The tornadic thunderstorm events during the 1998-1999 South African summer

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Abstract

Due to the occurrence of several tornadoes in the summer of 1998/99 it was decided to research the occurrence of tornadic events over South Africa. A general overview of tornadoes is given along with a way to classify the intensity of these events. This is followed by a section on the frequency, occurrence and location of tornadoes over South Africa. Severe weather and/or tornado events can be expected when certain atmospheric conditions prevail. These are defined and indications of threshold values for severe weather are given. Three tornadic events which occurred in 1998/99 in South Africa are then discussed by means of these parameters. The first is the Harrismith tornado in November 1998 which was classified as an F3 tornado by the Fujita-Pearson (FP) classification. The tornado which occurred in Mount Ayliff in January 1999 was seemingly the most severe ever reported - FP classification F4 - and was the next case considered. Finally a short summary on the Umtata event of December 1998 is given. The aim with these case studies was to see which synoptic, mesoscale, model and radar characteristics could be identified to indicate severe weather and/or tornado possibilities. Knowledge of these indicators can help operational forecasters to know what to look for in future severe weather events in order to forecast with greater accuracy. Reasonable success was achieved through the use of model data fields to "see" tornado signatures or at the very least indicators of severe weather conditions. With the aid of real-time radar to monitor the development of the severe storms (in two of the cases) it was possible to identify the tornado cloud structure. Without radar coverage not much can be said about these kinds of events.

Introduction

A tornado is defined as a violently rotating column of air with small diameter extending from a thunderstorm to the ground (Goliger et al., 1997). Tornadoes are small-scale by-products of thunderstorms, with less than 1% of thunderstorms producing tornadoes. Tornadoes occur in many parts of the world, but are most frequently found in the United States of America east of the Rocky Mountains during the spring and summer months (NOAA Pamphlet, 1995).

Despite all the research into the origin and prediction of tornadoes (mainly in the USA), this phenomenon is still not fully understood or predictable (Goliger et al., 1997). Until the middle of 1998 a general public perception prevailed that tornadoes do not occur in South Africa, but occur almost exclusively in the USA. This perception seems to have changed during the 1998-1999 summer season, with tornadoes accompanying several severe storms over the eastern escarpment, generating widespread interest through extensive news media coverage. Severe storms associated with extensive wind damage can, however, be erroneously reported as tornadic storms.

An important point to remember is that a tornado's size is not necessarily an indication of its intensity. Large tornadoes can be weak, and small tornadoes can be violent and *vice versa*. The life cycle of the tornado should also be taken into consideration. A "small" tornado may have been larger at one stage but is at the "shrinking" stage of its life cycle. The Fujita-Pearson (FP) scale is based on damage and not the appearance of the funnel, and is shown in the **Appendix** (Fujita, 1973a; b). Damage varies from F0 to F5, with increasing numbers indicating increasing damage and therefore increasing intensity. Storm observers often try to estimate the intensity of a tornado, basing their judgement on the rotational speed and amount of debris being generated as well as the width of the tornado. However, the official estimate (in the USA as well as South Africa) is only made after the tornado has passed. The FP scale is, however, subjective and varies according to the degree of experience of the surveyor.

During the 1998/99 summer season seven "tornadoes" were reported in the Eastern Cape of which only three have conclusively been identified as tornadoes (Van Niekerk and Sampson, 1999). One of these, which occurred in Mount Ayliff, was confirmed as an F4 tornado. This event seems to be the most severe ever reported and will, along with the Harrismith event, be discussed in this paper.

Summary of South African tornado history

The CSIR maintains a database of tornadic activity (Goliger et al., 1997), which currently contains nearly 200 events dating from 1905 to 1996. A map of the tornado events over the eastern parts of South Africa up to 1997 (unfortunately excluding the 1998/1999 season) is given in Fig. 1. Most tornadoes have been observed over the eastern escarpment areas of the subcontinent.

Classification of tornadoes in Southern Africa was based on an assessment of the damage, with less emphasis placed on the path length and width (Goliger et al., 1997). Where insufficient information was available for positive classification, the tendency was towards a lower FP-scale intensity. Confirmation of tornadic events remains a challenge in South Africa. The authors are aware of more than 20 severe storm events during 1989 to 1998, which were not surveyed for damage and/or evidence of tornadoes. There exists a need to carry out damage surveys within two days of a severe event.

The tornadoes documented by Goliger et al. (1997) had the following characteristics: They occur over a broad spectrum of

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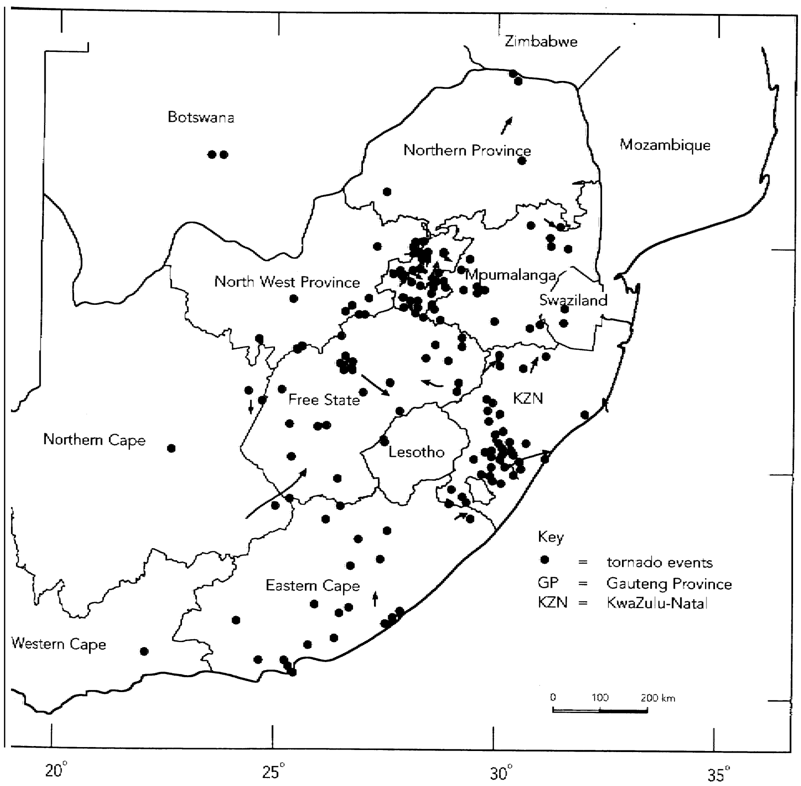


Figure 1
Distribution of tornado events over the eastern parts of South Africa in the period 1905-1997 (after Goliger et al., 1997)

intensity, lifetime and size, with path lengths varying form 5 to 170 km, path widths from 20 m to 1 700 m and intensity from F0 to F3. A seasonal distribution of tornadic events shows that most tornadoes occur in midsummer (November to March). Most of the tornadoes were assessed at F1 intensity, while more than 90% of all tornadoes were classified less than F2. Only about 8% of the documented tornadoes were F3. The period 1948 to 1996 contains 174 tornadoes with an average of about four events per year. The time of day at which most tornadoes occur in South Africa is typically between 16:00 and 19:00 (all times are local - SAST).

Conditions conducive to severe storm and/or tornado outbreaks and methods to identify these conditions

McNulty (1995) argued that it is very important for forecasters to be able to distinguish between severe and non-severe thunderstorms. Studies by McNulty (1988) and Johns and Doswell (1992) have indicated that the three determining factors in such a decision are, firstly, extreme instability, secondly, strong vertical wind shear and thirdly, mid-level dry air or an intrusion of dry air at mid-levels.

Goliger et al. (1997) list the meteorological features necessary for tornado formation as, firstly, a deep layer of mid-atmospheric dry air above a moist surface; secondly, steep moisture and temperature gradients; thirdly, high surface temperature; fourthly, low-level convergence and upper-air divergence; fifthly, vertical wind shear; and lastly, atmospheric instability.

Several parameters can be used to get an indication of the stability or instability of the atmosphere:

- **Convective available potential energy (CAPE)** represents the amount of buoyant energy available to accelerate a parcel vertically (Moncrieff and Miller, 1976). McNulty (1995) considered CAPE values above 3 000 J·kg^{1} as an indication of "extreme instablility". A CAPE value greater than 1 500 J·kg^{1} was suggested by Rasmussen and Wilhelmson (1983) as necessary for supercells to form, but Johns and Doswell (1992) found that a number of supercells over the United States also arise in situations with CAPE values of less than 1 500 J·kg^{1}, as in cases where the shear is high. Johns et al. (1993) and Korotky et al. (1993) extended the use of CAPE for tornadic environments to include high CAPE/low-shear as well as low CAPE/high-shear situations.
- The **Lifted Index** measures the difference between a parcel's temperature compared with the environmental temperature at 500 hPa, after the parcel has been lifted from the lifting condensation level (LCL) (AWS, 1990). Experience in the US has shown that Lifted Indices with values less than -6°C can be considered to be extreme (McNulty, 1995) with heavy to strong thunderstorm potential (AWS, 1990).
- The **Showlater Index** is calculated by lifting a parcel dry adiabatically from 850 hPa to its LCL, then moist adiabatically to 500 hPa and comparing the parcel vs. environmental 500 hPa temperature. Values of less than -6 are indicative of extreme instability and possible tornadoes (AWS, 1990).
- Miller (1972) introduced the **Total Totals Index** for identifying areas of potential thunderstorm development. It accounts for both static stability and the presence of 850 hPa moisture. Values of more than 50 are adequate for severe thunderstorms with tornadoes (AWS, 1990).
- The **SWEAT Index** evaluates the potential for severe weather by combining into one index several instability parameters like low-level level moisture, instability, low-level jet, upper level jet and warm advection. Studies in the USA show that severe thunderstorms do not occur with SWEAT indices less than 272, and tornadoes with SWEAT indices less than 375 (AWS, 1990).

Figure 2
Funnel occurring in the Harrismith tornado

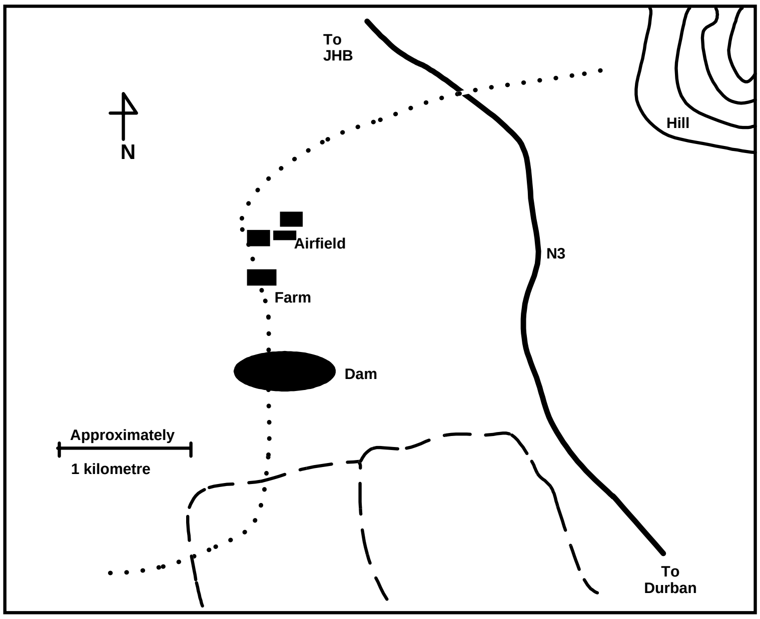


Figure 3
Path of the Harrismith tornado (Goliger and Van Wyk, 1999)

Strong shear contributes to the development of rotation within a thunderstorm (Davies-Jones, 1984). Shearing can be measured in several ways:

- According to Colquhoun (1987) the **vertical wind shear** from the surface to 600 hPa and surface to 500 hPa respectively can be used as indicators of tornado intensity. If the surface to 500 hPa vertical wind shear exceeds 29 knots, or the surface to 600 hPa wind shear exceeds 22 knots, F0 to F2 tornadoes can be expected.
- The **Bulk Richardson Number** (BRN) is used to quantify the relationship between buoyant energy and vertical wind shear (Weisman and Klemp, 1982), both of which are critical factors in determining storm development, evolution and organisation. Weisman and Klemp (1986) suggest that BRN values of between 10 and 40 favour supercells. Because tornadoes are usually associated with supercell thunderstorms, indicators of supercell formation will also have the possibility to produce tornadoes.
- Moller et al. (1994) stated that supercell environments are associated with the spatial and temporal limits of two elements: deep, moist and persistent convection and vertical wind shears conducive to mesocyclones. Davies-Jones et al. (1990) suggested that the 0-3 km **storm relative helicity** (SRH) is an indicator of mesocyclone formation. Helicity is defined as the product of the storm relative wind speed and the stream-wise vorticity (Davies-Jones et al., 1990). The application of SRH is related to the fact that 40 to 50% of the time, tornadoes are associated with mesocyclones, and severe weather occurs with mesocyclones 80% of the time. Values of SRH smaller than -150 $m^2 \cdot s^{-2}$ indicate the potential for mesocyclones and possible tornadoes, and can be used as an alert to forecasters (McNulty, 1995).
- Thompson (1998) considered the storm inflow and mid- and upper-level **storm relative wind speeds** and showed that they provide a more comprehensive picture of the environment favouring supercells with sustained low-level mesocyclones and tornadoes than do the BRN or SRH. He made use of a 48 km horizontal resolution Eta model (Black, 1984). Thompson found that 81% of 69 storms were associated with tornadoes if the mid-level (500 hPa) wind speeds were greater than 10 $m \cdot s^{-1}$, while 87% of the cluster ranged from 8 to 19 $m \cdot s^{-1}$. He also saw that most of the surface wind speeds were between 8 and 22 $m \cdot s^{-1}$ for tornadic supercells, while the storm relative wind speeds at 250 hPa were distributed between 8 and 35 $m \cdot s^{-1}$. He found that 500 hPa storm relative wind speed differentiates the **best** between tornadic and non-tornadic supercells.

Case Study 1: Harrismith tornado: 15 November 1998 at 15:00

General features

A tornado struck Harrismith (located at 28°17' S and 29° 08' E) between 15:15 and 15:30 on 15 November 1998. It was accompanied by heavy rain and hail. This was probably the most "spectacular" of all local tornadoes with the best photographical coverage of the funnel itself (Fig. 2). The total length of the damage path is about 9 km (Fig. 3) stretching from south-west to north-east. Van Wyk and Goliger (CSIR) compiled a report on the events, damage and path of the tornado (Goliger and Van Wyk, 1999).

Figure 4
Damage in Intabazwe (Goliger and Van Wyk, 1999)

Figure 5
Remains of a telephone line (Goliger and Van Wyk, 1999)

Figure 6
Damage to a farmhouse (Goliger and Van Wyk, 1999)

Description of the damage and impact on human lives

According to Goliger and Van Wyk (1999) the following damage was reported. In the township Intabazwe (see Fig. 4) damage to 50 houses was reported. This included damage to roofs and other minor outdoor structures. The damage path was about 200 to 300 m wide. Debris were, however, scattered even further, up to 2 km away from the township. Signs of extreme wind speeds were observed, including pieces of roof sheeting folded around a telephone post (Fig. 5). Figure 6 shows the devastation to buildings on a nearby farm. The entire roof was blown away and the buildings suffered severe structural damage. All gable walls and some structural walls (220 mm thick) were leveled. Trees were uprooted and two vehicles were uplifted and carried for 200 to 300 m also being utterly destroyed. Five other vehicles on the premises suffered damage due to flying objects and/or were covered with debris. A power line supported by two 230 mm bluegum poles was flattened. At the local airport severe damage occurred to three hangar structures. Three of the aircraft and a helicopter were damaged. A large amount of debris was scattered throughout the airfield. Telephone and power lines in the vicinity of the N3 were blown over, covering a distance of approximately 300 to 500 m.

Newspapers claimed that the total damage cost was estimated at between R3 m. and R4 m. According to newspaper reports 15 people were injured and 750 left homeless. The damage to property included about 50 formal houses and 100 informal houses.

The damage survey was completed by Goliger and Van Wyk on the day after the tornado. No aerial survey was done. Due to the width of the path and the magnitude and severity of the damage, preliminary classification indicates an F2 (perhaps even F3) tornado event on the Fujita scale.

Weather patterns and analysis at 14:00 on 15 November 1998

At the 850 hPa level a high-pressure system was present over the north-eastern parts of the country, while a low/trough extended over the Cape interior. A weak high-pressure system was situated east of the country (Fig. 7). Temperatures above 30°C were recorded over the central interior, while cooler conditions (temperatures less than 25°C) were reported over the south-eastern parts of the country.

A high-pressure system was present at 500 hPa with westerly flow over the eastern Free State, while at 700 hPa the wind came from the north-west. Humidity at 500 hPa was 44% at Bloemfontein and 67% at Durban, while at 700 hPa it was 30% and 26% at Bloemfontein and Durban, respectively.

Measured rainfall was generally less than 10 mm. Although it was reported that a great deal of rain fell in Harrismith, no official reports are available.

Mesoscale analysis

A steep temperature gradient was observed over the eastern parts of the country. Temperatures in excess of 30°C (and even up to 39°C) were reported over the central interior, while temperatures south and east of Harrismith were in the order of 18 to 25°C. The cooler air formed a tongue extending from the south-east north-westwards into the north-eastern Free State. A distinct dryline - where dewpoint temperatures ranged from 20°C just east of Harrismith to 7°C west thereof - was visible (Fig. 8). It has often been found that the dryline can be the trigger mechanism for the development of severe thunderstorms (Bluestein and Crawford, 1998). Wet bulb potential temperatures were in excess of 20°C with even higher values (exceeding 24°C) over Mpumalanga and KwaZulu/Natal. Pressures values were dropping at a rate of 2.5 hPa per 3 h over the eastern Free State. The south-easterly flow from the Indian ocean was perpendicular to the topography (Drakensberg) which possibly added to the uplift of this airmass.

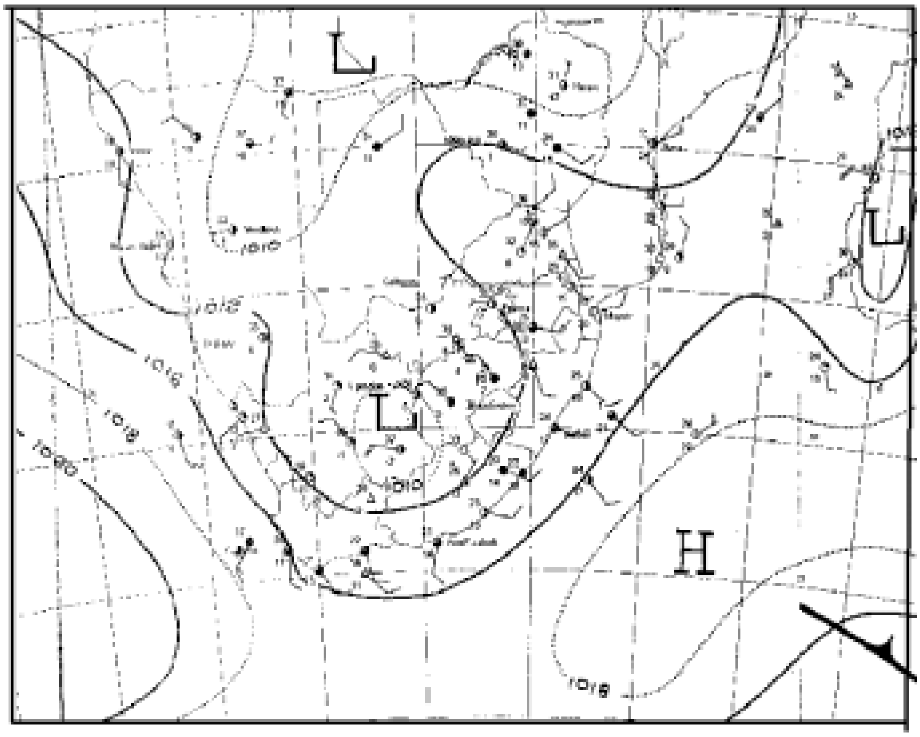


Figure 7
Surface pattern at 14:00 on 15 November 1998

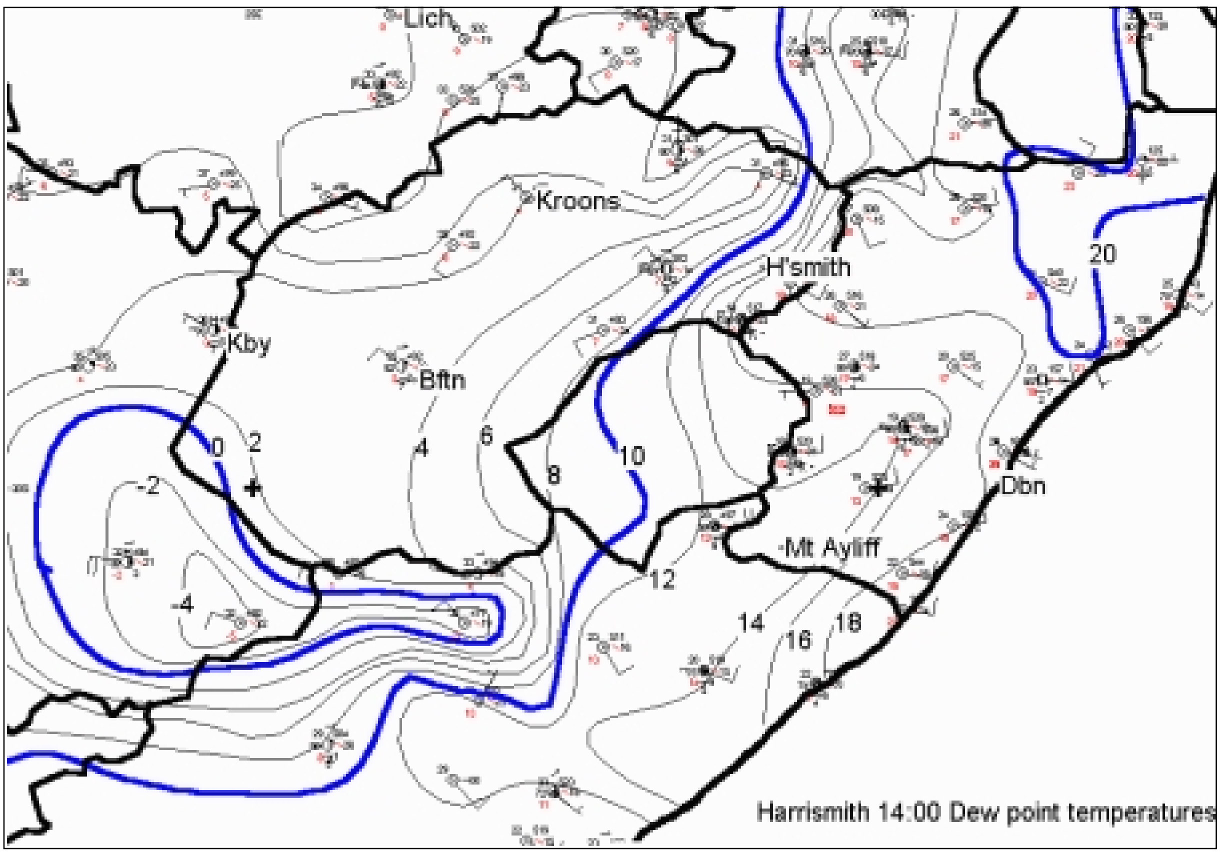
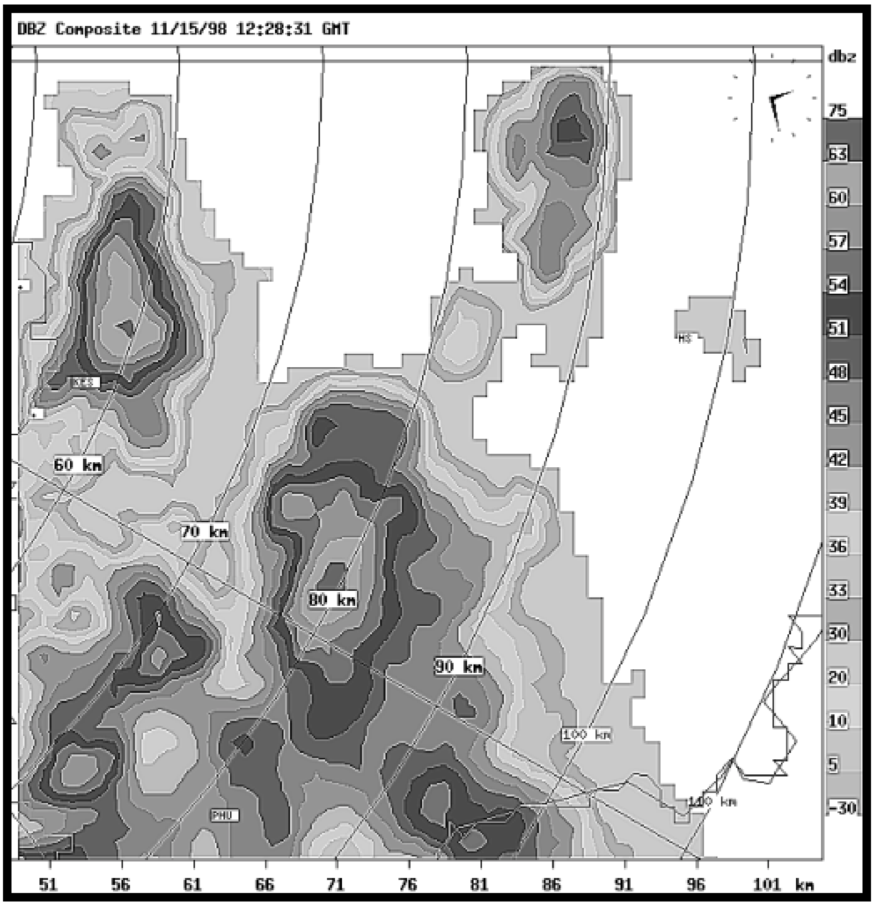
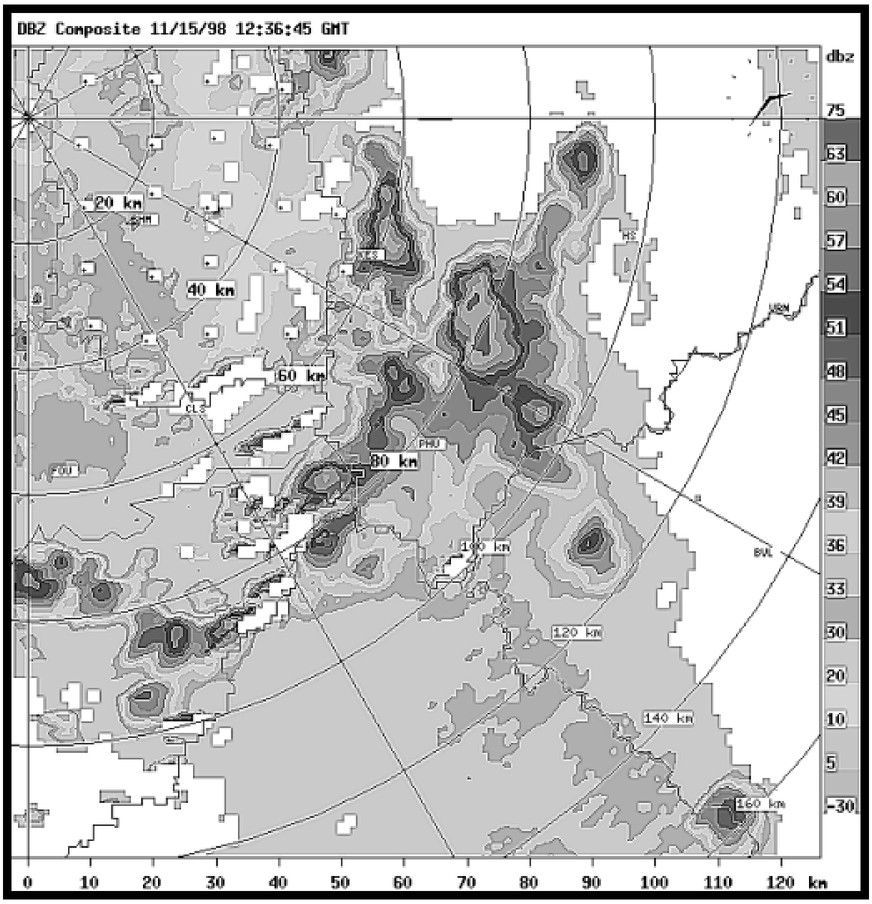


Figure 8
Dew-point temperature (°C) analysis from observations at 14:00 on 15 November 1998





Radar imagery during the event

For this study the S-band MRL-5 radar at Bethlehem was used. At 14:16 the storm was 80 km south-east of the radar with maximum reflectivities between 60 and 63 dBz and storm tops at 16 km. At this time there were three separate convective cells visible lying in a north-west/ south-east orientation. During its lifetime the storm moved in a north-easterly direction at speeds of between 13 and 20 km·h^{-1}. At 14:28 the storm cell had intensified and core reflectivities were in excess of 63 dBz at a height of 6 km (Fig. 9). A dual core was evident at 14:36 (Fig. 10) with the highest reflectivities above 63 dBz at 5 to 8 km. The storm seemed to have lost some of its intensity after this, until it merged with development which took place on its northern flank at 14:45. By 14:53 the reflectivity pattern still showed two cores which were higher than 63 dBz. One extended from 5 to10 km in the vertical with a 4 km horizontal extent. Storm tops at this stage were of the order of 18 to 20 km. Visser (2000) developed a method (called the Storm-Structure-Severity method) to identify the stages of development of cells within a storm with regard to new convective development or dissipation. According to his analysis the dominating structure of the storm at this stage would have been centered in the top of the cell, indicating that there must have been strong updrafts at the time. A bow echo, similar to those described by Weisman (1993), was evident at 15:01. Strong updrafts were still evident on the eastern flank of the storm, while an anti-clockwise rotating mesocyclone could be seen on the northern flank and a clockwise rotating mesocyclone on the southern flank of the storm (Visser, 2000). By 15:09 the double core structure was still present with reflectivities in excess of 63 dBz. The end of the strong updrafts and the collapse of the mesocyclones could be seen at 15:21 (Fig. 11) with a large descending rain mass (Visser, 2000). After this time the storm split into two and later three cores, while continuing its eastward movement without any further severe weather.

Figure 9 (top left)
Bethlehem's MRL-5 radar - composite radar image at 14:28 on 15 Nov. 1998

Figure 10 (bottom left)
Bethlehem's MRL-5 radar - composite radar image at 14:36 on 15 Nov. 1998

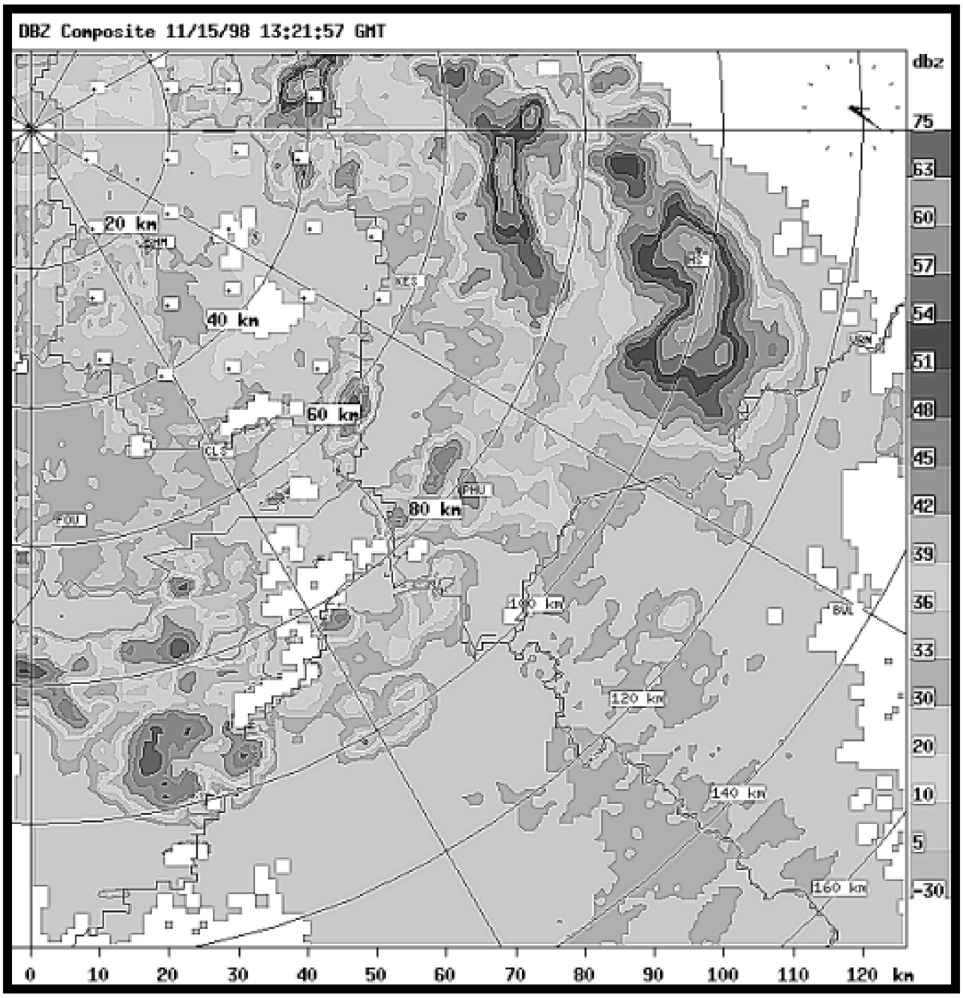


Figure 11
Bethlehem's MRL-5 radar - composite radar image at 15:21 on 15 November 1998

Eta Model data for 14:00 on 15 November 1998

The analysis from the locally operated Eta modelling system (Black, 1984), valid at 14:00, was used. This model has a 48 km horizontal resolution and 38 levels in the vertical.

Moisture indicators from model data:

Variable	Value
Relative humidity at 850 hPa	35%
Relative humidity at 700 hPa	60%
Moisture convergence in the boundary layers combined with 700 hPa uplift (Fig. 12)	A strong influx of moisture was evident from the south-east, with weaker influx from the north-west; convergence was taking place north-west of Harrismith, but no 700 hPa uplift was shown in the area.

Instability parameters from the model data:

Variable	Value	Meets threshold?
CAPE	200 $J \cdot kg^{-1}$	×
Lifted Index	-1 to -2°C	×
Showalter Index	-1 to -3°C	×
Total totals Index	50 to 55	✓
SWEAT Index	200	×

Shearing indicators from the model data:

Variable	Value	Meets threshold?
Surface to 500 hPa shear	< 29 knots	×
Surface to 600 hPa shear	< 22 knots	×
BRN	< 10	×
SRH	> -150 $m^2 \cdot s^{-2}$	×
SR wind speed at the surface	< 8 $m \cdot s^{-1}$	×
SR wind speed at 500 hPa	8 - 12 $m \cdot s^{-1}$	✓
SR wind speed at 250 hPa	18 $m \cdot s^{-1}$	✓

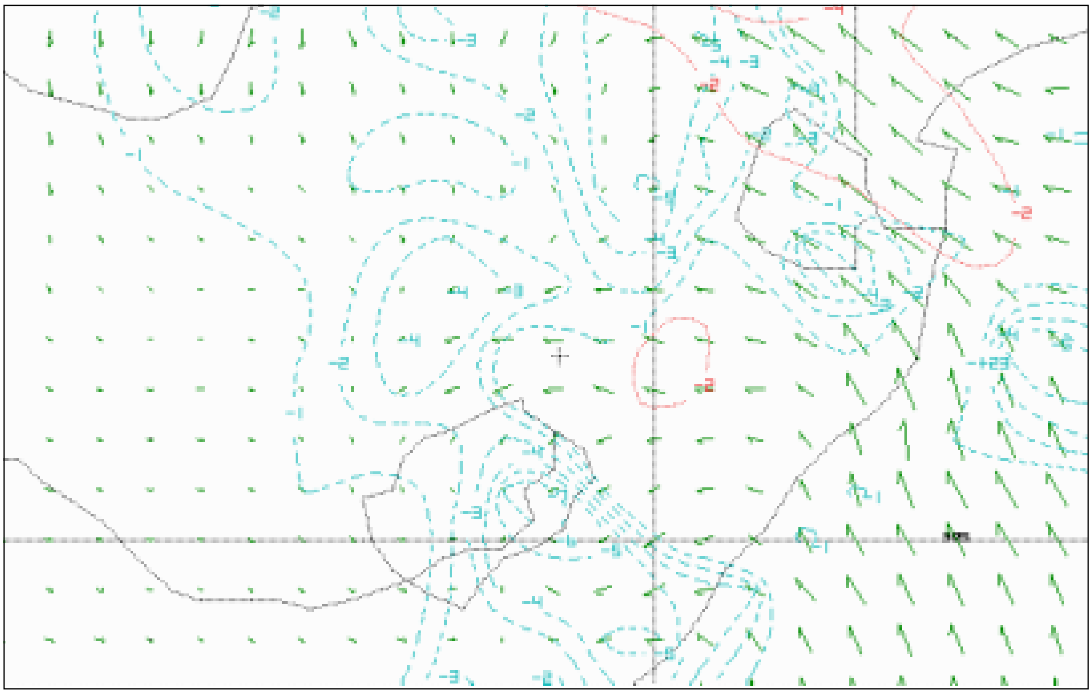


Figure 12

Moisture flux (arrows) convergence (dash) in the boundary layers overlain with 700 hPa uplift (dots) at 14:00 on 15 November 1998

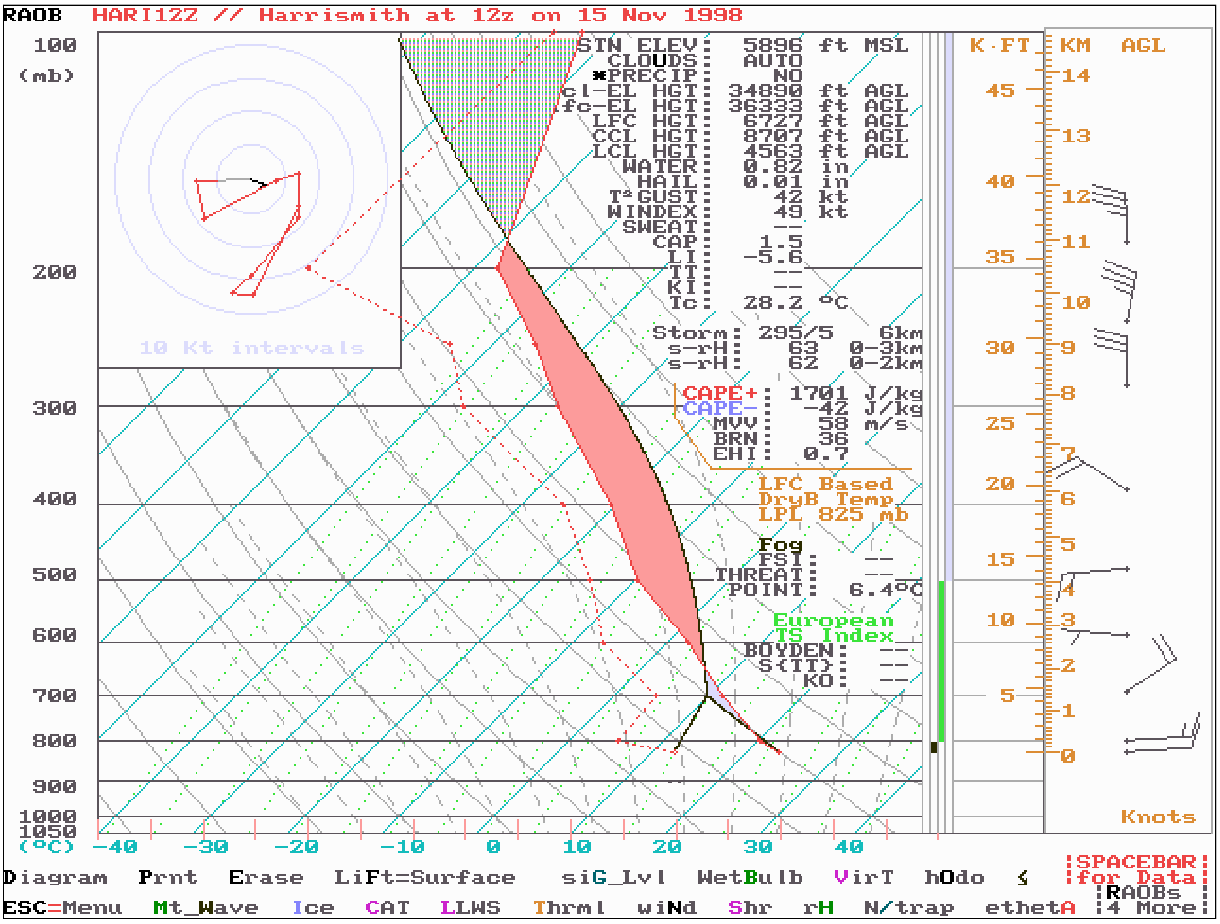


Figure 13

Eta model sounding created at Harrismith for 14:00 on 15 November 1998. Hodograph in top left hand corner.

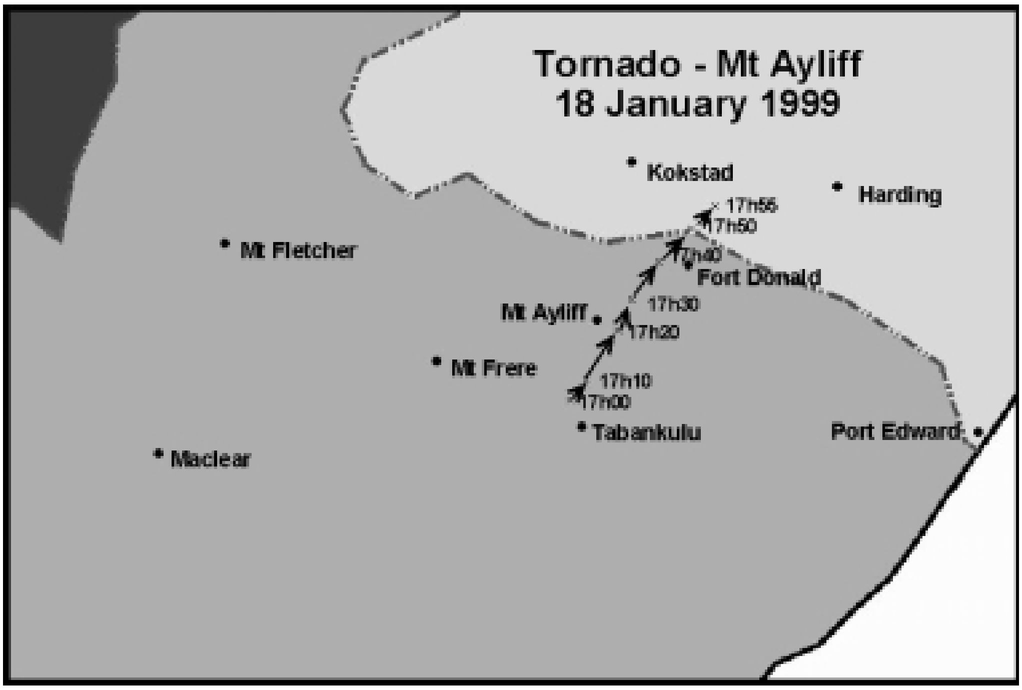


Figure 14
Path of the Mount Ayliff tornado on 18 January 1999 (adapted after Van Niekerk and Sampson, 1999)

Model sounding data for the Harrismith grid point plotted by RAOB (Fig. 13):

Variable	Value	Meets threshold?
CAPE	1701 J·kg^{-1}	✓
Lifted Index	-5.6°C	Almost
BRN	36	✓
SRH	- 63 m^2·s^{-2}	×

Despite substantial change in the wind direction with height, the wind speed was not very strong in the upper layers and subsequently SRH at this grid point was not favourable for tornadic development. Mid-level (500 hPa) dryness was not significant.

Summary of Case Study 1

At the time that the tornado occurred in Harrismith there was a low-pressure system over the interior of South Africa at 850 hPa and an upper-air high-pressure system situated over the central parts of the country. Very hot conditions dominated the central parts of the country with a steep temperature gradient on the surface from west to east. The dryline, between a drier air mass to the west and a more humid air mass to the east, ran through Harrismith. From the Bethlehem radar data it could be determined that there were very strong updrafts and high reflectivities (more than 60 dBz) during the storm's life time. A bow echo with a double core structure was evident and signs of mesocyclonic circulations could be seen on the northern and southern flanks. The Eta model's moisture indicators showed that low-level moisture convergence was taking place in the Harrismith area, but no significant mid-level dryness. Indicators of instability were not conclusive for severe weather. Only some of the shearing indices showed adequate evidence of tornado possibilities. The sounding constructed at the Harrismith location from model data showed more positive signs of severe weather, although SRH remained low.

While the model could have been helpful in identifying the area where thunderstorms might occur, the radar proved the most helpful tool in the identification of the severity of the storm. This was specifically so since the Storm-Structure-Severity method could also be used.

Case Study 2: Mount Ayliff tornado: 18 January 1999 at 16:30

General features

A tornado struck Mount Ayliff (located at 30°48' S and 29°22' E and 975 m a.s.l.) on 18 January 1999. Two Port Elizabeth Weather Office staff members compiled a report on the events which included a damage survey (Van Niekerk and Sampson, 1999). According to radar imagery from the Durban Weather Office radar, the cell which probably contained the tornado moved in a path depicted in Fig. 14.

Van Niekerk and Sampson (1999) reported that a medium sized car was carried 500 m through the air onto a field. The driver escaped serious injury, but his passenger was killed. Twelve to fifteen trucks were overturned. Horses and cows were flung against buildings and cars. Walls were blown over and roofs ripped off with roof sheeting wrapped around fence poles as shown in Fig. 15. There was widespread disruption of telephone and electricity services after the event. Some 95% of the people living in the Mount Ayliff and Tabankulu areas were left homeless, with more than 50 informal houses in the Mount Ayliff area destroyed (Fig. 16). A large truck parked on the side of the road was picked up by the wind and carried several metres into a field. Many 100-year old oak trees were flattened. Reports indicated that 21 people died and 350 people were injured. Numbers of livestock were also killed while many farmlands and crops were flattened. The area was later declared a national disaster area by the South African Government.

The damage survey was based on newspaper reports and photographs taken by the public. No aerial survey was done. Due

Figure 15
Sheeting wrapped around fencing on 18 January 1999 (Van Niekerk and Sampson, 1999)

Figure 16
Damage done to informal housing on 18 January 1999 (Van Niekerk and Sampson, 1999)

to the fact that several vehicles were reportedly carried over significant distances by the wind, an F4 classification was given (Van Niekerk and Sampson, 1999).

Weather patterns and analysis for 14:00 on 18 January 1999

At 850 hPa a low-pressure system was present over the interior to the west of Mount Ayliff (Fig. 17). The wind direction over the interior was mainly north-westerly, but south-easterly along the south-east coast due to an on-shore flow behind a weak coastal low-pressure system. Ahead of the coastal low-pressure system air temperatures over the interior were in the region of 28°C, but behind it cooler air was present with temperatures around 22°C. In the vicinity of where the tornado occurred the temperatures were 25 to 28°C. A weak cold front was situated in the Port Elizabeth region and a tropical low-pressure system was present in the Mozambique channel.

A temperature drop of 2 to 3°C was observed at 700, 500 and 250 hPa between 14:00 on 18 January 1999 and 02:00 on 19 January 1999 indicating that a weak upper-air disturbance could have passed through the Eastern Cape in this time. At 250 hPa a 50 to 60 knot wind was present over the eastern coastal areas of the country. An increase in 500 and 700 hPa moisture was noted between 02:00 and 14:00 to 85% and 81%, respectively.

Rainfall was reported over the Eastern Cape and Natal. Most of the falls for the 24 h up to 08:00 on 19 January were below 20 mm with a few isolated places reporting more than 20 mm. At Kokstad hail was reported with a diameter of 10 to 15 mm. Between Elliot and Encobo hail the size of marbles was reported and it lay white on the ground.

Mesoscale analysis

A significant dew-point temperature gradient existed between the coastal areas (where the coastal low-pressure system advected cool, moist air) and the adjacent interior. Warm, dry air was present over the north-western part of the relevant region separated by a dryline (distinct gradient in dewpoint) from the cooler, more humid air in the south-east (Fig. 18). Dew-point values ranged from below 10°C west of Mount Ayliff to above 22°C just east of Mount Ayliff (where it was raining). Relatively high wet bulb potential temperatures in excess of 20 °C were reported. In the area where the tornado occurred, the values were around 24°C. Pressures were falling by up to 2 hPa per 3 h in the vicinity of the low-pressure system which was situated north-west of Mount Ayliff. The south-easterly wind from the ocean to the interior had to rise against the topography (southern parts of the Drakensberg) which certainly added extra height to the rising of the incoming cool, maritime air into the area where the tornado occurred.

Radar imagery during the event

At 16:46 the storm in question was situated 190 km south-west of the Durban radar, with maximum reflectivities of 51 to 54 dBz, and tops at 18 km. The storm moved rapidly north-eastwards with speeds varying between 25 and 50 km/h. Between 16:46 and 17:11 the storm showed signs of decay with maximum reflectivities less than 51 dBz. Shortly after 17:11, however, the storm reorganised and showed signs of a bow echo (Weisman, 1993) on the south-western flank (Fig. 19). By 17:15 the reflectivities were still below 55 dBz but were elongated (Fig. 20) with a north-west/south-east alignment. The most intense activity could be seen just north-east of Mount Ayliff with reflectivities at 17:19 exceeding 57 dBz (Fig.

21). A strong reflectivity gradient could been seen along the leading edge of the storm which is a sign of storm severity (Lemon, 1980). By 17:23 the storm tops extended to 18 km and reflectivities were all below 57 dBz. The storm started showing signs of decay at 17:31 (not shown) and was then situated 10 km north-east of Mount Ayliff with maximum reflectivities at 54 dBz. Signs of re-intensification were evident at 17:39 (not shown) when a double core (with reflectivities of 51 to 54 and 57 to 60 dBz respectively) manifested.

In this case the Storm-Structure-Severity method of Visser (2000) could not be used to analyse the storm since it was more than 120 km away from the radar.

Eta model data for 14:00 on 18 January 1999

The analysis fields from the Eta modelling system valid at 14:00 on 18 January 1999 portrayed the situation.

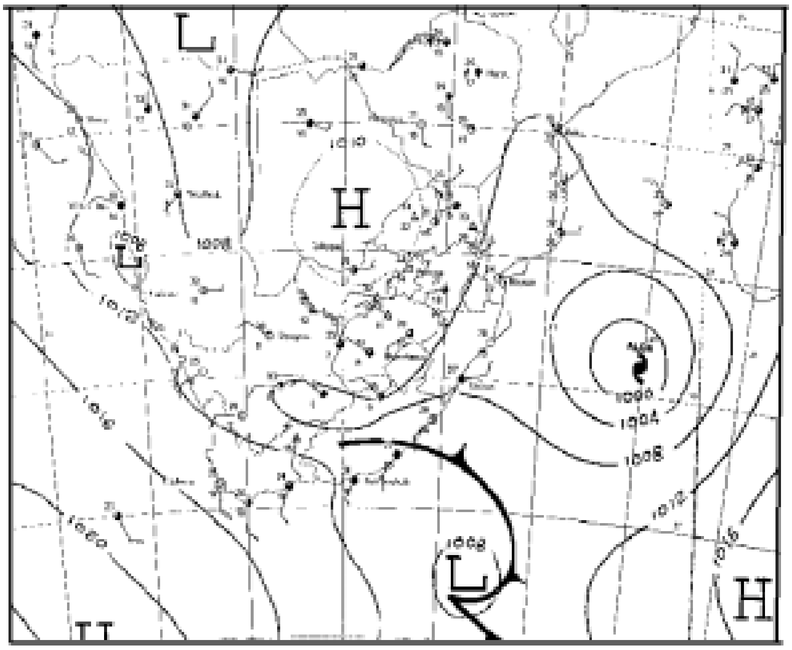


Figure 17
Surface patterns at 14:00 on 18 January 1999

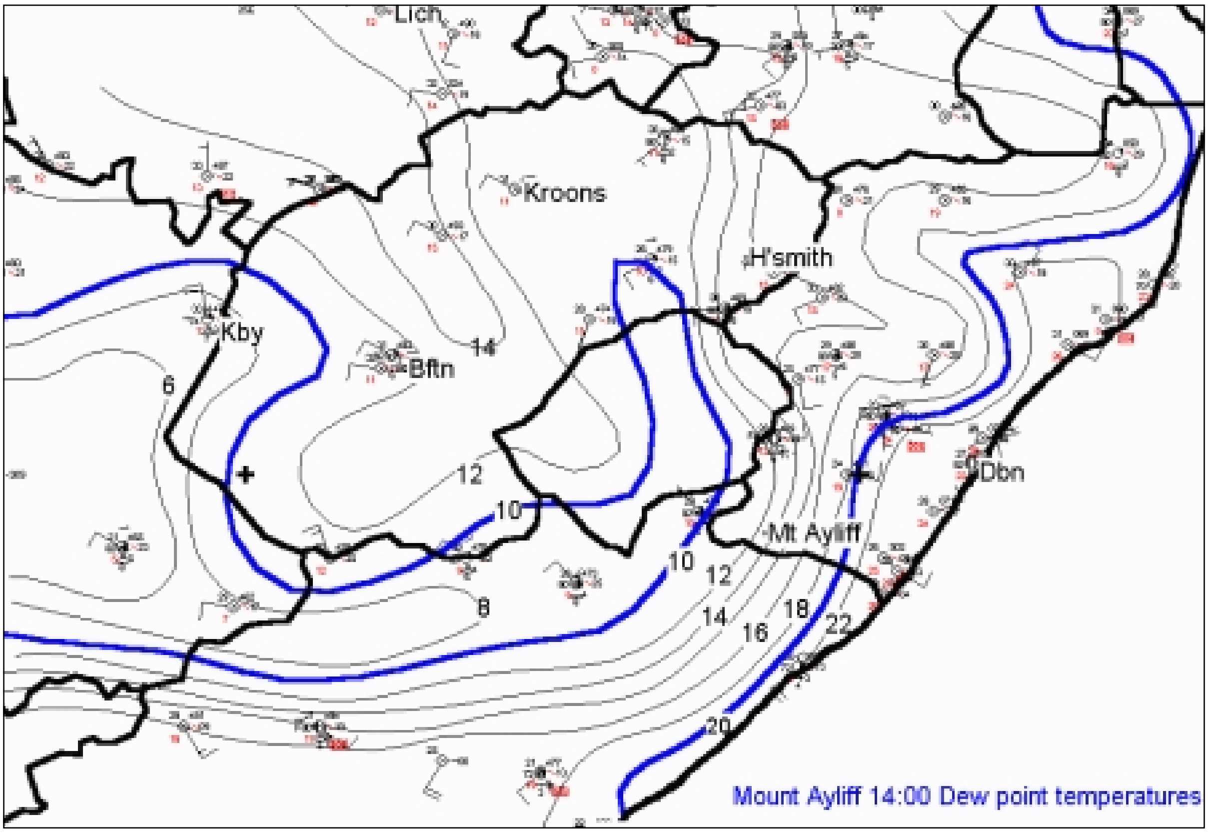


Figure 18
Dew-point temperature (°C) analysis from observations at 14:00 on 18 January 1999

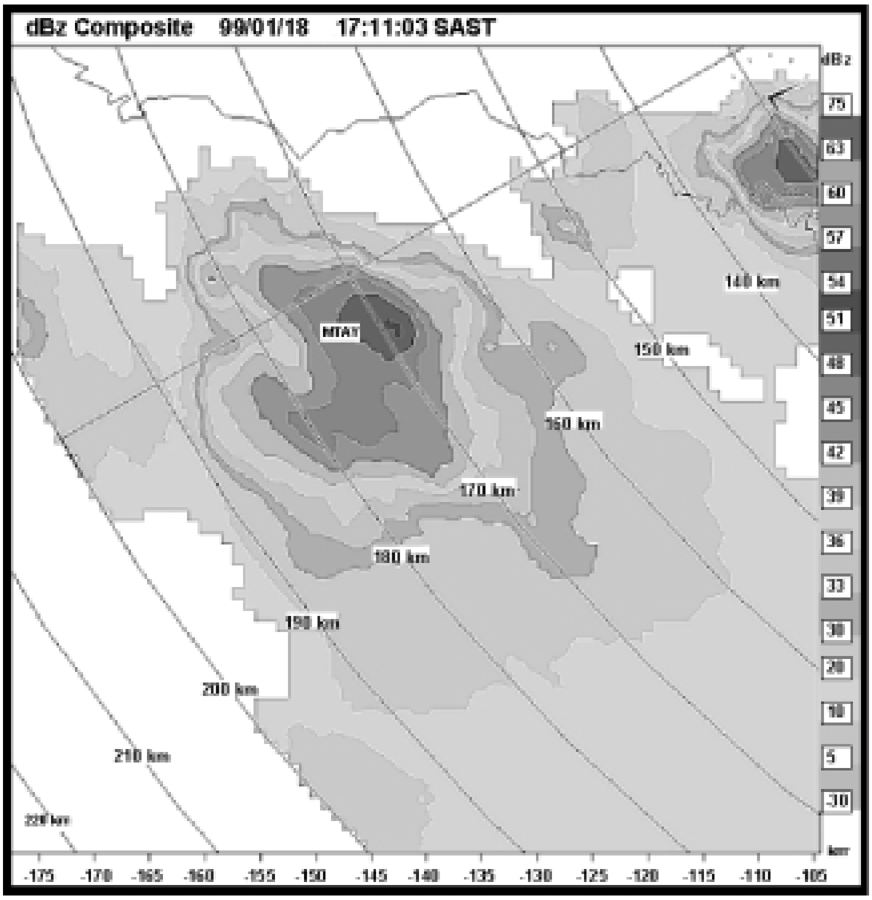


Figure 19
Durban radar's composite radar image at 17:11 on 18 January 1999

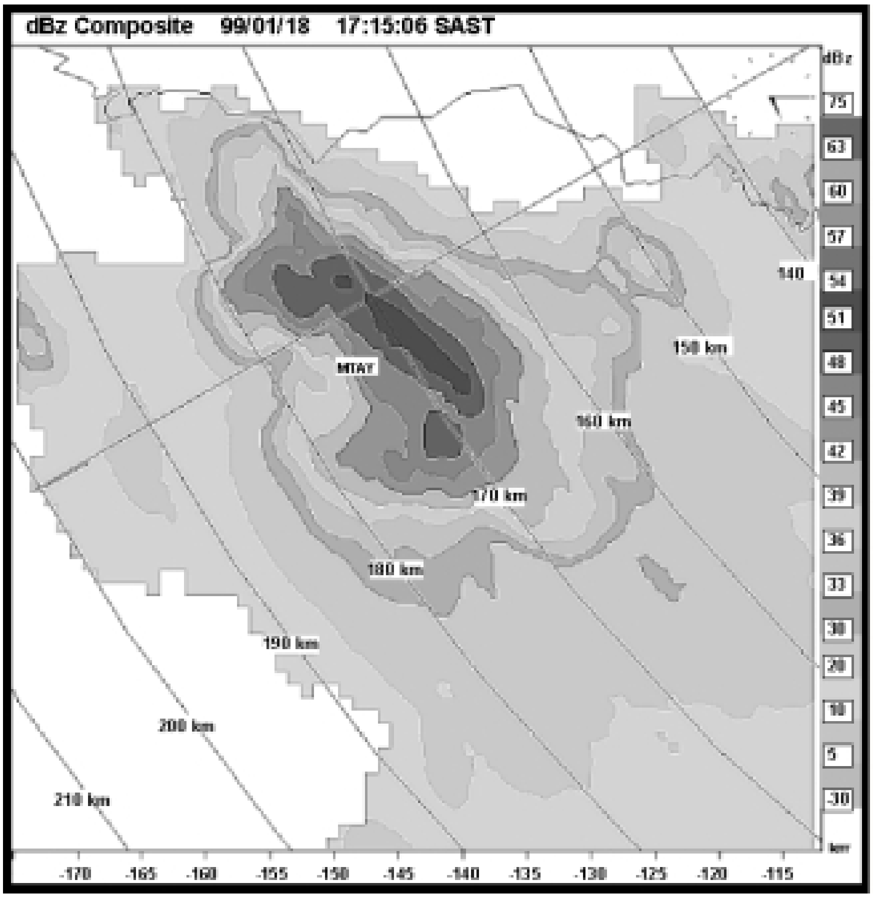


Figure 20
Durban radar's composite radar image at 17:15 on 18 January 1999

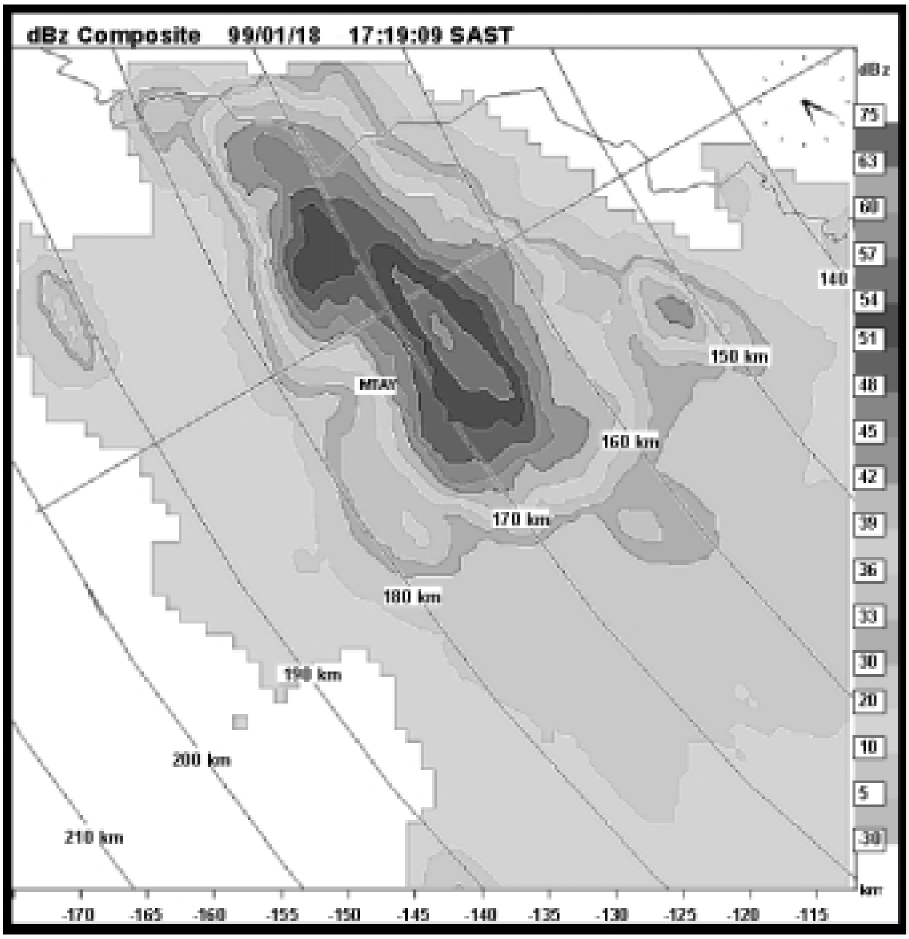


Figure 21
Durban radar's composite radar image at 17:19 on 18 January 1999

Moisture indicators from model data:

Variable	Value
Relative humidity at 800 hPa	65%
Relative humidity at 700 hPa	60%
Moisture convergence in the boundary layers combined with 700 hPa uplift (Fig. 22)	Moisture was flowing into the area from the north-west and south-east causing convergence, but it was not overlaid by 700 hPa uplift

Instability parameters from the model data:

Variable	Value	Meets threshold?
CAPE	500 to 700 J·kg^{-1}	×
Lifted Index	-4 to -5°C	×
Showalter Index	-5 to -7°C	✓
Total totals Index	52 to 57	✓
SWEAT Index	300 to 350	✓(severe storms)

Shearing indicators from the model data:

Variable	Value	Meets threshold?
Surface to 500 hPa shear	35 knots	✓
Surface to 600 hPa shear	25 knots	✓
BRN	<10	×
SRH	> -150 m^2·s^{-2}	×
SR wind speed at the surface	< 8 m·s^{-1}	×
SR wind speed at 500 hPa	14 m·s^{-1}	✓
SR wind speed at 250 hPa	24 m·s^{-1}	✓

Model sounding data for the Mount Ayliff gridpoint plotted by RAOB (Fig. 23):

Variable	Value	Meets threshold?
CAPE	1719 J·kg^{-1}	✓
Lifted Index	-7.0°C	✓
Total Totals	55	✓
SWEAT	349	✓
BRN	41	✓
SRH	16 m^2·s^{-2}	×

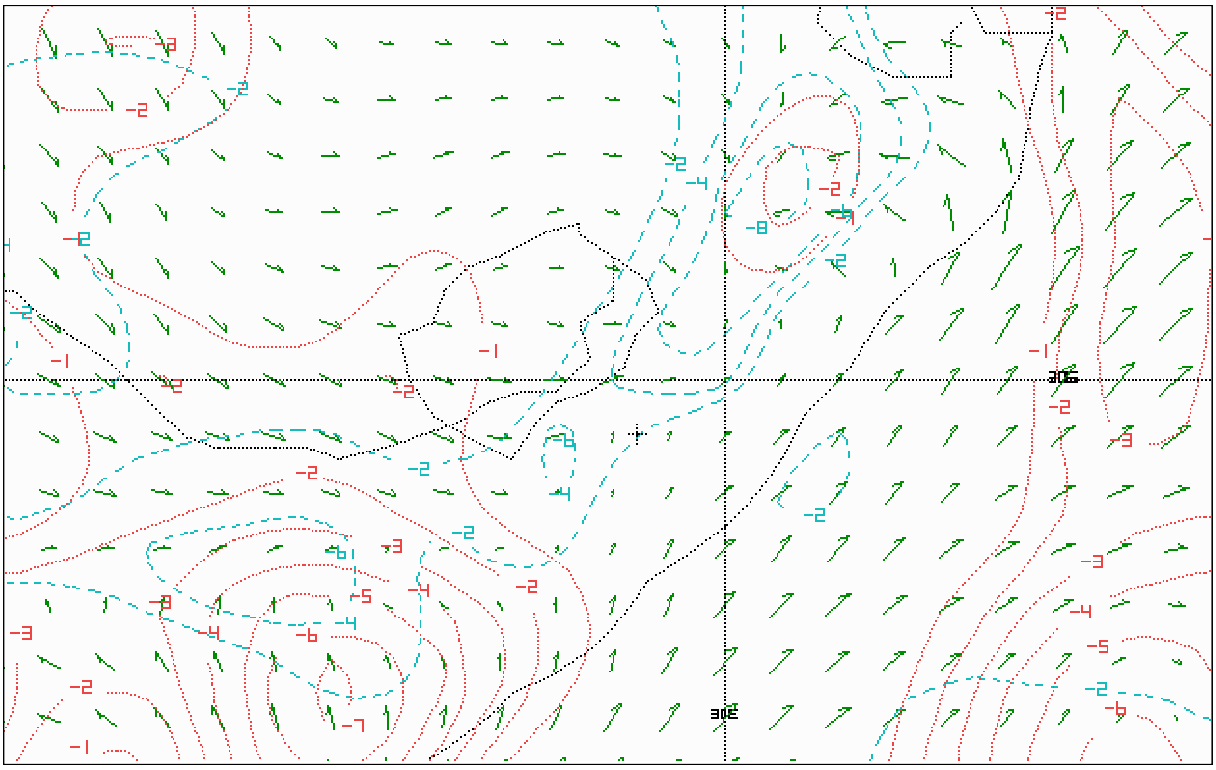


Figure 22
Moisture flux (arrows) convergence (dash) in the boundary layers overlain with 700 hPa uplift (dots) at 14:00 on 18 January 1999

The hodograph constructed from the model data has better resemblance to the multicell hodograph (McNulty, 1995), and SRH wasn't favourable at all, but in this case the topography most probably played a major role in creating rotation since the height a.s.l. from one grid point to the next varies by about 400 gpm on average. A slight indication of mid-level dryness was evident at 400 hPa.

Summary of Case Study 2

The tornado event in Mount Ayliff occurred with a low-pressure system over the interior of South Africa and a weak upper-air disturbance passing through the area. Temperatures north-west of Mount Ayliff were much higher than those south-east of Mount Ayliff. The interior was covered with very dry air while the coastal regions were more humid, with the dryline in the Mount Ayliff area. Air was flowing into the area from the north-west and the south-east where it converged and was most probably lifted by the topography. The Durban radar imagery showed that the storm had reflectivities of more than 55 dBz, but it was too far away from the radar to allow any thorough analysis. Lower level moisture and convergence was indicated by model data, but mid-level dryness was insignificant. Instability indices calculated by means of Eta model data showed significant instability in the area, while the shearing indicators were also favourable for severe weather and/or tornadoes.

Although the Durban radar data proved to be helpful, it would have been more ideal to have had a radar closer to where the storm occurred.

Case Study 3: Umtata tornado: 15 December 1998 at 14:30

General features

Umtata is located at 31°32' S and 28°40' E and it is 747 m a.s.l. It was struck by a tornado at 14:30 on 15 December 1998. The path followed by the tornado was difficult to pinpoint but it seemed to have moved from south-west to north-east. This tornado occurred in the area of responsibility of the Port Elizabeth Weather Office and a report from eyewitnesses, on weather events and damage, was compiled by Van Niekerk and Sampson (1999).

Van Niekerk and Sampson (1999) reported that a wall of a disused bus station collapsed killing 11 people. Trees in Umtata's main street were uprooted, walls were blown down and roofs were torn off. Several buildings were badly damaged and some reports stated that 1 500 buildings were damaged in a 70 km radius around Umtata.

The damage survey by Van Niekerk and Sampson (1999) was based on newspaper reports and photographs taken by the public. No aerial survey was done. Due to the fact that the main damage was limited to a few hundred metres with a path length of 8 to 10 km only, the classification was F2 (Van Niekerk and Sampson, 1999). Despite the extensive news coverage the damage was considerably less than in the other two cases described here.

The event took place embedded in a surface low-pressure system which was present near East London, and a small cut-off low was situated inland north-west of Port Elizabeth at 500 hPa. Extensive rain was reported over the Western and Eastern Cape. A few places in the Eastern Cape reported rainfall of more than 20 mm. Instability parameters from the model data at 14:00 that afternoon were favourable for severe weather, but the shearing

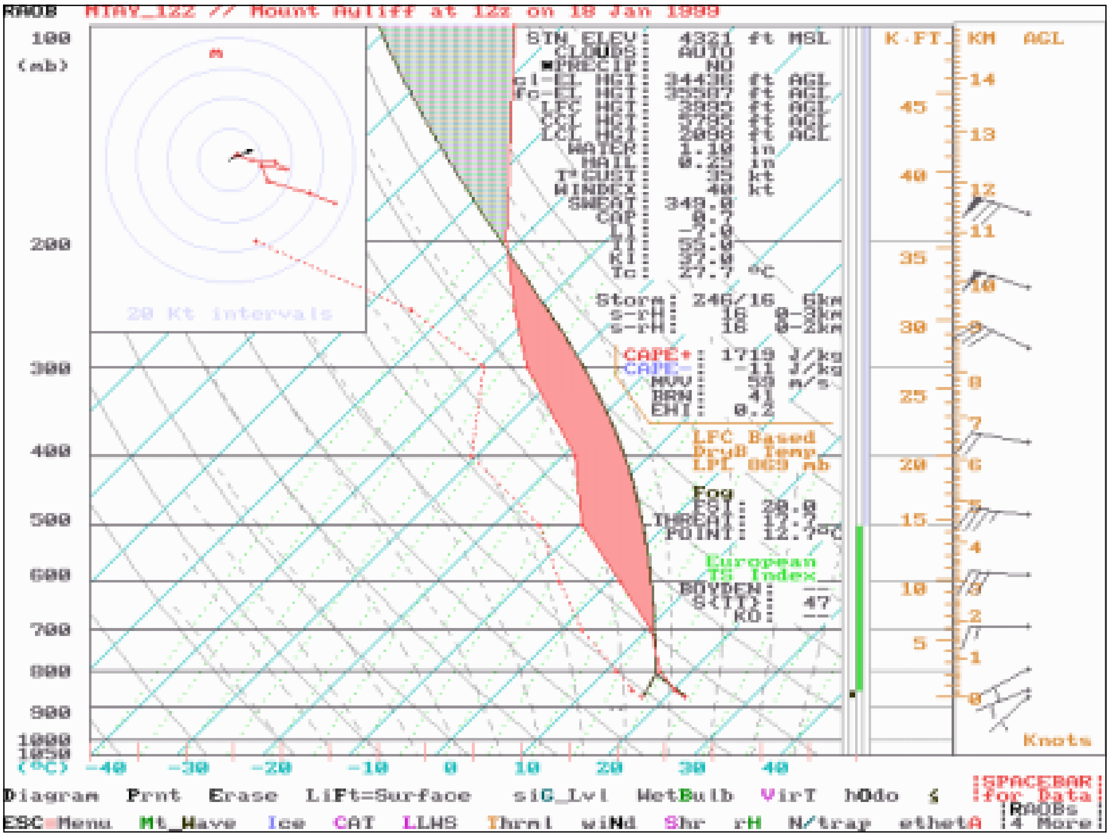


Figure 23
Eta model sounding created at Mount Ayliff for 14:00 on 18 January 1999. Hodograph in top left hand corner.

indicators were not convincing. No sounding or radar data were available for this case.

Summary and conclusions

In the USA the prediction, detection and monitoring of tornadoes are some of the most important services provided by the meteorological profession. Throughout the world the timely issue of warnings for severe weather is critical to the protection of life and property, even more so for tornadoes. Nevertheless, timely warnings remain very difficult. Lead times of warning for tornadoes have increased in the USA from an average of almost zero to more than 10 minutes during the past decade (Brooks and Weiss, 1999).

In order to provide a forecast of severe weather, one should use model fields. The Eta model analysis fields proved to be of value in the more intense case mentioned here. By considering the model's moisture indicators, instability parameters, and shearing parameters the areas where severe weather and/or tornadoes could occur, could be identified. South African Weather Bureau forecasters should be trained in the use of these parameters. All of these parameters can be displayed in PCGRIDDS (**PC**-based **G**ridded **I**nformation **D**isplay and **D**iagnostic **S**ystem) which is the graphical display system used by operational forecasters in South Africa to display model output.

Severe weather events such as tornadoes can only be accurately predicted in situations where a severe storm already exists. Real time data such as radar, satellite, upper-air soundings and visual observations are of utmost importance once thunderstorm development has started. Radar reflectivity values and the shape of the more intense cells can say much about the possibility for tornadoes to develop. Improved and timeous warnings of tornadoes can only be made if real-time observations and quality radar data are available. If an additional radar could be stationed in the Eastern Cape, where so many severe weather events occur, better coverage of the many severe weather events in this area could mean more accurate forecasts.

Since South African meteorologists should endeavour to improve weather forecasting techniques, especially so where life and property are in danger, the importance of observation data (surface, upper-air soundings as well as radar) can not be underestimated. For an improved understanding and anticipation of all severe weather events (including tornadoes) radar and upper-air sounding data will have to play a crucial role in the future.

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The authors would like to thank Kevin Rae and Lucian Banitz who helped to develop the macros for PCGRIDDS used in this study. A great deal of assistance was also received from Mr Banitz in the graphical work for the article. The damage reports and surveys compiled by Garth Sampson and Hugh van Niekerk (from Port Elizabeth Weather Office) and Adam Goliger and Ters van Wyk (from the CSIR) also proved invaluable. This paper would have suffered without the photographs, newspaper clippings and eye-witness reports they provided.

Appendix

Fujita Pearson Tornado Scale (after Fujita, 1973a;b)

Maximum wind speed (m·s^{-1})		Path length (km)		Path width (m)	
F0	20 - 30	P0	0.5 - 1.5	P0	5 - 15
F1	30 - 50	P1	1.5 - 5	P1	15 - 30
F2	50 - 70	P2	5 - 16	P2	30 - 160
F3	70 - 90	P3	16 - 50	P3	160 - 510
F4	90 - 115	P4	50 - 160	P4	510 - 820
F5	115 - 140	P5	160 - 500	P5	820 - 2800

Damage	
F0	***Light*** - some damage to chimneys, tree branches broken, shallow-rooted trees blown over.
F1	***Moderate*** - moving cars pushed off the road, roofs peeled off.
F2	***Considerable*** - large trees snapped or uprooted, light-object missiles generated.
F3	***Severe*** - roofs and some walls torn off, most trees in forested areas uprooted, heavy cars lifted off the ground and thrown around.
F4	***Devastating*** - well-constructed houses levelled, cars thrown and large missiles generated.
F5	***Incredible*** - strong frame houses lifted off foundations, are carried considerable distances and disintegrate, auto-mobile-sized missiles fly through the air further than 100 m, trees debarked.

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