An F3 tornado in Heidelberg, South Africa on

21 October 1999

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Abstract

On 21 October 1999, a severe thunderstorm developed over areas 50 km south of Johannesburg. This weather system produced a large tornado (F3 on the FP scale) which crossed the Heidelberg farming district (between Vanderbiljpark and Secunda). Relatively little damage occurred, but there were minor injuries and damage to property. In this paper the event is analyzed by means of all available observation data, including conventional radar data which showed significant reflectivities as well as good reflectivity gradient. The authors also made use of the 0 and 6 h fields of the local version of the Eta model (48 km resolution) in order to supplement the sparse data coverage over the country. Indications of instability and shear were analyzed on plan view as well as by means of model soundings. Several indicators of severe weather and possible tornadic activity could be found. Although only a few tornadoes occur every year in South Africa, these events cause damage and loss of life. It is therefore essential to investigate and research the occurrence of tornadoes with the little bit of observational data that is available.

1. Introduction

On the late afternoon of 21 October 1999, a severe thunderstorm developed over areas 50 km south of Johannesburg (Fig. 1). It started at about 1600 (all times are UTC) and travelled in an easterly direction until about 1730. This weather system produced a large tornado (F3 on the FP scale) which crossed the Heidelberg farming district (between Vanderbiljpark and Secunda). In general the terrain was flat, with the exception of a couple of low hills (about 150 meters above the general ground level). In one place the tornado sucked nearly all the water from a relatively large, but shallow, dam and discharged it almost on top of one of these hills.

The event received only minor media attention, and was referred to as a "freak tornado" because its trail crossed areas with low population density. The reports on human loss and damage to property mentioned 40 people injured, 10 people hospitalised, 300 people left homeless and 400 houses and farm dwellings damaged. Relatively little damage occurred. It is of interest that on the same evening another, smaller tornado (F1) developed 30 km north of Johannesburg. Due to the high population in that area this event received the attention of local authorities and businesses.

The site investigation (which started on the following day) revealed a consistent tornado path more than 100 km long and between 200 and 250 m wide. If this event had occurred 50 km to the north, it would have resulted in the loss of many lives and the destruction of property.

The tornado developed in the most "tornado prone" area of South Africa with a rate of occurrence of $10^{-4}/km^2/year$ (Goliger et al., 1997). Figures 2a and 2b present the seasonal and time-of-the-day distributions of South African tornadoes. It can be seen that the 21 October tornado is consistent with these characteristics. Furthermore, 80% of South African tornadoes travel in general eastward direction and the longest documented tornadic trail in South Africa was 140 km.

2. Weather conditions preceding and during the event

The 1200 synoptic weather map issued by the Central Forecasting Office in Pretoria (Fig. 3) showed that an area of low pressure dominated the entire subcontinent. Low pressure areas of 1004 hPa were evident over the southern Free State and just off the south-east coast of the country. Moisture was fed into the north-eastern part of the country by means of a north-easterly flow around a high pressure system east of the country. The 500 hPa heights on the 1200 upper air chart (not shown) showed that an upper air trough and low pressure system were present over the central parts of the country.

Maximum temperatures for the day were not very high, with most temperatures not exceeding 22°C. During the day the dew point temperatures were above 15°C over Gauteng. Rainfall amounts of more than 10 mm were recorded at a few places in Gauteng and the Free State, but none of these exceeded 35 mm.

The Automatic Weather Station (AWS) data for Vereeniging (about 40 km southeast of Heidelberg) show that it started to rain at 1700 and 19.2 mm of rain fell between 1730 and 1900, 14 mm of which fell in the first hour. Wind gusts of up to 25 ms^{-1} were measured around between 1700 and 1800 which is an underestimation of the tornado wind strength because Vereeniging lies outside the path of the tornado. A significant pressure drop was evident earlier in the evening around 1630, after which the pressure increased again.

The severe storms were best observed by an MRL5 dual wavelength radar operating at 10 cm wavelength, situated in the Bethlehem (Fig. 1) area (Terblanche et al., 1995). Due to the distance of the relevant storms from the MRL5 (about 180 km), it could provide only qualitative information on the storms, since at the lowest scan (1.5°) the radar sees about 7 km above ground level (AGL).

Between 1630 and 1730 a series of storms developed over the Vanderbijlpark area, while a series of line storms (oriented north-west to south-east) moved through the radar range until after 1740 that evening. Fig. 4 shows a MRL5 scan for 1559 with the storms over the area. The storm west of Vanderbijlpark showed maximum reflectivities above 57 dBZ with a tight gradient on the northern and southern sides of the storm. Both of these characteristics are typical of severe storms (Donaldson, 1961). During their lifetimes the storms were fast moving at a speed of 50km h^{-1} or faster. Cloud tops for the storms were between 14 and 16 km AGL. Fig.5 shows an animation of radar images for 1630, 1645, 1701 and 1716. At 1641 the 60 dBZ reflectivity pattern was situated at a height above 8 km, while the 48 dBZ reflectivity pattern remained above 10 km for most of the storm's life - another severe storm indicator (Mather et al., 1976). By 1645 the storm east of Vanderbijlpark was showing a bow-echo shape (typical of severe storms), while it also kept the tight reflectivity gradient on the north-western flank. The storm showed signs of intensification by 1701 as it moved eastwards towards Balfour.

3. Eta model

The local version of the Eta model runs twice daily on a 48 km horizontal grid with 38 levels in the vertical. Eta model fields were used in this study purely as a substitute for observation data - of which we have very little - and not to try and predict the event. The analysis and 6 h forecast fields of the midday run of the model were investigated to give an idea of the storm environment at 1200 and 1800.

Studies by McNulty (1988) and Johns and Doswell (1992) have indicated that three of the most important factors to examine in determining severe weather potential are, first, extreme instability, second, strong vertical wind shear and lastly, the presence of low theta-e air in mid-levels. Signs of these were found in the model fields discussed below.

a. Surface and upper-air pattern

At both 1200 (Fig. 6a) and 1800 the model's 850 hPa pattern showed the area of lower pressure over Botswana and parts of the Northern Province. A second low pressure area was evident off the south-east coast, extending a trough into the south-eastern interior. At 1200 (Fig. 6b) the 500 hPa height pattern had a cut off low pressure system on the south-east coast, but by 1800 the upper-air low had weakened to a trough. The relative humidity pattern at 850 hPa (Fig. 6c) showed ample moisture (>60%) over most of the country, with a slight eastward shift in the areas of maximum moisture towards the evening. An area of 80% relative humidity was located over north-eastern part of the country at 1200 and 1800. Surface moisture was overlaid by mid-level dryness at 500 hPa at 1200 (Fig. 6d) when the mixing ratio was a mere 0.4 g kg^{-1} evident in a dry tongue which stretched from the northwest to the southeast. By 1800, however, the mid-levels had become much more humid with a mixing ratio of 2.8 g kg^{-1} in the Heidelberg area; which was the effect of the convective precipitation which the model had generated since 1200.

b. Instability indicators from the model:

Convective Available Potential Energy (CAPE) represents the amount of buoyant energy available to accelerate a parcel vertically and a CAPE value greater than 1500 Jkg^{-1} is suggested by Rasmussen and Wilhelmson (1983) as being necessary for supercells to form. 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. Johns and Doswell (1992) found that a number of supercells over the United States also arise in situations with CAPE values less than 1500 Jkg^{-1}.

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 (Air Weather Service Technical Report, 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 Technical Report, 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 versus environmental 500 hPa temperature. Values of less than -6 are indicative of extreme instability and possible tornadoes (AWS Technical Report, 1990).

The SWEAT index evaluates the potential for severe weather by combining into one index several instability parameters like low 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 Technical Report, 1990).

Basic instability parameters for Heidelberg (26.5S and 28.4E) vicinity had the following values and attached interpretation (from Louisville Science Page, and AWS TR, 1990):

Parameter	At 1200	At 1800
CAPE	1000 Jkg^{-1}	400 Jkg^{-1}
Lifted Index	-4	-2
Total Totals Index	57	54
Showalter Index	-7	-5
SWEAT Index	400-450	350

c. Shearing indicators from the model:

A Bulk Richardson Number (BRN) of between 10 and 40 is the range within which supercells usually form (Weismann and Klemp, 1982), and tornadoes usually form within supercells.

Storm-relative helicity (SRH) in the lowest 3 km is one of the most popular tools in forecasting tornadoes. Davies-Jones et al. (1990) found that weak tornadoes coincide with SRH values of -150 to -299 m^2s^{-2} (negative for the southern hemisphere).

Thompson (1998) found that storm-relative wind speed at various levels can be used to predict tornadic and non-tornadic supercells. He found that if the surface-relative wind speed varies between 8 and 22 ms^{-1}, the 500 hPa-relative wind speed varies between 8 and 19 ms^{-1} and the 250 hPa-relative wind speed varies between 8 and 35 ms^{-1}, chances of a tornadic supercell are very good.

Coloquhoun (1987) showed that vertical wind shear in the surface-to-500 hPa or surface-to-600 hPa layers can give an indication of tornado likelihood. He found that vertical wind shear of 29 to 52 knots in the surface-to-500 hPa layer and 22 to 44 knots in the surface-to-600 hPa layer is adequate to produce F0 to F2 tornadoes.

Shearing indicators from the model:

Parameter	1200	1800
Bulk Richardson Number	10	20
Storm Relative Helicity	-350 m^2s^{-2} (Fig. 7a)	-250 m^2s^{-2} (Fig. 7b)
Energy Helicity Index (combination of SRH and CAPE)	-2.4	-1
Surface-relative wind speed	8 ms^{-1}	13 ms^{-1}
500 hPa-relative wind speed	20 ms^{-1}	20 ms^{-1}
250 hPa-relative wind speed	>36 ms^{-1}	20 ms^{-1}
Surface to 500 hPa shear	40 knots	38 knots
Surface to 600 hPa shear	40 knots	35 knots

d. Model soundings

South Africa only has two upper-air ascents (at Irene and Cape Town) which is done twice daily and both of these are not relevant to the location of the tornadic event. To start with, the upper-air sounding done at Irene at 1200 was verified against the model sounding for Irene and it proved to be very similar. It was then decided to make use of the latitude and longitude of Heidelberg to construct model soundings with RAOB. This is shown in Fig. 8a (for 1200) and Fig. 8b (for 1800). On Fig. 8a (1200) the surface moisture as well as mid- level dryness is quite evident.

Instability indicators from the soundings:

Parameter	At 1200	At 1800
CAPE	1914 Jkg^{-1}	564 Jkg^{-1}

Lifted Index	-6.2	-2.2

Shearing indicators from the soundings:

Parameter	1200	1800
Bulk Richardson Number	16	7
Storm Relative Helicity	-423 m^2s^{-2}	-354 m^2s^{-2}
Energy Helicity Index (combination of SRH and CAPE)	-3.8	-1

The hodograph constructed in RAOB at 1200 (top left corner of Fig. 8a) seemed similar to supercell storm hodographs presented in McNulty (1995), after adjustment for the southern hemisphere.

From the abovementioned values is seems that the situation was more favourable at 1200 (prior to the tornado event) than at 1800 itself. The model did, however as mentioned before, generate precipitation in the 6 hour period from 1200 to 1800 and it was of a convective nature. The model makes use of the Betts-Miller convective parameterization scheme. This scheme moved the sounding towards moist adiabatic and thus weakened the instability. It is therefore understandable that the fields would seem more stable or less favourable for the severe event later on.

4. Conclusion

Our site investigation following the event and further evaluation proved beyond any doubt that this had been a severe tornado - an F3 on the FP scale. It is alarming that an event of such magnitude would have gone unnoted or ignored, especially in view of its closeness to South Africa's largest metropolitan area.

Very little meteorological data corresponding to the time of the event is available, although the conventional radar imagery shows significant reflectivities as well as a good reflectivity gradient. Sounding data is only available at two locations in South Africa on a twice daily basis and these are not relevant to the area where the tornado occurred. Model-sounding were thus used to get an indication of the state of upper air winds, rotation and instability. More surface and upper-air observations and better radar facilities are needed in South Africa in order to forecast the severe weather events ahead of time.

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Biography:

Estelle de Coning: Obtained her MSc in Meteorology in 1997. She works for the South African Weather Bureau as a Specialist Scientist, mainly in short term forecasting and related research fields. Her main interest is in the severe weather and tornadoes.

Frank Adam: Obtained his BSc (Hon) in Meteorology in 1991. He works for the South African Weather Bureau as Specialist Scientist. His current research is directed at radar applications for severe weather forecasting and radar rainfall measurement.

Adam Goliger: Obtained his MSc in Civil Engineering in 1974. Since 1985 he is mainly involved in wind tunnel work at the Council for Scientific and Industrial Research. He has visited and surveyed several areas in South Africa devastated by severe winds and is the co-author of a book on SA tornadoes.

Ters van Wyk: Obtained a T4 diploma in Engineering. He has been working for the CSIR since 1990 as responsible person for the operations of the Boundary Layer Wind Tunnel Laboratory. He visited and surveyed several sites of severe wind damage including tornadoes.