A tornadic thunderstorm in northwest Tasmania: 22 November 1992

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A severe thunderstorm affected Smithton, northwestern Tasmania, at 1700 UTC 21 November 1992, spawning an F3 tornado. The impact of the storm is described and its nature is assessed. The associated meteorological conditions are examined using conventional observations and modelled using a PC-based version of the operational Australian numerical weather prediction model, RASP. Model experiments suggest that the Tasmanian topography affected the location and, in some areas, the strength of atmospheric vertical motions during this event.

Introduction

At about 1700 UTC 21 November 1992 (0400 22 November Australian Eastern Summer Time), a severe thunderstorm occurred at Smithton, in northwest Tasmania, affecting the town and surrounding areas (see Fig. 1 for locations). The storm damaged thirteen houses and numerous cars and outbuildings along a path of some 14 km.

The storm occurred as a pool of very cold middle-level air moved over Tasmania. Cold air tornadoes have been documented in other parts of Australia (Brook 1965; Seaman 1966; Foley and Hanstrum 1990; Watson 1994) and the United States (Montiverdi 1993; Fike 1993), while Cooley (1978) documented Michigan funnel clouds occurring in cold air well behind surface cold fronts.

The first part of the paper documents this severe thunderstorm event. A description is given of the thunderstorm and storm damage, the meteorological situation preceding thunderstorm development is described, and pertinent meteorological observations are detailed.

The second part of the paper describes experiments conducted using a PC-based numerical model, based on the Australian operational numerical weather prediction model, RASP. The model is briefly described, and comparisons are made between model output and observations to validate the model simulations. A detailed analysis is then conducted of the model output to elucidate aspects of the atmospheric dynamics affecting thunderstorm development. Finally, significant points arising from the study are noted.

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Fig. 1 Locality map for Tasmania.
Thunderstorm damage

An active cold front crossed Tasmania between 0400 UTC and 0700 UTC 21 November. Damage caused by lightning and thunderstorm-associated winds was reported from a number of areas in Tasmania. In Queenstown, on the west coast, one house lost its roof in strong winds, damage was sustained at the Mt Lyell mining operation on the outskirts of the town and power was cut for up to eight hours in some parts. Many large trees were uprooted, power lines were cut and two Hydro-Electric Corporation transformers were severely damaged at Winkleigh, on the central north coast (see Fig. 1). Parts of Victoria and New South Wales also suffered thunderstorm damage with the passage of this front.

Damage reports were not sufficiently detailed to determine whether the storms in these areas were tornadic, and a damage survey was not conducted.

More severe damage occurred about twelve hours after the passage of the front, resulting from thunderstorm activity associated with the upper-atmospheric cold pool as it crossed northwest Tasmania. At Smithoton, people were wakened by a roaring sound, generally lasting about 30 seconds, and by the noise of the storm damaging vegetation and buildings. Two of the authors (JB and PFH) conducted an inspection of the area on 23 and 24 November. Damage was confined to a path about 14 km in length oriented northwest to southeast, the width of which varied between 50 and 150 metres. The damage was not continuous along the path. Significant damage sites are indicated in Fig. 2, and are briefly detailed below.

Thirteen houses were affected, with four losing part or all of their roofs, and a number of outbuildings were demolished. A shed was destroyed on a coastal road west of Smithoton (location 1 in Fig. 2(a)). Further inland and towards Smithoton, another shed was destroyed and a brick wall of a
house buckled (location 2). The roof and ceiling of another substantial brick house (location 3) was lifted some 15 to 20 cm before being dropped back in place. The extent of the lifting in this case was able to be estimated as a hanging basket of those dimensions, originally inside the house, was left hanging outside the building still attached to an interior rafter (see Fig. 2(b)). Other structural damage occurred to a number of houses immediately south of Smithton (location 4) and a chimney was lifted from a roof and placed upright on the ground nearby further along the tornado track (location 5). Approximately two thousand mature eucalypt trees (30 to 50 metres high) were uprooted or snapped off above ground level and entire stands of smaller trees were similarly damaged or destroyed (location 6). Most of the damage path lay in open farmland, containing isolated buildings and small stands of trees. Location 4, however, consisted of a row of houses lining a main street leading south from Smithton, and farmland gave way to eucalypt forest about 1 km further along the damage path from location 5.

Two cows were killed when impaled by flying roofing iron. Fortunately, there were no human casualties, probably in part because the thunderstorm occurred very early on a Sunday morning. Investigation of the storm track indicated an intense gradient of damage. At location 3 in Fig. 2(a), considerable damage was inflicted on a well-built brick dwelling, while some 30 metres to one side of the house an old and poorly maintained glasshouse was left intact. Similar contrasts were noted at other locations along the storm track. An aerial survey over a forested area showed a very sharp delineation between trees felled by the storm and those left intact (see Fig. 2(c)). At one point, near location 4 in Fig. 2(a), localised tree damage was evident one to two hundred metres to one side of the main damage path.

The orientation of the damage path was directed from 300 degrees, while almost all felled trees were oriented between about 330 and 010 degrees (with the lower parts of the trees northward), suggesting the wind had applied a force to trees consistently to the right of the storm track. At isolated points along the damage path through forested areas, however, trees lay in a clockwise orientation to each other.

As noted, substantial damage occurred to well-built brick houses (locations 2 and 3 in Fig. 2(a)) and all trees in forested areas within the damage path were uprooted or snapped (location 6 in Fig. 2(a)). This degree of damage is F2 to F3 on the Fujita scale, suggesting maximum wind speeds of the order of 60 m/s (Fujita 1981). The combination of a long, narrow damage path with intense gradients of damage, reports of a roaring sound heard by those close to the storm and the cross-path orientation of felled trees suggest that the damage was most probably caused by one or a number of tornadoes, spawned by a single thunderstorm (Bunting and Smith 1992).

The occurrence of a tornado had to be determined indirectly, as the storm occurred during the hours of darkness on a Sunday morning. Only one eyewitness was available and, interestingly, he did not provide a conventional description of a funnel-shaped cloud. The witness was a security guard who had been driving from one of his assignments, in heavy rain, when, at a distance of one to two kilometres toward the southwest, he saw a ‘glowing blue ball’ two to three hundred metres wide, illuminated from below and within. The ball extended as high as he could see (which was probably 300 to 600 metres, given the likely cloud base at the time). The eyewitness was adamant that the source of the illumination was not lightning. The glow subsided, before flaring up again twice as it crossed his field of view.

It seems most likely that the eyewitness saw a tornado illuminated by electrical activity other than lightning. Reports of glowing nocturnal tornadoes have occurred in, for example, the United States (Seargent 1991; Vonnegut and Weyer 1966) but, to the authors’ knowledge, they have not previously been recorded in Australia.

Broadscale meteorological setting

Strongly meridional flow prevailed over the Australian region in the days preceding the Smithton thunderstorm. This is illustrated by a series of manual mean sea-level pressure (MSLP) analyses from the National Meteorological Centre (NMC) of the Australian Bureau of Meteorology (Fig. 3). Air of polar origin was advected north over Western Australian longitudes during the days preceding 18 November which later resulted in snowfalls over southern agricultural areas of Western Australia, a rare event in November. The thermal contrast between this air mass and warmer air further east contributed to the development and rapid intensification of a low pressure system off the south coast of Western Australia on 18 November. By 1200 UTC 19 November, the central pressure of this low was being analysed at 980 hPa.

Over the next two days, the low and associated cold front moved slowly eastward. By 0000 UTC 21 November, the low had become elongated and a second centre of below 980 hPa had formed further south. During the next 24 hours, the long
wave trough in which the lows were embedded declined in amplitude and a more zonal westerly flow became established south of the Australian continent. As this occurred, the northern low moved southward and the associated cold front crossed Tasmania. About twelve hours after the passage of the cold front, a pool of very cold middle to upper-level air also passed over the State.

**Observed meteorological conditions**

**Surface observations**
Little observational data are available near the storm in time and space. Synoptic observations are carried out in Smithton during daylight only. Reports from stations within about 100 km of Smithton suggest the surface temperature at the time of the thunderstorm was in the range 11–13°C, with a dew-point in the range 8.5–10°C. The wind at stations along Tasmania’s north coast and on King Island backed from northwest to westerly between 1600 and 1900 UTC, indicating the passage of a trough across the north of the State between these times. It may be that surface convergence associated with the trough contributed to the development of the thunderstorm and tornado at Smithton.

**Upper-level temperatures**
Satellite imagery from the Japanese Geostationary Meteorological Satellite (GMS-4) (Fig. 4) indicated that the cold pool passed close to Mt Gambier at about 1000 UTC 21 November, the time of the evening radiosonde sounding. Unfortunately, there was no evening sounding on 21
November, but there were soundings at Laverton, to the east of the coldest air at that time, and at Hobart, still under the frontal cloud band.

Substantial cooling through the depth of the troposphere was evident on the 1000 UTC Laverton sounding (not shown) in comparison to the previous flight, 12 hours earlier, with the greatest cooling above 600 hPa. At 850 hPa, the atmosphere had cooled 8°C, while at 500 hPa cooling was 12°C. The tropopause height dropped from about 180 hPa to 350 hPa. Greater cooling above 600 hPa suggested a significant increase in instability, however convective available potential energy (CAPE) calculated from this sounding was 0 J/kg. (Earlier, the lower atmosphere was more conducive to deep convection and thunderstorms were reported in Victoria.)

At this time, the coldest air, as inferred from enhanced cumulus activity evident on GMS imagery (Fig. 4(a)), was still 600 km to the west-
southwest of Laverton. Hobart lay beneath a middle-level cloudband, with cloud base at about 700 hPa, and the temperature sounding was stable (Fig. 5(a)). By 2200 UTC 21 November, the cold pool had moved over Tasmania and significant cooling had occurred above 950 hPa (Fig. 5(b)). The maximum cooling of about 15°C occurred near 400 hPa, with the tropopause again dropping from 150 hPa to 350 hPa.

CAPE calculated from the 2200 UTC 21 November Hobart sounding was 107 J/kg, suggesting the possibility of convection. Convexion was still evident over Tasmania on the 2030 UTC satellite image (Fig. 6), however an area of suppressed convective activity existed over southeast Tasmania, within the broader region of cloud that identified the location of the cold pool. In addition, model output for this time indicated strong downward motion over and immediately south of Hobart below about 5000 metres, in a configuration that suggests topographic forcing. With these points in mind, it is likely that the Hobart 2200 UTC sounding is not entirely representative of the vertical structure of the atmosphere over Smithton five hours earlier. In particular, the atmosphere near the surface is likely to have been warmer and drier in southeast Tasmania than was the case some hours earlier in the northwest. In an attempt to account, at least partly, for this, the maximum likely values of temperature and dew-point (13 and 10°C, respectively) at Smithton at the time of the thunderstorm were inserted into the 2200 UTC Hobart sounding. The modified sounding returned a CAPE of 317 J/kg, a substantial increase on the original value. It is likely that the actual value was still higher, as model output (to be discussed later) suggests.

Upper wind analysis

300 hPa. Analyses for this level are presented in Fig. 7(a). The 300 hPa analysis at 0400 UTC 21 November (not shown) indicated a west-northwesterly jetstream at 300 hPa over southeastern Australia extending a northerly lobe of 50 m/s over Victoria and Tasmania. By 1000 UTC, the jet had translated southeastward, following the movement of the trough, and declined slightly in intensity. The southward lobe had begun to wrap more around the region of coldest air.

The intensity of observed winds continued to decline, as the trough at upper levels tilted and became more peaked. At 1600 UTC, the jet was westerly over Victoria, while further south a northeast to northerly wind of 45 m/s was reported at Hobart, with the likelihood of a 50 m/s isolacth to the southeast (1800 UTC satellite cloud-drift winds (Le Marshall et al. 1993) suggested 54 m/s at this level about 500 km southeast of Hobart). By 2200 UTC, the wind had backed to westerly at both Hobart and Launceston, indicating that the trough had moved out into the Tasman Sea.

500 hPa. Analyses for this level are presented in Fig. 7(b). The situation at 500 hPa was broadly similar to that at 300 hPa. This is to be expected given the maturity of the trough system. The strongest winds observed at 0400 UTC (not shown) were close to 50 m/s, immediately downwind of the trough.

By 1000 UTC, the tilting of the trough was more clearly evident. A jet streak wrapped around the trough at this level with the strongest reported wind occurring over Launceston, north to north-easterly at 50 m/s, on the eastern flank of the trough.

With the relaxation of the trough, wind speeds decreased. At 1600 UTC, a westerly jet persisted across southeastern Australia, while winds had backed somewhat and eased over Tasmania. By 2200 UTC, winds over Tasmania had backed further as the trough continued to weaken and move southeastward.

Severe thunderstorm activity is frequently associated with the presence of a jet streak aloft, in addition to a number of other factors (e.g. Jones 1990; Uccellini and Johnson 1979). Certainly, in this case, there was a significant jet close to Tasmania at the time of the storm, which suggests that circulations associated with the jet contributed to the intensity of upward vertical motion over northwest Tasmania at that time. Because the jet was highly curved, however, it is not obvious where regions of enhanced upward vertical motion might be expected.

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Fig. 6 Enhanced GMS IR image for 2030 UTC 21 November 1992. Arrow indicates suppressed convective activity near Hobart.
Model simulations

A numerical weather prediction model, TRAM (Training Regional Atmospheric Model), was employed to investigate the situation over Tasmania during the night of 21–22 November 1992. TRAM is based on and nested within the operational Australian region numerical model, the Regional Assimilation Prognosis (RASP).

The RASP model is described in Leslie et al. (1985). Briefly, it is a gridded primitive equations model using semi-implicit time differencing and a vertical mode initialisation scheme. The operational grid spacing in 1992 was 150 km and the model employed 15 vertical levels on sigma surfaces.
TRAM is essentially the same model as RASP, recast to run on a personal computer. The model boundary conditions are taken from the six-hourly RASP output fields, and both horizontal and vertical grid spacings are scalable. In this case study, the grid spacing used was 30 km with 14 vertical levels ($\sigma = 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.78, 0.85, 0.90, 0.95, 0.975, 0.99, 0.995, 0.998$). The domain over which the model was run, together with the model topography, is shown in Fig. 8. The boundaries were chosen to include the area of most active convection at the time of the analysis, 1100 UTC 21 November, and to minimise any boundary effects over Tasmania.

**Verification of model output**

A number of checks were employed to assess the validity of the TRAM output for the situation on 21–22 November. Comparisons were made between model and observed upper level winds at Hobart and Launceston, and between model and observed upper temperatures at Hobart at 2200 UTC, 21 November. In addition, satellite images were compared with TRAM vertical motion fields, to assess whether observed areas of cloud corresponded to prognosed regions of upward vertical motion.

Figure 5(b) displays the Hobart temperature sounding for 2200 UTC 21 November. Overlaid on the sounding are a series of dots, indicating temperatures and dew-points obtained from the 12-hour TRAM prognosis, valid for the same time for a vertical section over Hobart. The two sets of data correspond closely. Model temperatures and dew-points are within two degrees of observations below the tropopause, and at most levels they are considerably closer than that. Above the tropopause, the temperature discrepancies are larger (up to five degrees) but the trend with altitude is the same, so that the upper parts of the observed and model soundings are qualitatively very similar. In both cases, dew-points above the tropopause are negligible. The period of greatest interest in this study is only six hours after analysis time, and given the accuracy evident in

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**Fig. 8** TRAM model domain, contoured at 50-metre intervals. Lines AB and CD represent cross-sections in Figs 11 and 12 respectively.
the temperature profile twelve hours after analysis, it seems reasonable to be confident about model-derived temperature profiles for the Smithton area immediately before the severe thunderstorm.

Winds at a number of levels, derived from model output, were compared to those observed at Launceston at 1600 UTC. While the times of the observed and modelled winds are nominally identical, some discrepancy will exist because the wind observation flight extended over about one hour. This is of some significance because the system was evolving rapidly. In addition, the balloon travelled about 70 km during the flight, while the model winds were taken directly above Launceston. Table 1 lists both sets of winds.

At the lowest level, 950 hPa, the model does not compare closely with observed winds. This may be a consequence of boundary-layer processes, not adequately parametrised by the numerical model. It is also likely that the model topography is not sufficiently detailed to allow realistic low-level winds to be generated near Launceston, which lies at the base of a broad north-south valley approximately 1000 metres deep. At other levels below 600 hPa, however, there is close agreement between the two sets of winds. The model winds differ from observed winds by no more than 5° in direction and 4 m/s in speed. Above 600 hPa, the discrepancies are larger: 20–30° in direction and up to 7 m/s in speed. Given the inherent inaccuracies of positioning the observed winds in time and space, these results still indicate a good agreement between the model and observed conditions.

GMS infrared satellite imagery (Fig 4) was compared with the model analysis of 700 hPa vertical motion for 1100 UTC 21 November (Fig. 9(a)) and the six-hour prognosis for 1700 UTC 21 November (Fig. 9(b)) to assess consistency between cloudy areas and upward vertical motion. Upward vertical motion may occur in cloud-free areas, while cloud may form as a result of upward motion at levels other than 700 hPa, of course. This test is still useful, however, as a qualitative comparison between observed and modelled conditions.

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![Fig. 9 (a) Model output of 700 hPa vertical motion in hPa/h at (a) analysis time 1100 UTC, 21 November 1992, and (b) +06 hours 1700 UTC, 21 November 1992. Solid lines indicate downward motion, dotted lines upward motion.](image)

### Table 1. Comparison of observed and model upper-level winds (in m/s) over Launceston at 1600 UTC 21 November 1992.

<table>
<thead>
<tr>
<th>Level (hPa)</th>
<th>950</th>
<th>900</th>
<th>850</th>
<th>700</th>
<th>600</th>
<th>500</th>
<th>400</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated</td>
<td>320/09</td>
<td>315/20</td>
<td>315/22</td>
<td>310/23</td>
<td>310/27</td>
<td>315/28</td>
<td>325/23</td>
<td>350/35</td>
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</tbody>
</table>
At analysis time (the analysis is based on the coarse, or 150 km resolution RASP), moderate upward vertical motion at 700 hPa is indicated over the northwest corner of the model domain, close to the region of active convection evident on the satellite image (Fig. 4(a)). The peak of convective activity, however, lies to the south of the peak model vertical motion values. A second area of upward vertical motion is indicated to the southeast of Tasmania, coincident with the frontal cloudband. Between these two regions lies an area of downward vertical motion, broader in the model output 700 hPa vertical motion field than appears to be the case in the satellite image. Broadly, however, the model analysis reflects the information available in the GMS image.

At six hours into the model simulation, strong upward vertical motion was indicated over northwestern Tasmania, consistent with the intense convection evident on the GMS image for the same time (Fig. 4(b)). This was close to the time of tornado occurrence. The model output and satellite imagery are also broadly consistent over the rest of the model domain for this time.

Satellite imagery was also consistent with the +3 and +9-hour vertical motion fields (not shown), lending support to the thesis that the model run captured the evolution of the synoptic system over the Tasmanian region.

The three tests applied support the hypothesis that the TRAM captured the essential details of the evolution of the synoptic system over Tasmania. While in many severe thunderstorm cases, important atmospheric processes are below the resolution of numerical models and can only be approximately parametrised, it appears that in this instance development was strongly driven by large-scale dynamics, which were adequately resolved by the numerical model.

Analysis of model output
Estimation of thunderstorm environment
Vertical profiles of temperature and dew-point were constructed from the model output over Smithton at three-hourly intervals from 1100 UTC, 21 November (Fig. 10). Simulated surface temperature and dew-point were taken from the lowest sigma level of the model at each timestep, nominally at about 60 metres above ground level.

Between 1100 and 1700 UTC, steady warming occurs up to 600 hPa, while marked cooling occurs above. In addition, a strong increase is evident in the moisture content of the model atmosphere, with, for example, the 850 hPa dew-point increasing from -11.5°C (1100 UTC) to 1°C (1400 UTC) and 4°C (1700 UTC). After 1700 UTC, the surface temperature remains almost constant, cooling is evident above the surface to 500 hPa and warming occurs above 500 hPa. Meanwhile, the atmosphere dries substantially as southwest to westerly winds become established.

At around 500 hPa, slight warming does occur between 1400 UTC and 1700 UTC, increasing the overall stability of the atmosphere. Convective available potential energy (CAPE) calculated from model output (using the lowest model sigma level as the base of the sounding) decreases somewhat from 900 J/kg to 700 J/kg at 1700 UTC. Possibly, this warming is due to the parametrisation of convective activity in the model. Nonetheless, the computed CAPE still represents a considerable degree of instability for the Tasmanian region, where CAPE values seldom exceed 200–300 J/kg (unpublished notes, Bureau of Meteorology, Tasmania). Interestingly, the vertical temperature profile at 1700 UTC is distinctly more moist than those at 1400 and 2000 UTC. Again, this may be related to the model parametrisation of convection.

The wind profile and vertical wind shear in the vicinity of Smithton were also examined. Model-derived winds for a number of levels at three-hourly timesteps from 1100 UTC are given in Table 2.

As was the case with observed upper winds at Launceston at 1600 UTC (refer Table 1), vertical wind shear is not large. Using the winds in Table 2, storm relative helicity values were calculated. Radar data were unavailable, so the storm motion used for helicity calculations was estimated from the direction and speed of movement of convective cloud tops between 1630 UTC and 1730 UTC to be 310° at 21 m/s. The direction is close to the observed orientation of the storm damage path (from 300°). The lowest model level (about 59 m above ground level) near Smithton at this time indicated a wind of 32 m/s, which the authors felt was too strong to be realistic given available surface observations along the north coast of Tasmania near this time. This is probably a consequence of the smoothing of topography within the model. As a result, the surface wind used was that of Cape Grim at 1600 UTC, 340° at 12 m/s. The storm-relative hodograph (not shown) based on this technique suggested sufficient helicity for a weak supercell tornado, -201 m²/s² (Davies-Jones and Burgess 1990).

As noted by Davies-Jones and Burgess (1990) and Mitchell and Griffiths (1993), storm-relative helicity is a very volatile parameter, subject to considerable variation in time and space. It is possible that significantly larger storm-relative helicity was generated in the vicinity of Smithton close to the time of the storm due, for example, to coastal convergence than is indicated above. In
addition, Cape Grim is very exposed and it is possible that the surface wind speed at Smithton was less than 12 m/s.

Because of the paucity of observed winds near the storm site, it is not possible to be certain whether or not the thunderstorm that generated the tornado contained a mesocyclone. Calculated helicity based on model and available observational data suggests the possibility of mesocyclone development. On the other hand, Wakimoto and Wilson (1989) suggest that non-supercell (and non-mesocyclone) tornadoes may achieve intensities as high as F3, a statement supported by Brady and Szoke (1989). The latter authors also note instances of the formation of such tornadoes in strongly forced environments, such as those detailed in Wilson (1986) and Weaver and Nelson (1982), and such as that which existed over northwestern Tasmania on 21–22 November.

**Topographic influence**

Topographic factors play a particularly important role in Tasmanian meteorology. The central highlands occupy over one-third of the land area of the State, with the northeast highlands occupying a
Table 2. Model output winds (in m/s) over Smithton at three-hourly intervals between 1100 and 2000 UTC 21 November 1992 at standard pressure levels 950 to 300 hPa.

<table>
<thead>
<tr>
<th></th>
<th>950</th>
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<th>400</th>
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</thead>
<tbody>
<tr>
<td>1100</td>
<td>328/16</td>
<td>300/24</td>
<td>295/26</td>
<td>295/26</td>
<td>300/24</td>
<td>335/18</td>
<td>305/24</td>
<td>020/40</td>
<td>030/42</td>
</tr>
<tr>
<td>1400</td>
<td>332/22</td>
<td>325/22</td>
<td>315/21</td>
<td>310/20</td>
<td>300/22</td>
<td>305/23</td>
<td>310/23</td>
<td>295/27</td>
<td>335/28</td>
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<tr>
<td>1700</td>
<td>310/33</td>
<td>300/30</td>
<td>295/28</td>
<td>305/27</td>
<td>315/26</td>
<td>320/26</td>
<td>325/23</td>
<td>310/23</td>
<td>295/42</td>
</tr>
</tbody>
</table>

Further ten per cent. About 50 per cent of the central highlands lies above 1000 metres and the highest point is a little over 1600 metres. A similar percentage of the northeast highlands is more than 1000 metres high, rising to 1570 metres at Legges Tor. It is of considerable interest, then, to assess the role played by the Tasmanian topography on the mesoscale environment of the Smithton thunderstorm.

Vertical cross-sections taken of the vertical motion field generated in the TRAM accord closely with areas of cloud in satellite imagery, as discussed in the model verification section. Of additional interest, the orientation and placement of the strongest vertical motion suggested considerable orographic influence.

To investigate further, the TRAM was rerun with the maximum height of the topography set to zero. Figure 11 shows cross-sections for topographic (Fig. 11(a)) and non-topographic (Fig. 11(b)) model runs taken along the line AB in Fig. 8. The cross-section was chosen to pass close to Smithton, along approximately the path taken by the mass of coldest air.

The two analyses differ slightly over Tasmania, due to the model initialisation. However, the broad features and the boundaries of upward and downward motion remain the same. At this time, subsidence was occurring, while at the eastern boundary of the cross-section, upward vertical motion associated with the cold front was evident, and to the west, the upward motion generated by the approaching cold pool can be seen.

At + 06 hours, considerably more detail is evident in each case. At the western and eastern extremes of the cross-section, away from the perturbing effects of the Tasmanian topography, details of subsident areas are very similar. In the vicinity of Tasmania, however, a number of differences are evident. Upward and downward vertical motions appear considerably enhanced by the presence of topography. To the west of the northeast highlands, upward vertical motion is also apparently enhanced by the topography. Recourse to a diagram of vertical motion on a constant pressure surface (not shown), however, indicates that the peak values of vertical motion in the non-topographic case are merely displaced slightly northward from the line of the cross-section. To the west of Tasmania in the non-topographic run, narrow areas of downward motion are evident, which appear (somewhat weaker) in the topographic run to the west of the region of maximum uplift. Overall, a comparison of the two runs at this time suggests that upward vertical motion over north coastal Tasmania was considerably enhanced by the presence of topography.

An interesting feature of the two cross-sections is that, below about 6000 metres, subsidence is enhanced in the topographic run compared to the zero topography case towards the east coast. Marked subsidence is evident in the topographic model run in the lowest several thousand metres, while a corresponding area of upward motion occurs above.

A comparison of the twelve-hour forecasts is also interesting in that it indicates fewer differences between the two runs than was the case for the six-hour forecast. Subsidence is dominant through the cross-section, somewhat enhanced in the topography run compared with the zero-topography run. It is likely that the greater instability associated with the passage across Tasmania of the cold air aloft at 1700 UTC was sufficient to allow greater expression of topographic effects than is the case at 2300 UTC.

Discussion

The numerical model experiments described above suggest that topographic forcing was significant in the severe thunderstorm event in northern Tasmania on 22 November 1992. A climatological preference exists for severe convection to occur in the north of Tasmania in comparison to, in particular, the southeast (Jones 1990). Figure 12 presents a cross-section view of the TRAM vertical motion field with and without topography at +09 hours (2000 UTC 21 November), at the time when the coldest air was moving over southern Tasmania and broadscale upmotion would be expected with the passage of the trough. The cross-section is taken through Tasmania from northwest to southeast (line CD in
Fig. 11  Cross-sections of model vertical motion fields in hPa/h along line AB in Fig. 8 for 1100, 1700 and 2300 UTC 21 November 1992: (a) with topography; (b) without topography. Arrow denotes position of Smithton. Solid lines denote down motion, dotted lines up motion.

Fig. 8). Southeastern Tasmania experienced downward vertical motion near the surface at this time in the topographic run (although upward vertical motion was evident above a height of about 2000 metres). This was despite the broad-scale up-motion being generated with the passage of the trough, which can be seen in the zero topography run. It may be that, as in this case, the Tasmanian topography regularly induces down-motion, which suppresses convection in the southeast, under synoptic conditions that would otherwise be favourable for strong or severe convection.

It would be useful to examine other severe thunderstorm occurrences along Tasmania's north coast in a similar manner to this case,
Fig. 12 Cross-sections of model vertical motion fields through Tasmania from northwest to southeast at 2000 UTC 21 November 1992: (a) without topography, (b) with topography.

thereby gauging the generality of topographic displacement of severe convection in the north and its suppression in the southeast. Examination of 'null' cases, where no severe convection occurred, would also be useful and may assist in improving severe thunderstorm identification methodologies in Tasmania.

The synoptic situation in which the tornado occurred is similar to that of some other documented Australian and United States tornadoes. Foley and Hanstrum (1990) indicated that approximately 25 per cent of southwest Western Australian tornadoes developed in post-frontal cold air, near the axis of the main thermal trough associated with the change. Similarly, Montiverdi (1993) noted that most Californian tornadoes developed in cold sector air. This suggests that severe thunderstorm forecasting techniques developed elsewhere may be applicable to the Tasmanian context. The similarity of the synoptic and topographic setting of the Smithton tornado to that of many Californian tornadoes may have implications for the usefulness of radar observations to warn for severe thunderstorms in northern Tasmania. Hales (1985) hypothesised that, in the case of Californian winter tornadoes, an area of much higher than average tornado incidence was a result of coastal frictional convergence coupled with the presence of mountains some distance inland. The juxtaposition of coast and mountain range is similar to the situation in Tasmania and both coastal convergence and topographic lifting have been suggested as contributing to the preference for tornadogenesis in northern Tasmania. Hales (1993) further noted that, in the area of the local maximum of tornado occurrence in California, markedly increased low-level helicity develops as a result of the influence of the terrain. The tornadic thunderstorms that developed in this situation, while possessing mesocyclones, were difficult to detect using conventional severe thunderstorm identification methodologies. The storms were often low-topped and lacked strong reflectivity, so that, for example, bounded weak echo regions and hook echoes were not easily visible.

It is not clear, from the evidence presented in this paper, whether the Smithton tornado was spawned by a supercell thunderstorm or was generated through near-surface shear. Wakimoto and Wilson (1989), among others, state that tornadoes formed through the latter mechanism develop early in the life of the parent thunderstorm and are generally short-lived. In either case, it may be difficult to identify the occurrence of many such tornadic severe thunderstorms with the recently installed weather watch radar in the north of Tasmania. This is not to discount the value of the weather watch radar in northern Tasmania, but to indicate that the radar may not be able to assist as much as might otherwise be expected in the detection and warning of events such as the tornado that affected Smithton on 22 November 1992.

Conclusion

This paper has described the damage caused by a severe thunderstorm that affected Smithton at about 1700 UTC 21 November 1992. From the nature of the damage, it was inferred that at least one tornado was responsible. An eyewitness account of the tornado, as a 'glowing blue ball, two to three hundred metres across illuminated from below and within' is believed to be the first documented example of a glowing nocturnal tornado in Australia. The meteorological environment within which the thunderstorm developed was similar to post-frontal cold sector environments in southwest Western Australia and California that have produced tornadoes.
A numerical weather prediction model was run over the area in which the storm evolved and, after comparison with available observations to assess the validity of the model simulation, model output was examined to provide further insight into the nature of the thunderstorm environment. It was tentatively concluded that the observed preference for severe thunderstorms to occur over northern Tasmania may in part be attributed to the topography of the State. Comment was made on the ability to reliably warn of events similar to the Smithton tornado, even with the use of weather watch radar.

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