

The Winchelsea Convergence – using radar and mesoscale NWP to diagnose cool change structure

Graham Mills

Bureau of Meteorology Research Centre, Australia,
and Bushfire Cooperative Research Centre

and

Evan Morgan

Victorian Regional Office, Bureau of Meteorology, Australia

(Manuscript received May 2005; revised February 2006)

A particular feature of dry cool changes in southern Victoria that is seen in clear-air radar reflectivity is described in this paper. The feature manifests itself as a trailing line echo oriented approximately normal to the leading edge of a dry cool change and on the cool-air side of the change. Using clear-air radar echoes, mesoscale NWP data, and observations, the evolving morphology of these convergence lines is described. It is shown that these convergence lines result from the confluence of diabatically modified post-frontal air that has had some hours of movement over land, and that of the cool air behind a coastal surging part of the same cool change. As the wind shifts associated with these dry cool changes are of critical importance to fire fighting operations, the concepts presented in this paper have potential for aiding very short-range forecasts of these wind changes and the consequent forecasting implications are discussed.

Introduction

The forecasting of the passage of wind changes associated with dry cold fronts is vital to safe firefighting operations in southeastern Australia (Cheney et al. 2001), and the issuing of 'Wind Change Forecast Charts' is an important part of the Victorian, South Australian and New South Wales Regional Forecast Centres' fire weather forecast product suite.

While weather radars are most commonly used for monitoring hydrometeors, it has long been recognised that low-reflectivity echoes can be received in clear-air environments, and that these are frequently associated with convergence lines. Wilson et al. (1994) discuss these echoes, and conclude that they are general-

ly caused by reflections from insects trapped in the ascending air in these convergence lines, but may at times be a result of refractive index variance at the convergence line. Dickins and Cusworth (2001) showed several examples of low-reflectivity weather radar line echoes in the South Australian Gulfs region that were associated with significant dry cool changes, and suggested that these observations may be valuable in fire weather forecasting. The Western Australian Regional Forecast Centre has also shown the potential for this form of data during the west-coast trough passage during the Gin Gin fire of 20 December 2002.

On the afternoon of 20 January 2004 a cool change was approaching Melbourne, Australia, and a convergence line marking the leading edge of the cool change was observed by the Laverton radar moving from the southwest towards Melbourne (see Fig. 1 for locations). The convergence line (Fig. 2) showed a generally west-northwest to east-southeast orientation, in accordance with the common orientation of such cool changes, but did consist of two convex segments, and also exhibited a lengthy line echo trailing towards the southwest and approximately normal to the leading edge of the cool change. This latter feature is not represented in any previously developed conceptual models of cool changes in southeastern Australia.

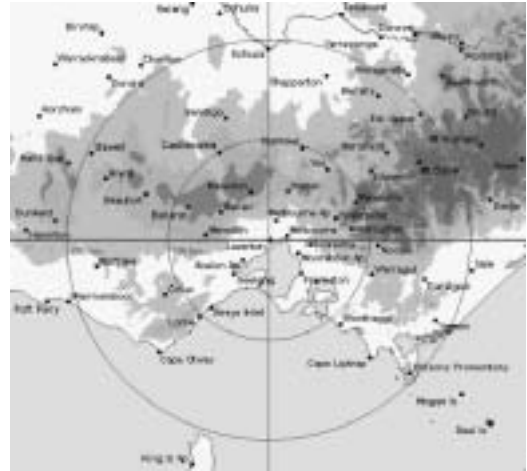
Mesoscale numerical weather prediction (NWP) models have been shown in a number of studies (e.g. Mills 2002, 2005) to accurately predict the structures and movement of these dry cool changes. The National Meteorological and Oceanographic Centre of the Bureau of Meteorology runs twice-daily operational mesoscale NWP forecasts over Victoria, using the LAPS NWP model (Puri et al. 1998) with a horizontal grid spacing of 0.05° (approximately 5 km). In this paper we will first relate the structures seen in the radar images on 20 January 2004 to the structures seen in the numerical forecast fields, and propose a mechanism to explain the trailing convergence line. Then, several other cases from the 2003-2004 summer will be examined. These cases demonstrate that not only are the structures seen in the radar returns regularly replicated in the model fields, but also that case-to-case variations in morphology of the cool changes are jointly resolved. Further, these cases show the trailing convergence line, which we will term the 'Winchelsea Convergence', is an inherent part of the structure of dry cool changes moving towards Port Phillip, rather than being a rarity. Finally the implications of these concepts for forecasting cool change structures near the Victorian coastline will be discussed.

Case of 20 January 2004

The radar sequence at 20-minute intervals on the afternoon of 20 January 2004 is seen in Fig. 2. At the initial time (0340 UTC) a curved arc stretches across the southern part of Port Phillip and through Corio Bay. There is a marked reversal of curvature just west of Corio Bay, with the convergence line oriented more to the northwest in the western part of the image, and is just approaching the AWS station at Sheoaks. This echo is interpreted to be the leading edge of the approaching cool change. The trailing line echo is clearly seen extending south-westwards

Fig. 1 Locality maps. Upper panel shows the topography (m) of central and western Victoria together with a variety of place names. The topographic shading shows elevations above 0, 150, 300, 500 and 800 m. The lower panel shows more detail of the region near and immediately west of Port Phillip, together with place names used in the text.

(a)



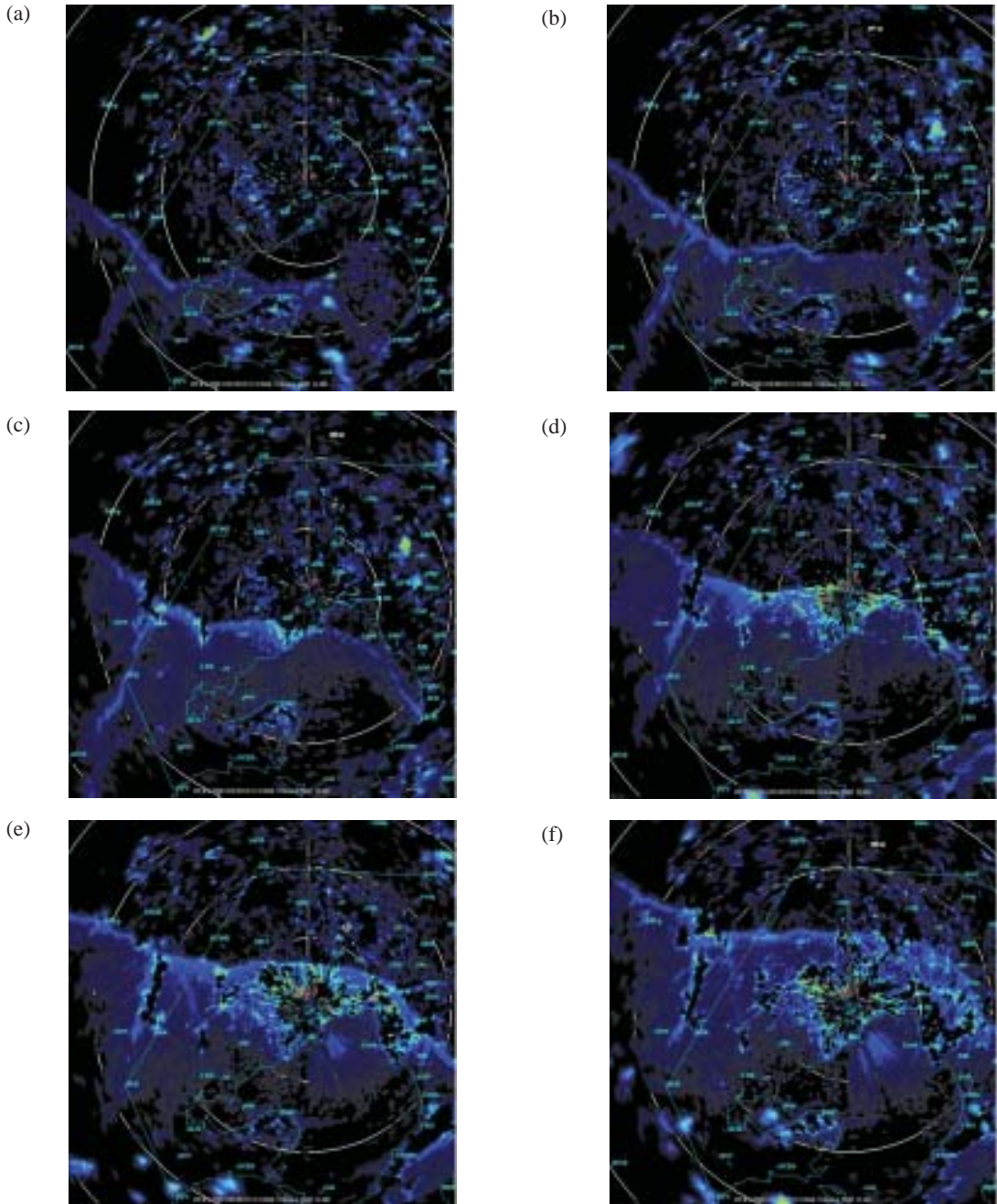
(b)



towards Winchelsea (WCS). Through the time sequence of images the leading edge of the cool change moves northeastwards through Port Phillip and the area to its west, but the trailing line appears to move slowly westwards.

The mesoscale NWP forecasts for the day (Fig. 3) show a weak change moving through western Victoria, southwesterly winds crossing the coast west of Cape Otway in the early afternoon, and a coastal surge east of Cape Otway. The wind change is associated with the warm-air edge of the zone of enhanced thermal gradient (Hewson's (1998) definition of cold-frontal location), and the sharpness of the wind

Fig. 2 Radar images from 0340 UTC (a) to 0520 UTC (f) 20 January 2004 at 20-minute intervals.

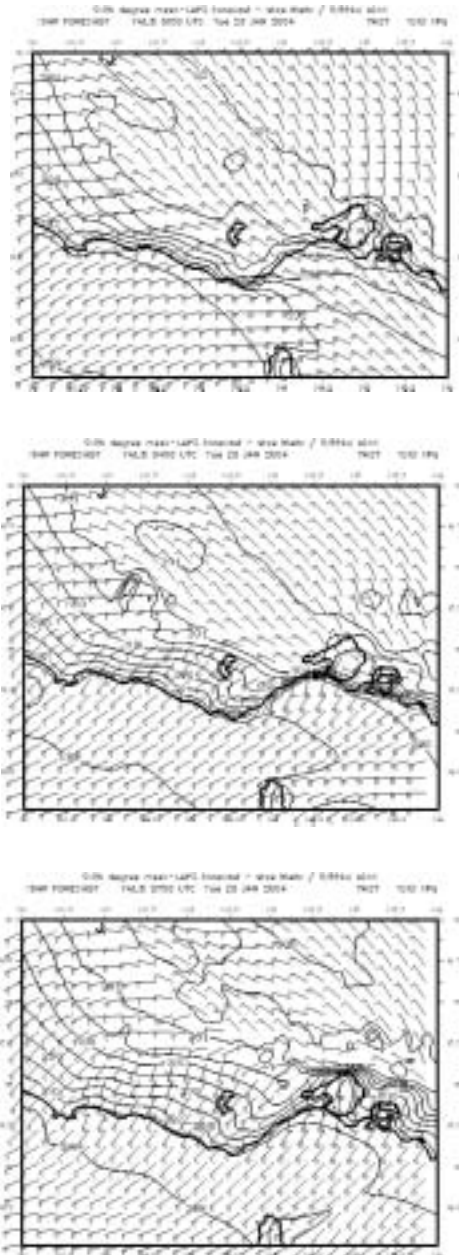


change is greater where the thermal gradient is stronger. The structure and evolution of this cool change shows considerable similarity to that discussed in detail by Mills (2002) where the processes leading to the development of the coastal surge east of Cape Otway are described.

Turning now to look in more detail at the area covered by the radar images, Fig. 4 shows hourly model output over a small area centred over and surrounding the Bellarine Peninsula. At 0400 UTC* the

* Local Daylight Savings time (LDST) is 11 hours ahead of UTC, so 0400 UTC is 1500 hours LDST.

Fig. 3 Meso-LAPS forecasts valid at 0100 (top), 0400, and 0700 (bottom) UTC 20 January 2004. The contours show potential temperature on the model's lowest sigma surface (approx 10 m above ground), and the wind fields are on sigma level 0.9943 (approx 30 m), and the bars have their usual meteorological meaning. Wind barbs are thinned to every 4th grid-point for clarity and the contour interval is 2 K.



forecast shows the coastal surge just crossing the south coast of the Bellarine Peninsula. By 0500 UTC the southwesterly change has crossed the western boundary of the plotted area, and by 0600 UTC the change structure shows remarkable similarities to that seen in the radar images at, for example, 0400 UTC. Tracing the 300 and 302 K isentropes at this time shows the same two convex shapes along the leading edge of the change as was seen in the radar imagery. Even more remarkably, it is clear that from 0500 UTC there is a confluence between the south-southeasterly winds following the coastal surge and the southwesterly winds following the inland portion of the change. This convergence line is located just to the warm side of the 300 K isentrope, extends southwestwards from the rear of the change, and is seen to move westwards with time, in spite of the westerly to southwesterly winds on its western side. This is the exact behaviour of the trailing line seen in the radar echoes, and it is difficult not to associate the two features. To make this clearer, and to provide background for the discussion of other cases later in this paper, Fig. 5 shows the NWP model forecast wind field for 0600 UTC 20 January 2004, with the bands between the 299 and 300 K, and the 303 and 304 K isentropes shaded. These bands represent, for this case, the approximate boundaries between the different airstreams being discussed. Airstream 1 is the hot, dry prefrontal air, airstream 2 is the post-frontal air representing the southwesterly change, and airstream 3 is the cool air in the coastal surge, with the boundary between airstreams 2 and 3 being proposed as the location of the trailing line seen in the radar imagery.

Comparing the time sequence of METAR observations at Grovedale and Sheoaks (see Fig. 1), shown in Fig. 6, the change moves through Grovedale at 0300 UTC with an abrupt direction change from northwesterly to southerly, a rapid decrease in temperature and an increase in dew-point. At Sheoaks the first change is from northwesterly to southwesterly at around 0330 UTC, with a marked increase in dew-point and a lengthy period of cooling to follow. At around 0900 UTC, though, there is a second wind change at Sheoaks, with the wind shifting to the southeast. These observations are consistent with the change structures diagnosed from the radar and NWP data above. The change at Grovedale is interpreted as the coastal surge crossing the station only some 10 km from the coast. The first change at Sheoaks is the inland part of the cool change (airstream 2), while the second change is interpreted as the westward passage of the trailing convergence line seen in the radar, and the inland propagation of the coastal surge air (airstream 3).

Fig. 4 Small subregion of the meso-LAPS forecasts valid at hourly intervals from 0400 to 0900 UTC 20 January 2004. The contours show potential temperature on the model's lowest sigma surface (approx 10 m above ground), and the wind fields are on sigma level 0.9943 (approx 30 m), and the barbs have their usual meteorological meaning. Wind barbs are shown at every grid-point, and the contour interval is 2 K.

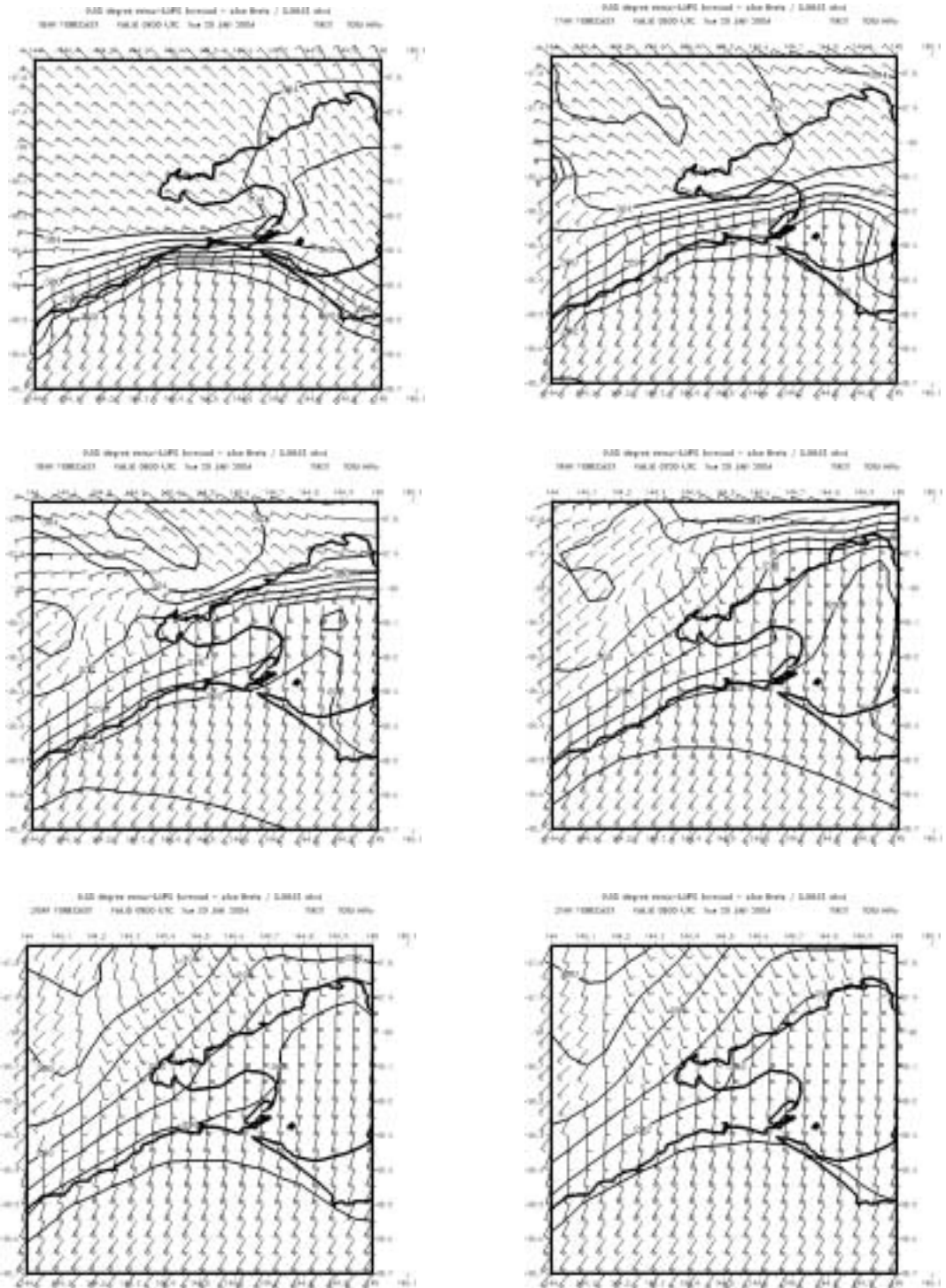
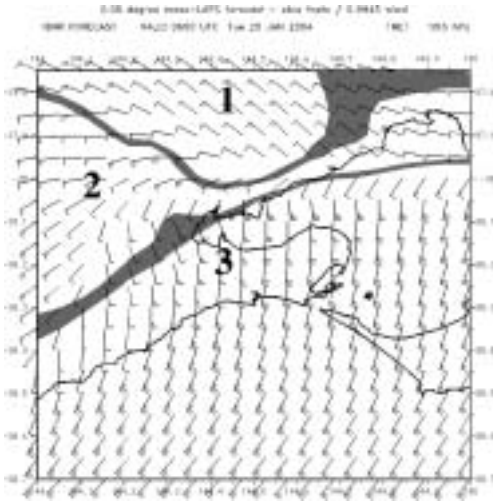


Fig. 5 Low-level wind field from the mesoscale NWP forecast valid 0600 UTC 20 January. Shaded are the regions between the 303 and 304 K isentropes and that between the 299 and 301 K isentropes, and the numbers refer to airstreams discussed in the text.



The NWP fields allow a physical explanation of this phenomenon to be developed. Once the wind changes to a southwesterly west of Cape Otway, cooler, postfrontal air parcels are advected to the northeast, parallel to the coastline, and the second panel of Fig. 3 clearly shows adiabatic cool advection in this area. However, diabatic processes are acting to counter this cool advection – model-calculated cool advection is of the order of -2 to -5 K h^{-1} , while model temperature changes are of the order of -1 K h^{-1} . Meanwhile air parcels that had a similar origin just southwest of Cape Otway, but that are part of the coastal surge are not being modified by diabatic heating, and so the air immediately behind the inland portion of the cool change is less dense than the air behind the coastal surge (see the temperature gradients in Figs 3 and 4). This results in a low-level westward-directed pressure gradient anomaly as a hydrostatic consequence of the temperature (density) gradient, and thus the westward propagation of the cooler air. Supporting evidence for this hypothesis is given in Fig. 7, which shows back trajectories from two points either side of the trailing convergence line, with both air parcels originating over western Bass Strait, but with one crossing the coast west of Cape Otway, and representing airstream 2, while that just a little further south represents airstream 3. Further,

Fig. 6 Time series of observations from 2000 UTC 19 to 1200 UTC 20 January 2004 at Grovedale (YGRD) and Sheoaks (SHEO). In the upper panels wind direction (degrees) is black, and uses the right-hand ordinate, while mean and gust speed (knots) are red and green respectively, and share the left-hand ordinate scaling. In the lower panels temperature (red) and dew-point (green) use the left and right-hand ordinate scaling respectively.

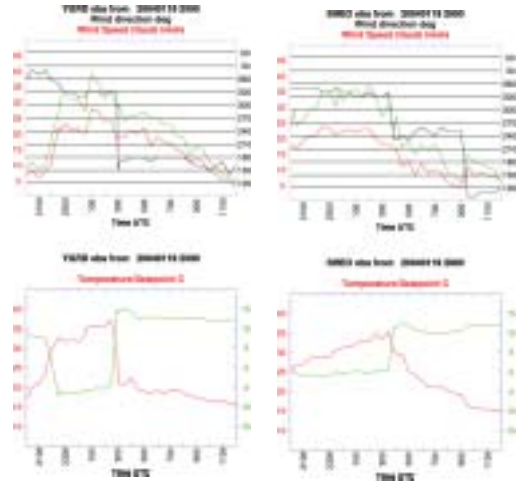


Fig. 7 Back trajectories over an 18-hour period calculated using the meso-LAPS 0.05° forecast based at 1200 UTC 19 January 2004. The end-points of the trajectories are marked by the stars, and are the air parcel positions at 0600 UTC 20 January 2004. The trajectories were computed using the HYSPLIT_4 transport and dispersion codes.

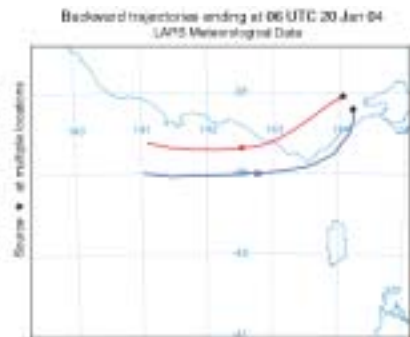


Fig. 6 shows that the dew-points after the initial cool change were very similar at both Grovedale and at Sheoaks, consistent with the hypothesis of a similar airmass origin for the two airstreams. It is also interesting that the isentropes appear to be retarded more strongly just inland of the coast east of Cape Otway than farther inland (e.g. lower panel Fig. 3). The increased topographic drag associated with the Otway Ranges (see the region of enhanced topography extending northeastwards from Cape Otway and parallel to the coast in Fig. 1(a)) may contribute to this feature; however there are insufficient observations in this area to corroborate this structure.

Given that the coastal surge/more gradual inland change structures are a regular feature of the summertime dry cool changes seen in Victoria, and that Mills (2002) has suggested that the topography and coastline of Victoria contributes to this structure, then

it is hypothesised that the trailing convergence line seen in the radar and NWP fields may be a normal part of the mesoscale meteorology of the area. Further, its location should generally be somewhat west of Geelong, and be in the region of Winchelsea. We propose therefore to refer to this convergence zone as ‘The Winchelsea Convergence’ hereafter in this paper.

Other examples

The case above has been treated in some detail, and following this initial examination, the radar image archive for the summer of 2003-2004 was examined and four other examples of the Winchelsea Convergence were identified. In each case the operational mesoscale NWP forecasts were extracted from

Fig. 8 On the left – radar images at 0450 and 0700 UTC 5 February 2004, and on the right meso-LAPS forecasts of low-level potential temperature and low-level wind speed at 0400 UTC and 0900 UTC 5 February 2004 based on initial fields at 1200 UTC 4 February 2004.

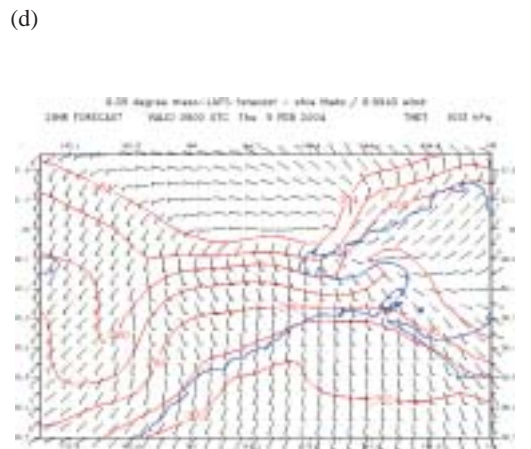
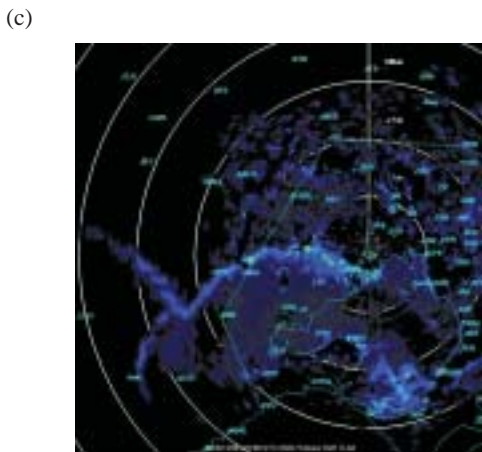
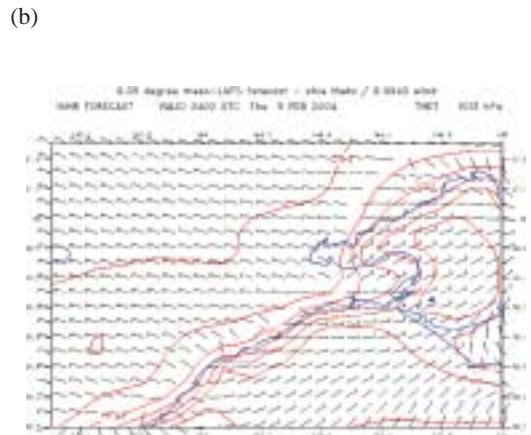
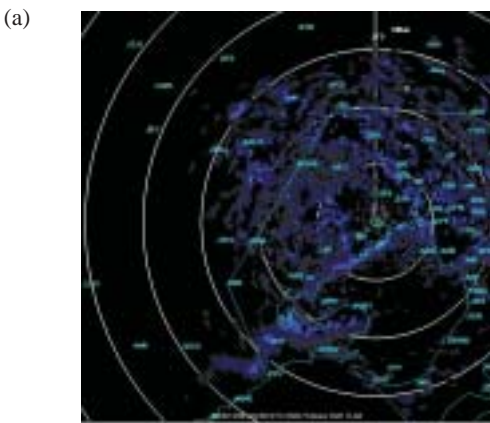
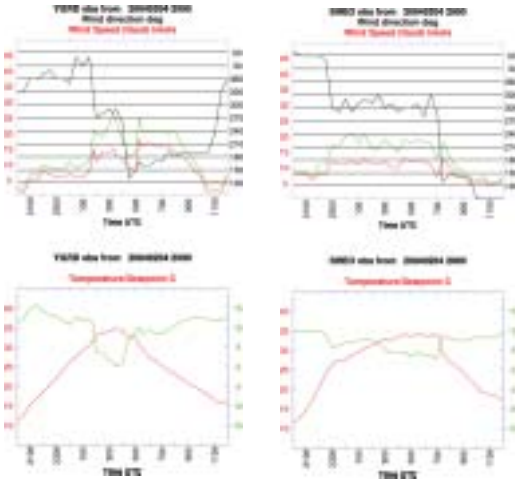


Fig. 9 As for Fig. 6 but for the time series of observations from 2000 UTC 4 to 1200 UTC 5 February 2004 at Grovedale (YGRD) and Sheoaks (SHEO).



archives and compared with the radar imagery, and also with the observations at Sheoaks and Grovedale. In these following cases two radar images are shown, one early and one later in the sequence of cool-change passage, and the two mesoscale forecast output times that most closely corresponded to the structures seen in the radar images are presented for comparison. The hypothesis here is that while the exact timing of the NWP model forecast of the cool change may be in error by 1-3 hours, the physical basis of the structures represented in the model fields may well be quite accurate, and so provide a framework for interpretation of the radar imagery and the surface observations. This is consistent with Browning's (1989) arguments about the ability of mesoscale NWP models to generate realistic mesoscale detail from synoptic-scale initial conditions, while not necessarily accurately predicting the exact timing or amplitude of such systems without mesoscale initial conditions.

Case 2: 5 February 2004

Radar images at 0450 UTC and at 0700 UTC, together with forecasts valid 0400 and 0900 UTC 5 February 2004 are shown in Fig. 8. At the earlier time the radar shows a convergence line along the

Fig. 10 On the left – radar images at 0815 and 1000 UTC 4 March 2004, and on the right meso-LAPS forecasts of low-level potential temperature and low-level wind speed at 1000 UTC and 1100 UTC 4 March 2004, based on initial fields at 1200 UTC 3 March 2004.

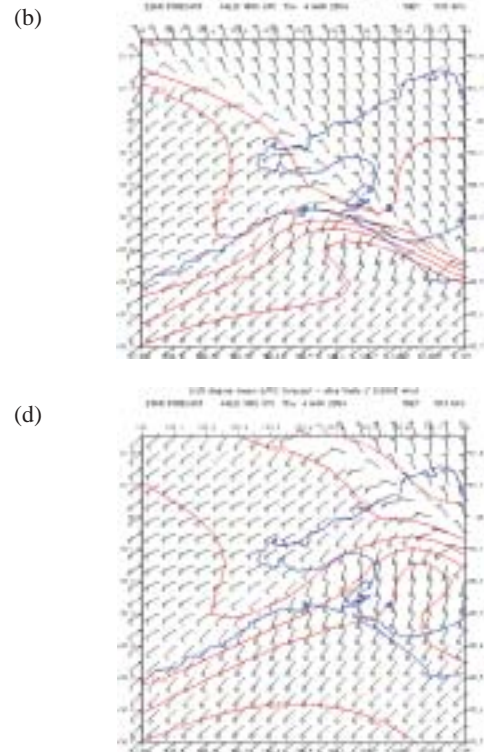
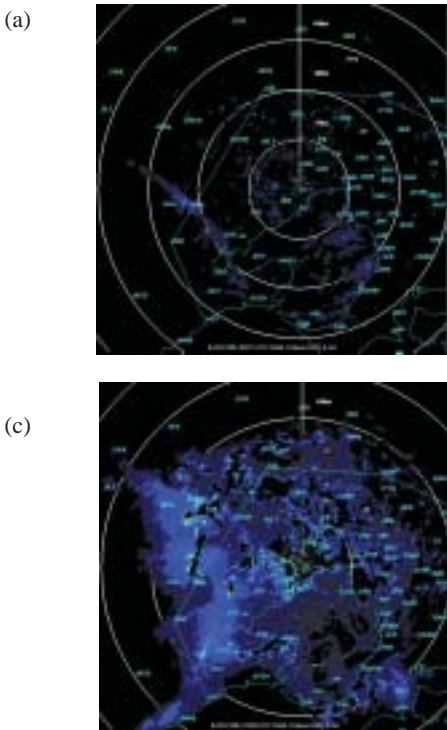
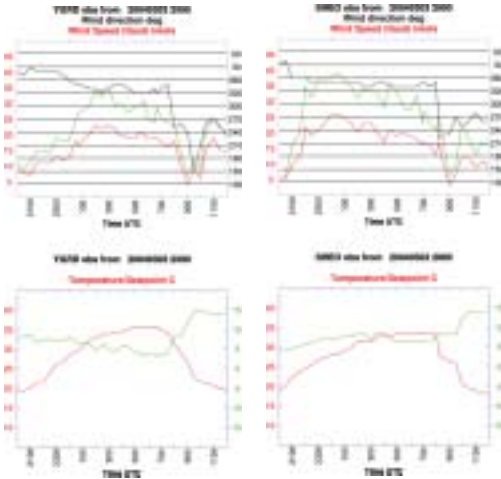


Fig. 11 As for Fig. 6 but for the time series of observations from 2000 UTC 3 to 1200 UTC 4 March 2004 at Grovedale (YGRD) and Sheoaks (SHEO).



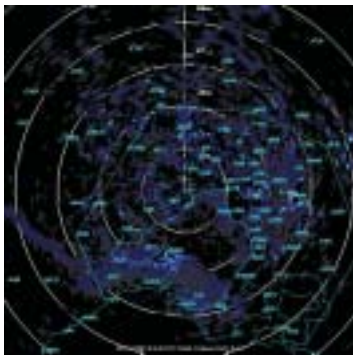
Bellarine Peninsula, and a coastal convergence is also seen in the NWP field at 0400 UTC. The radar image at the later time shows a similar ‘double convex’ convergence line, and a trailing Winchelsea Convergence line as seen in the 20 January case above, and the model fields replicate this structure quite well. Different to the 20 January case, though, is that the Winchelsea Convergence line is much further west, and the coastal surge part of the change penetrates much further inland, and is seen to be near Sheoaks at 0700 UTC. The observations (Fig. 9) show a change from around 290° to 160° at Grovedale around 0330-0400 UTC, and from 300° to 150° at Sheoaks at around 0700 UTC. The change at each station is interpreted in this case as being due to the passage of the coastal surge (airstream 3).

Case 3: 4 March 2004

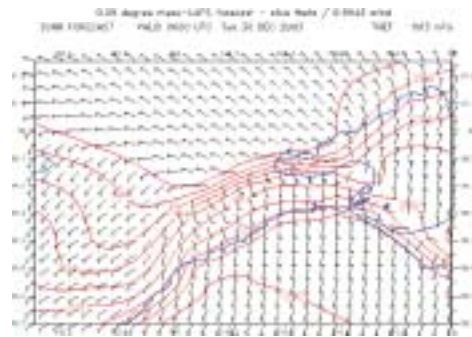
Figure 10 shows radar and NWP fields for the evening of 4 March 2004. In this case the dominant change is from the southwest (airstream 2), and this is the only convergence echo seen in the upper radar image, and is seen to be crossing the western end of Corio Bay at 0815 UTC. The model structure corresponding to that time shows only a weak hint of a convergence line associated with a coastal surge,

Fig. 12 On the left – radar images at 0440 and 0600 UTC 30 December 2003, and on the right meso-LAPS forecasts of low-level potential temperature and low-level wind speed at 0600 UTC and 0700 UTC 30 December 2003, based on initial fields at 0000 UTC 29 December 2003.

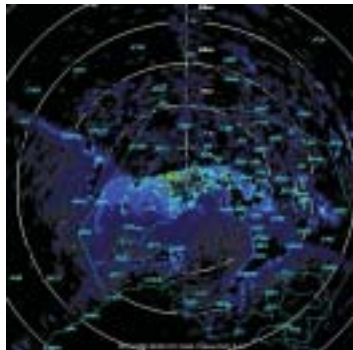
(a)



(b)



(c)



(d)

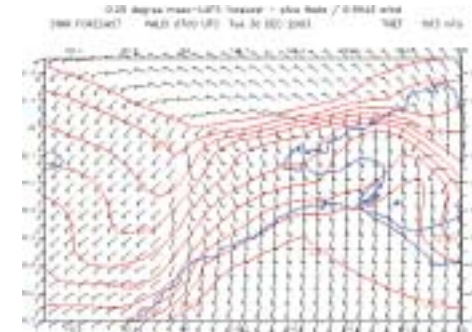
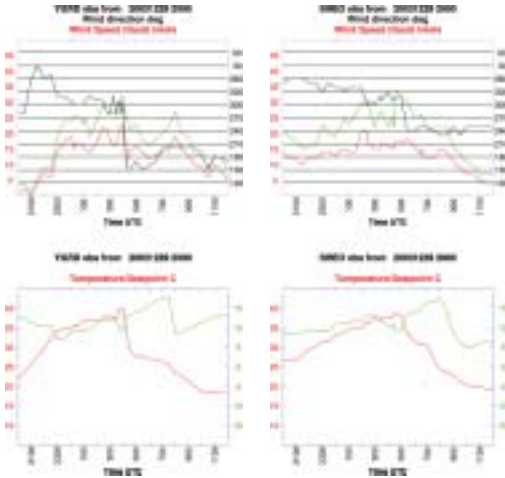


Fig. 13 As for Fig. 6 but for the time series of observations from 2000 UTC 29 to 1200 UTC 30 December 2003 at Grovedale (YGRD) and Sheoaks (SHEO).



and this is confirmed an hour later with the radar showing a convergence line just inland from the coast south of Grovedale, while the change from northwest to southwest winds progresses well into Port Phillip. The observations at Grovedale and Sheoaks (Fig. 11) show the initial wind direction change at each location to be from $\sim 340^\circ$ to $\sim 240^\circ$, with Grovedale showing a short period of southeasterly winds following the change. This might be interpreted as the coastal surge penetrating inland for a short period before moving southwards again, and the radar imagery does show some oscillation in a coastal convergence zone around that time, although the correspondence is not perfect.

Case 4: 30 December 2003

Figure 12 shows the radar and model fields for this case, and again the two arcs showing the leading edge of the coastal surge and that of the inland southwesterly change are seen, and in the latter radar image a very clear Winchelsea Convergence signature. The observation time series (Fig. 13) shows again an abrupt change to the south-southeast at Grovedale

(the coastal surge), but a change to the southwest (the southwesterly change, airstream 2) at Sheoaks. Again the structures seen in the radar images and the NWP forecasts are consistent with the evolution of the observations.

Case 5: 8 February 2004

The radar imagery in this case (Fig. 14) again shows the two arcs marking the leading edge of the cool change, but with only a very weak trailing Winchelsea Convergence echo. The model shows a marked coastal surge moving northward through Port Phillip, but the northwesterly winds ahead of the change are seen in the model to be steadily backing ahead of the change, and so the wind changes are less well resolved, and the thermal and directional gradient across the Winchelsea Convergence is rather less than in the other cases. The observations (Fig. 15) at Grovedale show an initial direction change from northeast to northwest at 0130 UTC that may be associated with the breaking of the nocturnal inversion (note the abrupt decrease in dewpoint at that time) and then at around 0230 UTC the passage of the coastal surge, consistent with the radar imagery and the NWP model's forecast change structure. At Sheoaks, however, the wind direction backs steadily both before and after the 'southwesterly' change, which might be interpreted to arrive at around 0330-0400 UTC based on the changes in time-tendencies of temperature and dew-point around that time. It is probable that synoptic influences were leading to the backing of the winds on a larger scale than that of the cool change circulation in this case. However, it is gratifying that features of the radar, NWP, and surface observations are still internally consistent with the conceptual model of the Winchelsea Convergence that has been proposed in this paper.

Conclusions

This paper has identified a particular feature of dry cool changes over central Victoria that results in a convergence line trailing and approximately normal to the leading edge of the cool change, and that this is a consequence of the particular distribution of land-sea boundaries along the Victorian coastline, and the frontogenetic role of the coastal thermal gradient during weak synoptic-scale frontal passage. The convergence line typically occurs in clear air to the west of Geelong, is oriented southwest-northeast, and is regularly discerned by the Laverton radar. It is argued that the convergence line marks the boundary between

Fig. 14 On the left – radar images at 0240 and 0340 UTC 8 February 2004, and on the right meso-LAPS forecasts of low-level potential temperature and low-level wind speed at 0300 UTC and 0600 UTC 8 February 2004, based on initial fields at 1200 UTC 7 February 2004.

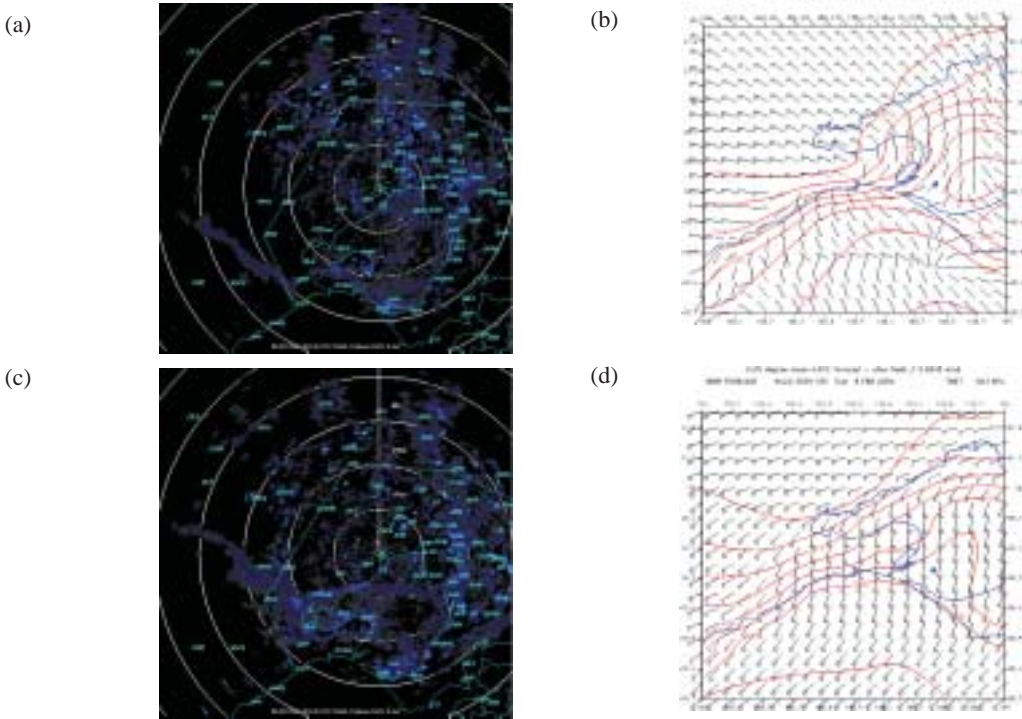
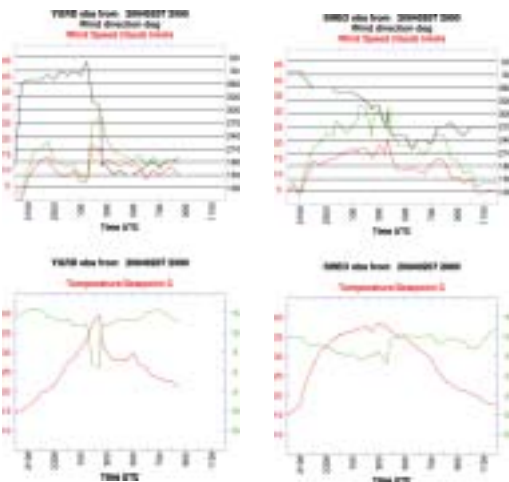


Fig. 15 As for Fig. 6 but for the time series of observations from 2000 UTC 7 to 1200 UTC 8 February 2004 at Grovedale (YGRD) and Sheoaks (SHEO).



diabatically modified post-frontal air of maritime origin on its western side, and that of air to the rear of a coastal surge on its eastern side, and thus marks a boundary between southwesterly and south to southeasterly winds. The fact that it is geographically tied to this one area has prompted the authors to refer to it as ‘Winchelsea Convergence’ in this paper. All cases presented here occur in the afternoon, consistent with the hypothesis in Mills (2002) that enhanced coastal temperature gradients during daytime heating contribute to the phenomena of ‘surging’ cold fronts along the coast east of Cape Otway, and also with the hypothesis of diabatic heating in the postfrontal (‘airstream 2’) air advanced in this paper. There may, of course, also be issues affecting radar reflectivity that make this phenomenon more likely to be seen in the radar reflectivity during the hotter parts of the diurnal cycle.

It has been shown that the operational mesoscale NWP forecasts show structures consistent with the radar returns, although it must be acknowledged that there are timing errors of 1-2 hours in several of these cases. It is diagnosis of these modelled atmospheric states that has formed the basis of the proposed physical model for the structure of the Winchelsea

Convergence. The AWS data in the area, while insufficiently dense to verify the spatial structure shown by the radar and NWP, do show time sequences that are consistent with those other forms of data. A particular feature of the NWP data is that it shows case-to-case variations in the structure of the cool changes and the Winchelsea Convergence that are consistent with case-to-case variations in both the morphology of the radar images and of the time sequence of observations at Grovedale and at Sheoaks. The ability of the NWP forecasts to resolve case-to-case variations in change morphology, even though there may be some timing errors, provides the potential to link the NWP, radar, and surface observations into a nowcasting process for short-range prediction of wind changes, for which there is a crucial need in forecasting support of fire-fighting operations. In such a model, the NWP forecasts would provide the first estimate of the wind change timing, and this would typically have a lead-time of 12-24 hours, and these forecasts would also provide the physical/conceptual model of the morphology of the individual cool change. Surface observations and the radar imagery would then allow late 'tuning' of the model forecasts to account for phase and shape errors in the model forecasts, while still retaining the NWP model's physical structure and evolution of the change. This 'nowcasting' phase might provide lead times of typically 1-3 hours, depending on the surface observation density and on the availability of radar or other forms of data.

While the term 'Winchelsea Convergence' has been used in this paper to describe the feature seen in

Laverton radar images in that region of Victoria, it should not necessarily be seen as a process unique to that part of Australia. Anywhere where the coastal orientation and coastal frontogenesis can come into play can produce the same ingredients, and, for example, Eyre Peninsula in South Australia, the southeast coast of New South Wales (the change in coastal orientation at Cape Howe), and the southwest of Western Australia are some other locations where such convergence lines might be observed.

References

- Browning, K.A. 1989. The mesoscale data base and its use in mesoscale forecasting. *Q. Jl R. Met. Soc.*, 115, 717-62.
- Cheney, P., Gould, J. and McCaw, L. 2001. The Dead Man Zone – A neglected area of firefighter safety. *Australian Forestry* 64, 45-50.
- Dickins, J. and Cusworth, A. 2001. Fire weather forecasting: using weather radar for detecting wind changes. Proceedings Bushfire 2001. *Australasian Bushfire Conference 3-6 July 2001*, Christchurch, NZ, 62-8.
- Hewson, T.D. 1998. Objective fronts. *Met. Appl.*, 5, 37-65.
- Mills, G.A. 2002. A case of coastal interaction with a cool change. *Aust. Met. Mag.*, 51, 203-21.
- Mills, G.A. 2005. A re-examination of the synoptic and mesoscale meteorology of Ash Wednesday 1983. *Aust. Met. Mag.*, 54, 35-55.
- Puri, K., Dietachmayer, G.D., Mills, G.A., Davidson, N.E., Bowen, R.A. and Logan, L.W. 1998. The new BMRC Limited Area Prediction System. LAPS. *Aust. Met. Mag.*, 47, 203-23.
- Wilson, J.W., Weckworth, T.M., Vivekanandan, J., Wakimoto, R.M. and Russell, R.W. 1994. Boundary layer clear-air radar echoes: origins and accuracy of derived winds. *J. Atmos. Ocean. Technology* 11, 1184-206.