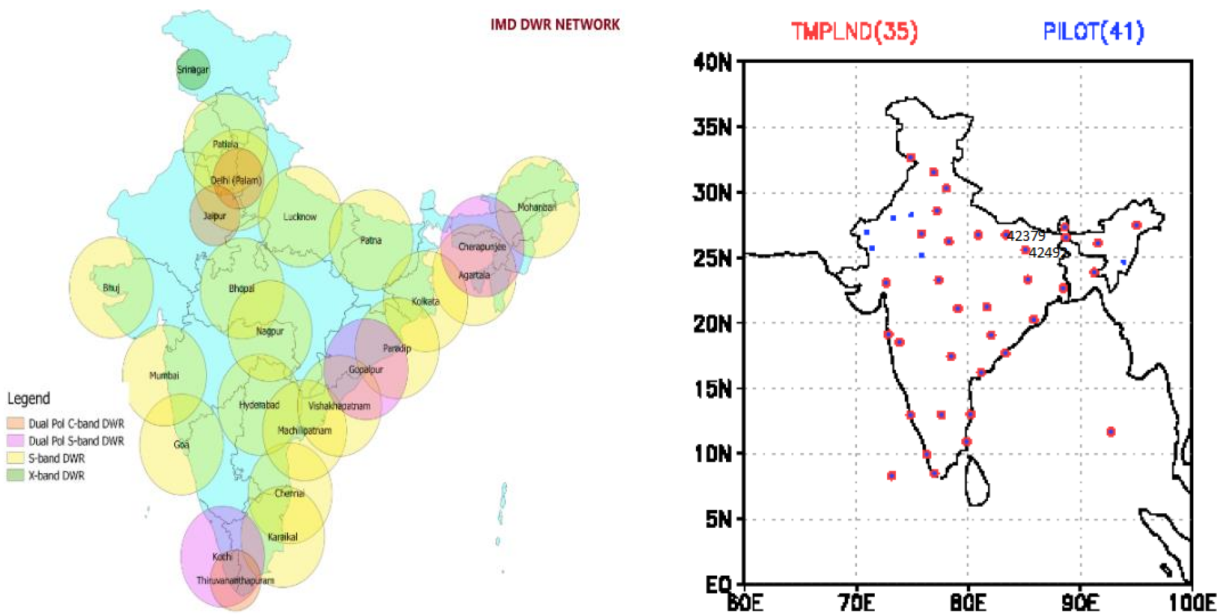
2.1. Dataset

S-band Doppler radar data from Patna, India, operated by the India Meteorological Department, were used to analyze the supercell's horizontal and vertical structure. The volumetric data was generated through automated scanning at 10 distinct elevation angles ranging from 0.2 degrees to 21 degrees. The total volume scan time was 10 minutes, with a maximum range of kilometers. All radar products in this investigation were generated using Vaisala's Interactive Radar Information System (IRIS). Analyzing the Doppler Weather Radar by-products has allowed us to learn more about the storm's anatomy. Doppler Weather Radar, Patna's location and range, as well as that of other IMD radars and upper-air sounding stations, are depicted in Figure.

Since it was operational in May 2011, the state of Bihar and the area around it have relied on this radar for accurate weather forecasts and analyses.

Independent of the local synoptic conditions, the initiation process is investigated using satellite-derived products. Using Radio Sounding/Radio Wind (RS/RW) measurements from Gorakhpur and Patna, we have analyzed the thermodynamic atmospheric conditions (instability and wind shear).

In addition to PPI Z (0.2 and 0.5), Plan Position Indicator-V (0.2), Max_Z (Maximum Reflectivity), Surface Rainfall Intensity, VVP (Velocity Volume Processing), and Precipitation Accumulation products, the radar can collect a number of other radar products, all of which are freely available to the public.



Source: IMD

Figure 1. *(a) India Meteorological Department Radar Networkand (b) Upper-Air Sounding stations across India.*

Table 1. *The characteristics of the S-band Doppler weather radar and details of its running program (automated).*

S.No.	Radar Parameter	Specifications
1.	Frequency	2.825 GHz
2.	Wavelength	10.61 Cm
3.	Peak Power Output	800 Kw
4.	Pulse Widths	1 µs (Velocity Mode), 2 µs (Low PRF Mode)
5.	Pulse Repetition Rate	300 Hz, 450 Hz, and 600 Hz
6.	Scanning Program	No. of Sacns-10, Time for One complete scans- Total:-10 Min (IMD-B: 6.22 Min, IMD C: 1.32 Min) Minimum Elevation-0.2 Deg, Maximum Elevation-21.0 Deg, Scan rate 12 Deg per sec Elevation angles:-IMD-B (0.2, 1.0, 2.0, 3.0, 4.5, 6.0, 9.0, 12.0, 16.0, 21.0), IMD-C (0.5, 1)
7.	Polarization	Linear Horizontal Polarization
8.	Receiver	Fully Coherent Digital Receiver linear Channel

2.2. Observations

As the Easterly winds at lower levels had been established for the previous four to five days and there had been thunderstorm activity on 4th April (mainly in Madhubani, Araria, Katihar, Purnea, and Munger) in Bihar, April 7th, 2018 appeared to be a weather day. Because there are lulls of three days, which could be an omen of impending severe weather (supercell). Hailstones larger than 7-8 mm have been reported in parts of the Paru (Muzaffarpur), Saraiya (Muzaffarpur) and Samastipur districts. The continuous weather watch was observed at Patna Airport (VEPT), where 1100 IST observations reported altocumulus and stratocumulus clouds. The North-East sector, where the supercell was nearest to the Patna airport observatory, was where cumulonimbus clouds were spotted after 1200 IST. The next day's newspaper headline drops across North Bihar like a white shroud. Eleven people have been killed across several districts in Bihar, with the lightning strike in Hajipur being responsible for one death (Vaishali). In Table 2, we can see the Doppler Weather Radar-derived properties of the supercell's physical state.

Table 2. *The characteristics of the physical parameters of a supercell are tracked by S-Band Doppler weather radar located at Patna.*

S.No.	Physical Parameter	Range
1.	Swathe	25-30 Km
2.	The extension (length)	220-230 Km
3.	Life Span	7-8 hours
4.	Speed of Thunderstorm	25-30 Kmph
5.	Time of Occurrence	04-12 UTC

Doppler weather radar located at Patna.

3. Results and Discussion

3.1. Synoptic Features and Accumulation of Cloud Mass in Foothills of Himalaya and Hilly Region of Nepal

According to the India Meteorological Department's meteorological inference, on April 7th, 2018, the primary synoptic features are (i) the east-west trough from West Rajasthan to Jharkhand, which stretches from southwest Rajasthan to Jharkhand via Madhya Pradesh and Chhattisgarh at altitudes of up to 0.9 km above mean sea level. (ii) a cyclonic circulation spanning from 1.5 kilometers above mean sea level is located over West Bengal and the neighboring country of Bangladesh. In order to keep the warm moisture coming from the Bay of Bengal, the second synoptic feature drives it in. In addition, during the evening of April 6th, 2018, the depth of moisture feeding jumped from 1.5 km to more than 2 km (weather radar observations).

Using satellite imagery from INSAT 3D and INSAT 3DR, we can see that a cloud mass is moving from West Uttar Pradesh to the Foothills of the Himalayas in the neighborhood of East Uttar Pradesh in a WSW (West South West) direction, and that another cloud mass is approaching from the Kathmandu Region and merging near the Foothills of Himalaya in the neighborhood of East Uttar Pradesh. As depicted in Figure 2. Thunderstorms begin in this combined cloud mass because it serves as the system that sparks updrafts. Additionally, these cells move north-westward under the influence of strong westerly winds and eventually reach the Indian state of Bihar.

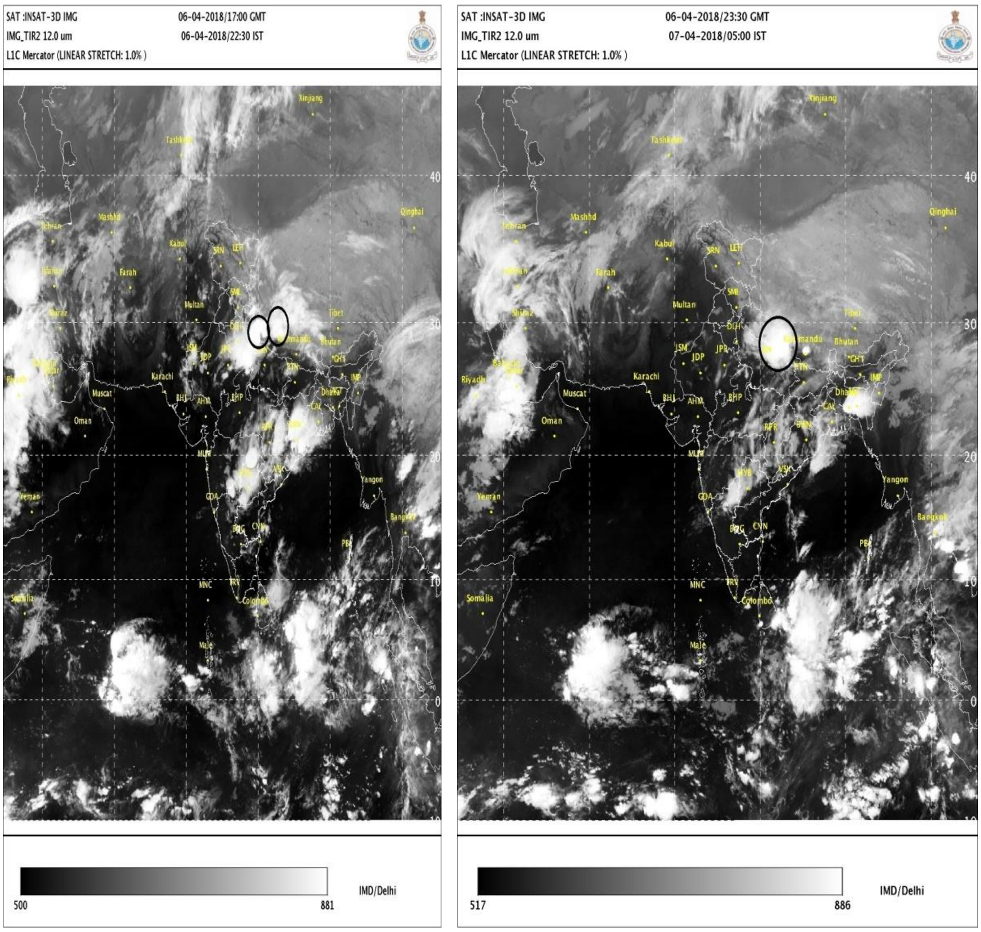


Figure 2. *Satellite imagery depicts the movement of two cloud masses merging into one another.*

3.2. Thermodynamic Environment

The Skew-T plot of the sounding of Patna (42492 on 6th April 2018 at 1200 UTC and 7th April 2018 at 0000 UTC) has been shown in Figure 3. Various stability parameters based on the sounding along with the freezing level and tropopause of Patna and Gorakhpur have been presented in Table 3. Convective instability and environmental shear play the most crucial roles in the generation and sustenance of severe thunderstorms. The Convective Available Potential Energy (CAPE), Level of Free Convection (LFC), and Bulk Richardson Number (BRN), as well as the winds responsible for moisture feeding, are important parameters describing the environment of convective storms.

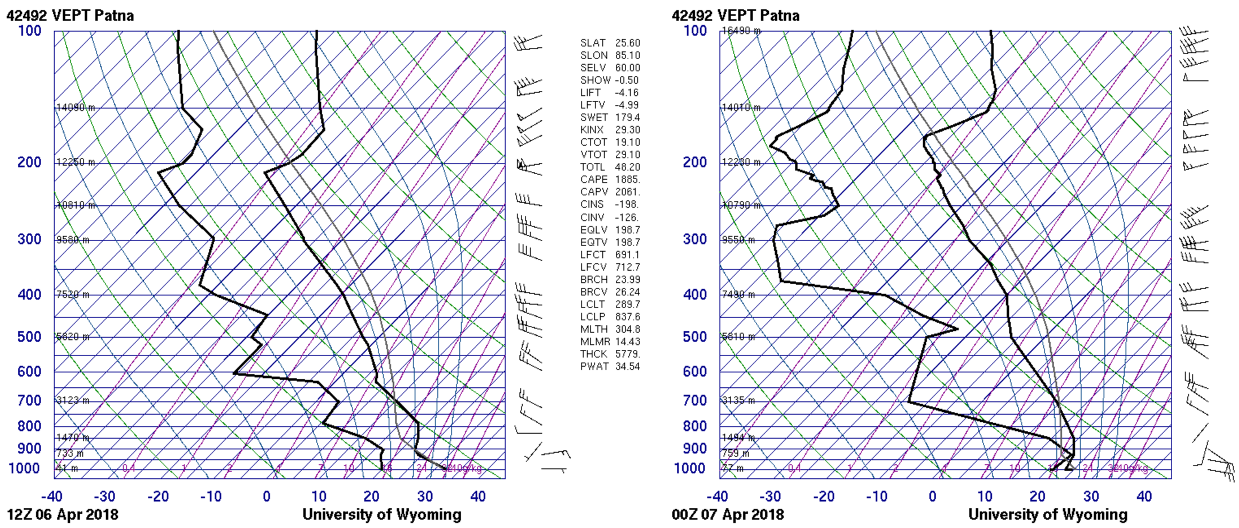


Figure 3. *Skew-T Plot of Patna Sounding on 6th April at 1200 UTC and 7th April 2018 at 0000 UTC.*

In the plains of Bihar, moisture-laden winds usually come from the Bay of Bengal, predominantly in the pre and post-monsoon season. These easterly winds bring a lot of moisture, with depths ranging from the surface to about 2-3 km. The 3-5 km winds from the surface act as mixing winds If it has cyclonic characteristics (anti-clockwise), then it creates buoyancy for thunderstorm development along with horizontal and vertical shear. Winds above 5 km mainly act as driving winds for storms In Figure 4, (VVP product of Doppler Weather Radar) and Max_V (Profile of Plan Position Indicator of Velocity) and Cross-section of Radial Velocity depict that there are cyclonic characteristics in winds as well as vertical shear. Also, wind speed increases with height. Also, it is seen that easterly winds are set for April 3–4, 2018, and there is no major thunderstorm that occurs during this period. so that the environment is full of energy (in the form of moisture). The direction of winds varies from 270 to 280, and the change in wind speed is from 5 knots to 40 knots, which is very pronounced. This type of situation leads to the generation of large-scale cross-wise vorticity. The horizontal vorticity tends to tilt vertically in the updraft region of the thunderstorm. Also, the subtropical westerly jet stream tilts the thunderstorm in the forward sector, which separates updrafts and downdrafts. The result of this process is the net increase in convergence, and if this process generates large enough values of positive vertical vorticity, a supracellular thunderstorm develops. When the wind shear inside the cell has a considerable vertical extension, the updraft and downdraft are so organized that they do not interfere with each other; instead, they complement the respective process. This particular feature distinguishes a supercell storm from an ordinary storm. They have indicated that a particular shear value of magnitude 20 m/s in the lower 6 km creates a favorable condition for organized updraft and downdraft and this, in turn, ffavors the sustenance of supercells. But this cannot be treated as a threshold value. In general, the deeper the environment is sliced, the more efficient the dynamic process that controls the supercell is. However, for the entire process, the value of shear should be taken together with the atmospheric instability.

Patna's sounding on April 6th, 2018 (1200 UTC) reveals a CAPE value of 1885 J/kg, which rises to 2088 J/kg by midnight on April 7th, 2018. At 1200 UTC on April 6th, CAPE is the greatest in Gorakhpur, just enough for the creation of supercell rotation. Therefore, a modest CAPE value favors the initiation of supercells in specific conditions, in addition to wind shear. Moreover, a high CAPE value is not associated with a more intense thunderstorm.

For their study, [10] analyzed soundings and concluded, among other things, that supercells that generate big tornadoes have lower LCLs than those that generate massive hail (2 inches or greater). They found that the average LCL for a supercell that produced a significant tornado was 0.78 km, while the LCL for a supercell that did not produce a big tornado was 1.23 km. The LFC height at the 1200 hours UTC sounding on April 6th, 2018 was 691.1 hPa, and the 0000 UTC observation on April 7th, 2018 was 721.1 hPa in Patna, but it was 669 hPa at Gorakhpur, which is a reasonable for the initiation of a thunderstorm. Increased potential for low-level acceleration is shown by the short LFC height, which suggests a high CAPE in the lower levels.

At 1200 UTC on April 6th, in Patna, the CIN readings were 198J/kg, a number that is a little higher than normal but not unprecedented for really intense thunderstorms. Model studies have shown that strong lower-level stability, expressed by a big value of CIN, acts against the development of intense surface vorticity, and a CIN value more than 150-200 J/kg extending through the lowest 2-3 km is not likely to create a severe thunderstorm. The CIN value near 100 J/kg is typically found to be related to supercell thunderstorms. The BRN was 23, which is conducive to the formation of thunderstorms.

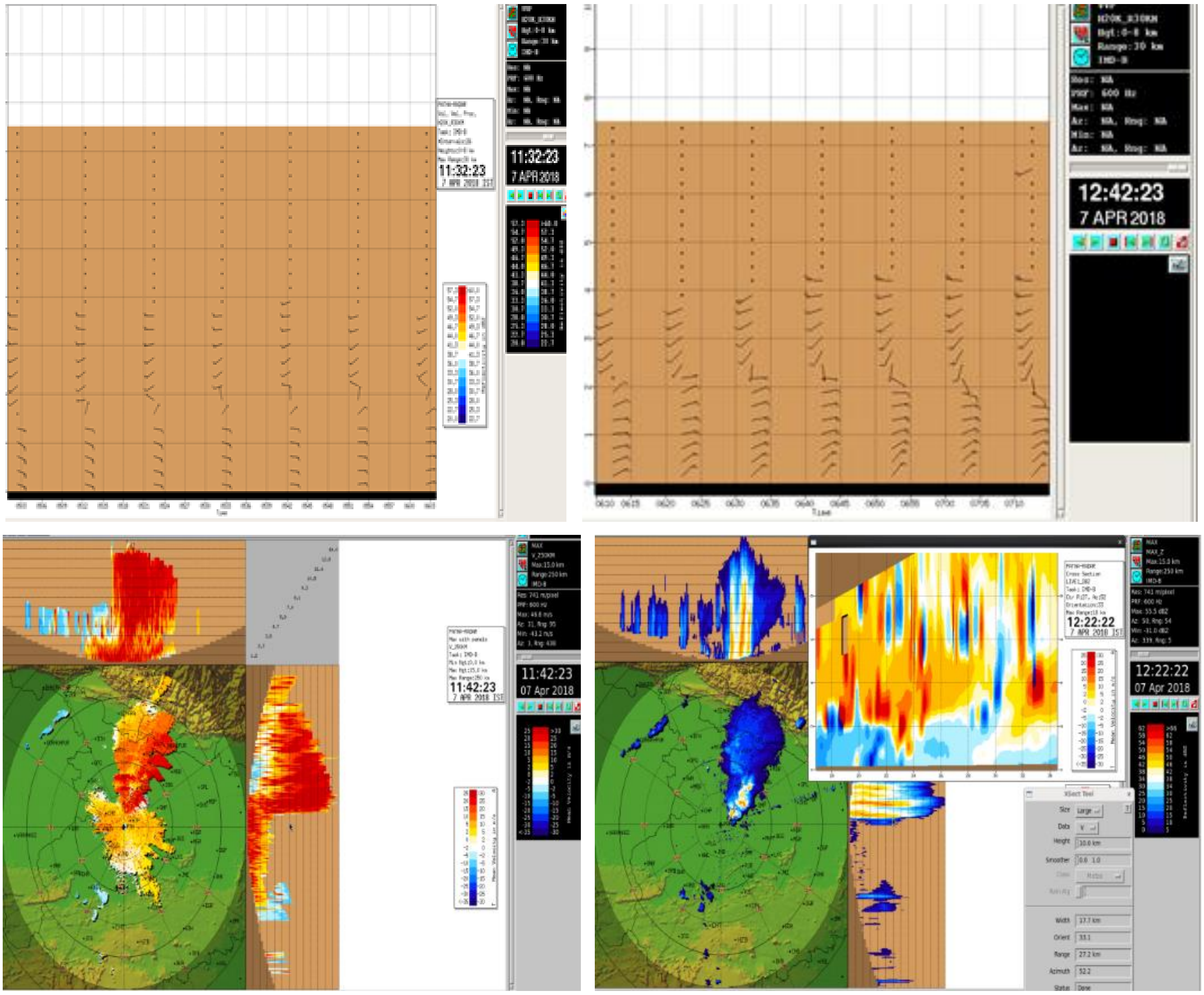


Figure 4. *VVP, Max_V, and Cross Section of Doppler Weather Radar Radial Velocity Products, Patna.*

Table 3. *Several environmental parameters like CAPE (Convective Available Potential Energy), CINE (Convective Inhibition Energy), BRN (Bulk Richardson Number), LFC (Level of Free Convection), etc.*

S.N		Date & Time	CAPE	CINE	BRN	LFC	Freezing Level	Tropopause
1.	Patna (42492)	6Th April 2018 1200 UTC	1885	198	23.99	691.1	588 hPa/4539gpm	080 hPa/17848 gpm
2.		7Th April 2018 0000UTC	2088	124	21.68	721.1	595 hPa/4619gpm	74.8 hPa/18220 gpm

S.N		Date & Time	CAPE	CINE	BRN	LFC	Freezing Level	Tropopause
3.	Gorakhpur (42379)	6Th April 2018 1200 UTC	1785	157	39.25	669.1	591.2 hPa/4510 gpm	--
4.		7Th April 2018 0000 UTC	435.9	286	4.36	663.3	624.2 hPa/4053 gpm	--

3.3. Radar Reflectivity

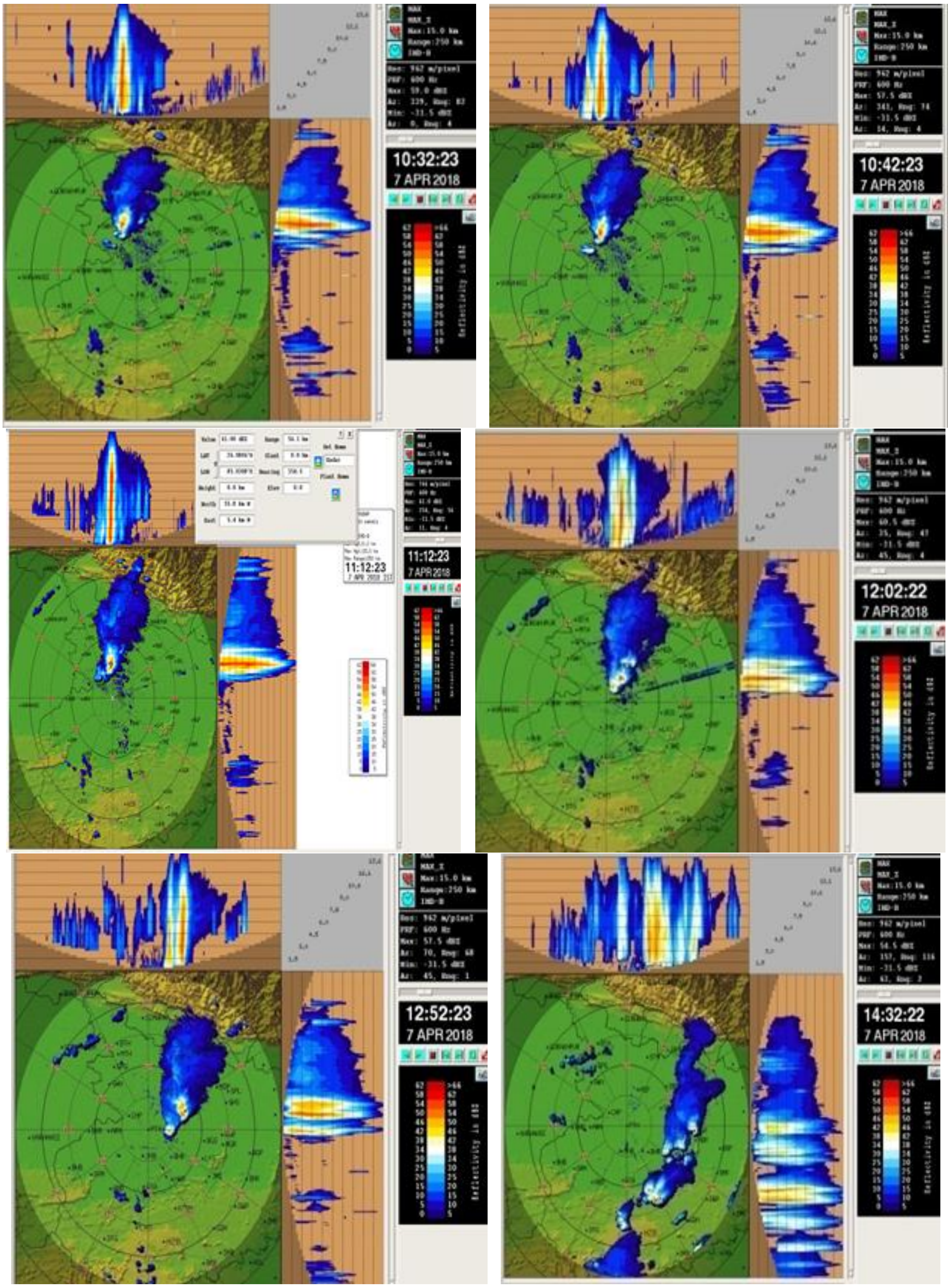


Figure 5. *Depicts the maximum reflectivity at various stages of a supercell thunderstorm's evolution.*

The intensity of the storm can be gauged from the radar reflectivity and other radar-derived products. Figure 5. depicts the maximum reflectivity picture (Max Z) for various phases of evolution between 0922 hrs IST and 1432 hrs IST, and Table 4 displays the characteristics of the determined parameters of doppler weather radar. The Maximum Reflectivity product offers a clear, concise representation of the echo height and intensity in a single interface. It's great for showing where severe weather is occurring. The product is derived from a volume scan task by first building a sequence of CAPPIs to span by the selectable layer, and then finding the maximum data value for the horizontal and two vertical projections, East-West and North-South. The radar image shows that three disorganised, weak thunderstorm cells interacted and travelled north-northwest near Gorakhpur (U.P.) at 0712 hours IST. After passing through Gorakhpur, the cells began to form into something more coherent; by the time they entered Bihar, they were well-organized. The highest reflectivity observed by Doppler Weather Radar Patna since its operation is 61 dBz, which it reaches at 1112 observations after initially reaching 44-45 dBz. Extreme damage was also reported in the neighbouring region of Muzaffarpur, Gopalganja, Vaishali and Samastipur districts of Bihar. Hail and strong winds are among the effects of this severe storm. Reflectivity and vertical extent were already striking during the early stages of this storm. This cell, unlike the others, consistently went over 14 km in height. During the time period of 10: 32 IST to 13: 52 IST, the vertical extension of this cell was well-defined above 14 kilometers, and its reflectivity hovered around 60 dBz. Outside of the well defined borders, the reflectivity of the cell declined dramatically in all directions except the North Sector. Hail of a specific type was most common, and the onset of cloud-to-ground lightning could be traced back to its distinct boundary and high reflectivity.

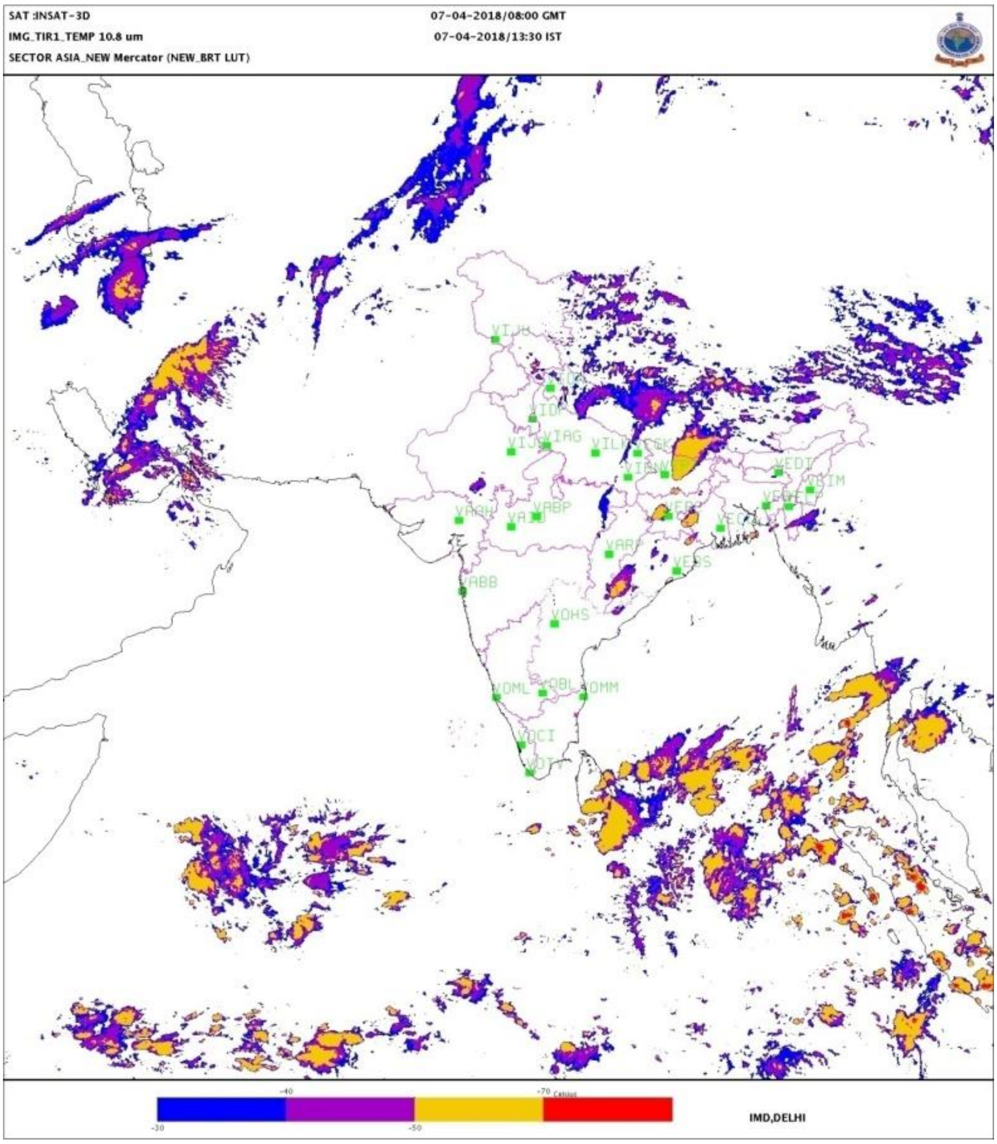


Figure 6. *Depicts the echo top reaching 14 km and contacting the tropopause, which is consistent with the -40 °to -70 ℃ cloud top temperature derived from INSAT 3D.*

Supercell was tracked from 1032 IST to 1432 IST, during which time it traveled at an average pace of 40 km/hr, as depicted in Figure 4. The cell first moved NNW before crossing into Bihar's territory, but once inside the state, it veered to the NW. Near the outskirts of Muzaffarpur (50 kilometers from DWR Patna, bearing 8°). The parent cell began mutilating, and the accompanying gust front produced daughter cells towards the southeast and southwest. At 14: 32 IST, further, mutilation occurred, and a few more cells formed in the SSE and SE regions. The echo tops began to deflate, and their original height of 20-24 km was now just 10-12 km. Between 1012 and 1252 UTC/GMT, the system moved between Gopalganj and Samastipur, where the cell acted like a supercell. After that, it began splitting into multiple daughter cells, eventually moving towards Jharkhand, and losing its reflectivity when night fell. After solar insolation ceased, thunderstorms in Bihar and Jharkhand were less intense. A combination of convergence, advection, and lifting is provided by this LLJ to the thunderstorm. The cell's core reflectivity was more than 55 dBz during its entire lifetime. The parent cell kept its reflectivity even after being mutilated on the southwest and southeast sides. Figure 5. depicts the echo top reaching 14 km and contacting the tropopause, which is consistent with the -40° to -70℃ cloud top temperature derived from INSAT 3D.

Table 4. *The characteristics of the radar parameters of a supercell tracked by S-Band doppler weather radar located at Patna.*

S. No.	Radar Parameter	Range
1.	VIL (mm)	30-60 mm
2.	VIL Density (mm/Km)	3-4 mm/km
3.	Height	12-16 Km
4.	Vertical dBz Gradient from surface to (10-14 Km)	50-61 dBz
5.	Max_Z	50-61 dBz
6.	Updraft Speed	20-30 mm

3.4. Vertical Profile of Radar Reflectivity

The environmental wind shear together with the updraft strength in a convective cell determines the vertical distribution of reflectivity. The echo at low, middle, and upper levels tends to be vertically aligned when the shear is weak. Using ground-based radar, Yuter and Hauz have suggested that updraft and high reflectivity tend to coincide at a high level, although the correlation is weak. As the cell attains a mature stage, the liquid water content is evenly distributed along the entire column, and this gives a uniform distribution of reflectivity. It is seen that vertical reflectivity is not uniformly distributed from 0922 Hrs IST to 12: 32 Hrs IST. However, the 1432 IST imagery clearly shows that the reflectivity is uniform and the thunderstorm is mature. Following that, the echo height began to decrease, indicating that the vertical reflectivity is uniformly distributed in the mature stage.

3.5. Surface Rainfall Intensity and Precipitation Accumulation Rainfall

The maximum rainfall rate reported from radar estimates is 20–50 mm/hr, which is very high. In the absence of an observatory in the swathe of the supercell, the rainfall rate was not verified. The only existing daily rainfall monitoring station, Rewaghat (Saran), which is on the fringe of the swathe, reported 10.4 mm of rainfall. Precipitation Accumulation Picture of Radar Imagery presents 10-20 mm of rainfall, which is in concurrence with reported rainfall and satellite-derived precipitation.

3.6. Vertical Integrated Liquid (VIL)

The VIL product may calculate several values throughout an atmospheric layer or height range. Integration in liquid, or averaged reflectivity, can be calculated by this method. These can be highly accurate predictors of heavy precipitation from the storm is useful for detecting precipitation aloft that is not making it to the ground, a situation that may be missed by a PPI or CAPPI display because of the limited depth to which these instruments can look. High VIL readings are highly predictive of severe storms and hail if the layer height is above the freezing level. Figure 7 displays the VIL profile of a supercell thunderstorm cell. When the picture was taken at 05: 42 UTC, the cell was between the Siwan and Muzaffarpur districts of Bihar. The cell's classic Hook form is readily seen. The presence of large-sized hail was confirmed by ground truth and the VIL value is around 32 mm. Table 4 shows the derived Doppler weather radar, Patna features for a supercell storm, including the VIL Range in millimetres and the VIL Density in millimetres per kilometre.

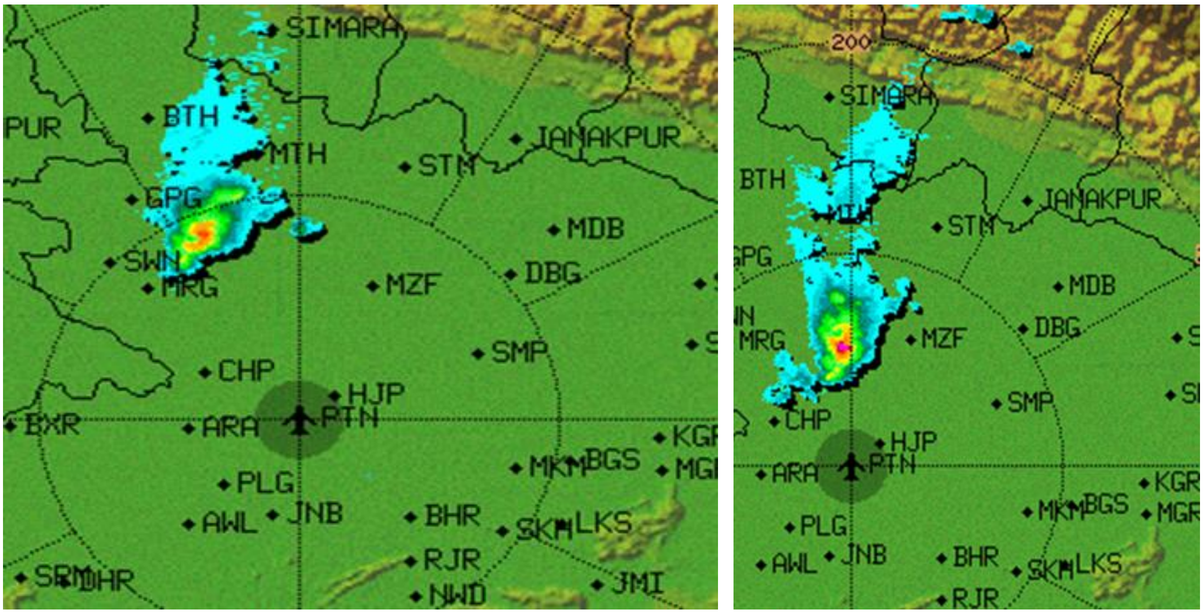


Figure 7. Perfect Hook shape echo and VIL Product tracked by Doppler Weather Radar Patna.

While the updraft of a supercell thunderstorm gradually decreases as the storm progresses, the VIL drops suddenly when the echo tops collapse and the downdraft increases.

4. Implications for Nowcasting

The damaged tracks depicted are most probably caused by non-tornadic winds. Here we summarise important aspects of the nowcasting of supercell storms:

4.1. Forecasting of the Initiation of Severe Thunderstorm

The Role of Orography in the Development of Severe Thunderstorms

Significant synoptic features may play a role in the destabilization of the atmosphere as a whole. Deep convection can be directed to a specific location by a number of factors, including solar radiation and topography, but ultimately it is these two factors that determine where convection will begin. Early detection of orographically produced convection can be aided by satellite data.

Conditions in the inflow regions of developing thunderstorms

Things like instability and wind shear affect how the storm moves and what it looks like on the inside. Knowing these factors can help you determine the likelihood of a supercell storm breaking out in the area. This is because the relevant parameter is subject to unpredictable modulations as a result of the combined influences of orography and already-established storms. That makes it harder to depict operational sounds over time and space.

It is believed that continuous observations from ground stations, sounding stations, and weather radars are the most useful tools for assessing such modulations at the regional level. Factors like instability and wind shear steer the motion and internal structure of the storm. To obtain an idea of whether the outbreak of supercell storms is possible, one needs to know these conditions. The problem is that the combined effects of orography and already-developed storms lead to unpredictable modulations of the relevant parameters. As a result, the spatial and temporal representation of operational sounds is hampered. Most people think that continuous measurements from ground stations, sounding stations, and weather radars are the best way to measure these changes on a local scale.

4.2. Spotting Developing Supercell Storms

Doppler weather radar is the most promising tool for the detection and identification of supercell storms. Doppler weather radar yields volume scan data with a temporal resolution of 10 minutes. The most important thing is to identify the gust front track, which will help in identifying the probable tracks of the supercell. Still, after looking at many tools, there aren't any specific tools that can be used to find the likely track and the exact time lag.

5. Conclusions

The features and sequence of weather events do indicate the presence of supercell storms. The entire duration of activity lasts about 7-8 hours, and the storms go through a series of generation and regeneration process. This indicates the complementary role played by the updraft and downdraft. This is unlike ordinary thunderstorms, where they have an adversary role to play. The main purpose of the study was to find criteria that contribute to improving the nowcasting of severe thunderstorms. The time periods of the damage tracks were determined with the help of Doppler Weather Radar Data. A series of criteria have been investigated that document the development and evolution of the storm. The following main results were found:-

1. The storms developed in the hilly Nepal regions and propagated towards the Gangetic Plains and accumulated clouds. In hilly regions, it started about 12–14 hours before the commencement of thunderstorms.
2. The thunderstorms were precisely detected with the Doppler weather radar about 2-3 hours before the disastrous weather occurred on the ground.
3. The time periods of the damage tracks coincided with explosive cellular growth.
4. Cloud to ground lightning occurred mainly in the fringe regions of the thunderstorms where the reflectivity falls sharply.
5. The height of thunderstorms above the freezing level plays an important role in determining hailstorms.
6. The characteristics of the radar parameter of a supercell storm have been derived which may be used for further analysis and nowcasting of the supercell storm.

A larger storm sample would allow statistical tests to determine the usefulness of the various criteria for the identification of severe thunderstorms.

Abbreviations

Acronyms	Full Name
DWR	Doppler Weather Radar
Max_Z	Maximum Reflectivity
Max_V	Maximum Velocity
VIL	Vertically Integrtaed Liquid
VVP	Volume Velocity Profile

Author Contributions

Anand Shankar is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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