8.8 METEOROLOGICAL ASPECTS OF THE 3 NOVEMBER 2000 SEVERE STORMS IN SYDNEY, AUSTRALIA

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1. INTRODUCTION

Severe thunderstorms developed on the afternoon of November 3rd during the Sydney 2000 Forecast Demonstration Project (Keenan et al., 2001). The storms produced three tornadoes, hail up to 7 cm in diameter and heavy rain in the Metropolitan Sydney area causing significant damage. Numerous pre-existing boundary-layer convergence lines (boundaries), including gust fronts and the sea breeze front, appeared to play a critical role in the enhancement of convective cells, their motion, and associated severe weather.

The purpose of this paper is to describe these thunderstorms, the severe weather they produced and the environment in which they developed.

2. DATA SOURCES

Three Sydney area radars were available during the project: Cpol (polarimetric Doppler C-Band), Kurnell (Doppler C-Band) and Letterbox (S-Band). Data from three rawinsonde launches per day were available as were surface measurements from a local mesonet of 29 stations. The times and locations of tornadoes, hail and heavy rain were determined using the Bureau of Meteorology storm log and post-event damage surveys initiated by the principal author. Finally, photographs and video of the storms were taken by several area residents and project participants, including the principal author. Satellite imagery was available for the Sydney region but not at high temporal or spatial resolution.

3. THE PRE-STORM ENVIRONMENT

A persistent surface trough was present over the eastern third of Australia on November 3rd. The trough axis was swinging slowly eastward and reached the Sydney area at approximately 1700 local time (LT).

Rawinsonde data from Sydney International Airport at 1000 LT show a deep, moist layer below 600 hPa with a considerably drier layer above. No capping inversion was present below 500 hPa. Analysis of the sounding gave a Lifted Index near -4°C (indicating moderate instability), a convective temperature near 28°C, and a Bulk Richardson Number near 30. A value of 30 in this region suggests the possibility of supercell thunderstorms (Mills and Colquhoun, 1998). However, vertical wind shear was weak with winds below 500 hPa ranging from 4 to 13 ms^{-1}. The storm-relative helicity (0-3 km, storm motion 3 ms^{-1} from 292°, southern hemisphere) was near 20 m^2s^{-2} indicating a low risk of supercell development. A notable feature of the wind profile was a deep layer of mainly westerly winds overlying a relatively shallow (<1 km) layer of north-northeasterly winds, possibly the developing sea breeze.

Surface observations from the region show that inland air temperatures in the pre-storm environment reached between 23°C and 26°C with dew point temperatures ranging from 14°C to 17°C. Thus, maximum surface air temperatures were several degrees below the diagnosed convective temperature of 28°C.

At around 20°C, sea surface temperatures off the coast of Sydney were several degrees lower than the maximum inland air temperatures indicating that a sea breeze was possible.

4. BOUNDARIES AND STORM DEVELOPMENT

Sydney-area radars began to detect developing thunderstorms just before 1100 LT. These convective cells were initiated along the Blue Mountain range and drifted eastward across the coastal plain, as often occurs in this area (Potts et al., 2000).

Between 1200 and 1300 LT, numerous showers and thunderstorms had developed with several of these deviating from the mean eastward storm motion, apparently due to terrain effects. Cpol and Kurnell clear-air radar returns revealed the sea breeze front lying inland from the coast and moving slowly westward. The inland progress of the front appeared to accelerate as the thunderstorms approached, possibly assisted by storm inflow.

The first thunderstorm to reach the sea breeze front southwest of Sydney near 1315 LT (Storm A, not

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shown) rapidly increased in intensity to around 55 dBz, crossed the front and began to back-build. Doppler velocity data show that Storm A developed a mesocyclone or rotating updraft region at this time. Storm A began to dissipate somewhat while another thunderstorm (Storm B, not shown) formed approximately 20 km to the west at 1415 LT. Storm B also developed a mesocyclone.

A distinct gust front (not shown) was first detected moving northwest away from Storms A and B at 1420 LT. This boundary collided with and undercut a weaker gust front approaching from the northwest at 1440 LT. Both Storm A and Storm B began to veer to the left of the mean flow at this time, propagating north-northeast along the sea breeze front.

Storms A and B appeared to merge into one storm (Storm C) near 1500 LT (Figure 1). At this time, clear-air radar returns continued to show a gust front arcing away from and to the west of Storm C while a second gust front could be seen moving southeast from weaker storms approximately 40 km to the north of Storm C. A segment of the sea breeze front was still evident between the outflow boundaries. The first reports of large hail and heavy rain with Storm C were received near this time as radar echo tops reached 15 km.

Storm C moved north-northeast, propagating along the sea breeze front and well left of the mean eastward storm motion. Though a hook echo became apparent on Cpol and Kurnell radars after 1520 LT, it was difficult to identify a persistent mesocyclone in the Doppler velocity data until 1540 LT, at which time a lowering became visible beneath the storm and bands of cloud from over the Tasman Sea could be seen streaming towards the storm core. Hail 1 to 4 cm in diameter and heavy rain were reported. It was also at this time that the gust front from the storm to the north collided with the sea breeze front and began to force it eastward.

At 1550 LT, the gust front from Storm C intersected the combined gust front / sea breeze front at the location of the hook echo. A large bounded weak echo region was present at this time and radar echo tops were near 19 km. Doppler velocity data now suggested an intensifying low-level mesocyclone with maximum tangential velocities near 18 ms^{-1} and a diameter of roughly 10 km.

The combined gust front / sea breeze front continued to move southeast but Cpol radar was able to detect a new boundary at 1600 LT to the west of a weak storm passing to the north of Storm C. This boundary now intersected the Storm C gust front, as shown in Figure 2. The intersection point was located beneath strong and deep rotation in the updraft region of Storm C evident in the velocity data from both Cpol and Kurnell radars. Several brief tornadoes were spotted over the next 30 minutes below a rotating lowering. No condensation funnels were visible so only dust and debris allowed the tornadoes to be detected visually. There was also a spectacular scene when the Storm C gust front passed over a quarry, lofting dirt and dust high into the air. A new lowering appeared to form where this dust entered the cloud base. In addition, there were reports of hail up to 4 cm in diameter and reports of roof and tree damage at this time.

Storm C was most intense at this point and decelerated noticeably while continuing to move toward the north-northeast. Photographs show the rotating lowering, with a tornado beneath, becoming entirely wrapped by outflow and dissipating. Hail up to 7 cm in diameter was also falling at this time roughly 5 km south of the location of the tornadoes.

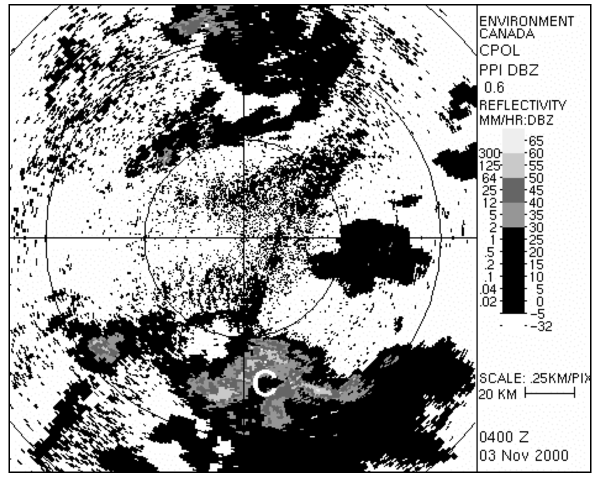

Figure 1. Cpol low-level (0.6°) radar reflectivity at 1500 LT (0400 Z) showing the location and intensity of Storm C. North is toward the top of the image. The gust front west of Storm C intersects the sea breeze front extending north, and a gust front to the north is about to collide with the sea breeze front.

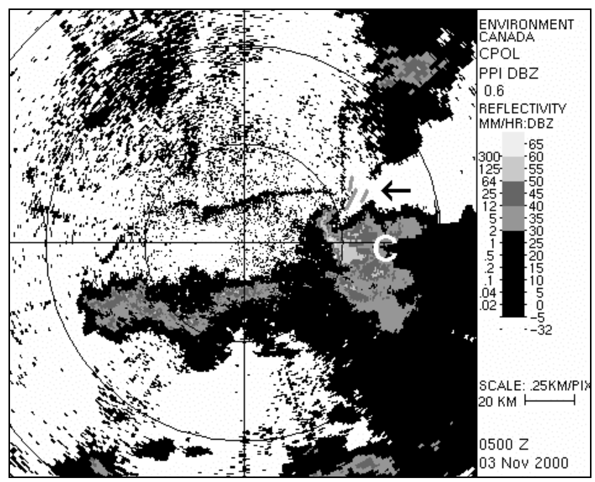

Figure 2. Same as Figure 1 but at 1600 LT (0500 Z). The gust front from Storm C is intersecting a new gust front to the north beneath a rotating updraft (hook echo). Grey lines (left of arrow) indicate surveyed tornado damage tracks.

At 1720 LT, the thunderstorm appeared to lose its connection with the various boundaries and changed its course, drifting eastward while quickly dissipating. By 1750 LT, only a weak area of precipitation was left moving out over the Tasman Sea. Numerous other showers and thunderstorms continued but no further reports of severe weather were received.

5. STORM DAMAGE

There were many newspaper and television reports showing the damage incurred by these storms. Entire neighbourhoods were whitened by hail, in some places several centimetres deep. Some large roofs collapsed under the hail's weight. Several traffic accidents with injuries were blamed on the storm. Just to the west of the Olympic Stadium, there were reports of damaged and destroyed roofs, trees snapped and uprooted, and witnesses claiming to have seen rotating clouds of dust and debris.

Damage surveys were conducted in the days following this event. Three distinct tornado tracks were found at the location where Storm C was most intense (see Figure 2). The tracks were clustered in a 6 km wide by 10 km long area though the tornado tracks themselves were no more than 400 m wide. Each of the tornadoes moved toward the north-northeast. One tornado caused F1 damage on the Fujita scale (Fujita, 1981) and had a track approximately 6 km long. Weaker F0 tornadoes had tracks approximately 3 km long. The damage consisted mainly of partially and totally removed roofing and siding, snapped and uprooted trees and toppled fences. One brick house was shifted on its foundation and was in need of rebuilding.

6. DISCUSSION

Since the convective temperature was not reached in the Sydney region, enhanced lift provided by the synoptic-scale trough and circulations driven by differential heating in the mountainous terrain to the west of Sydney likely initiated the first showers and thunderstorms. However, most of these cells remained below severe limits until encountering enhanced lift and horizontal shear at the sea breeze front, and later at gust fronts.

In this event, the gust front associated with the strongest storms moved at nearly the same speed as the storms themselves. This situation favours long-lived storms since the thunderstorm updraft continues to be fed by the low-level convergence at the gust front (see Wilson and Megenhardt, 1997). The fact that the storms propagated along the sea breeze front suggests that the storm updrafts were also being fed by low-level convergence at the sea breeze front.

Mesocyclones first became evident in the Doppler velocity data at 1315 LT and appeared to be transient features until about 1540 LT when strong and deep cyclonic rotation began to develop. It was at this time that the intersection point of two boundaries began to move beneath the updraft region of Storm C. Photographic evidence shows that a tornado had developed by 1600 LT. Surface-based tornadogenesis may have occurred as vertical vorticity associated with the boundaries was stretched vertically by the thunderstorm updraft. Thus, the mesocyclone may have built upwards from the lowest levels of the storm. Alternatively, the intense updraft may have tilted horizontal vorticity associated with the boundaries into the vertical, intensifying a weak mid-level mesocyclone and leading to the development of a tornado at the surface. A more detailed analysis of the Doppler radar data would be needed to confirm the processes at work. Unfortunately, the coarse temporal resolution of Cpol radar data and the attenuation of the Kurnell radar beam by Storm C may not allow for an adequate analysis leaving the mode of tornadogenesis unknown.

Tornadoes in the Sydney region are considered somewhat of a rarity. Yet an event like that of November 3rd appeared to involve ingredients that are frequently available during the warm season in this area. Weak tornadoes may occur regularly with such events but go unreported away from densely populated areas.

7. CONCLUSIONS

Through analysis of radar and other data, we have shown that pre-existing boundaries such as sea breeze fronts and gust fronts were critical to the development of severe weather, including tornadoes and large hail, on 3 November 2000. In addition, the interaction of boundaries appeared to be an important factor for tornadogenesis. In the absence of high-resolution satellite imagery, Doppler radar was the primary tool for monitoring these boundaries in real time and for gaining an understanding of the role these boundaries played in the generation of severe weather.

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