Abrupt surface drying and fire weather Part 1: overview and case study of the South Australian fires of 11 January 2005

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On the day of a severe bushfire on the lower Eyre Peninsula, South Australia (11 January 2005), an extreme reduction in near-surface humidity was observed. The meteorology of this event showed similarities to that observed at Canberra Airport on the day of the devastating fires of 18 January 2003, both in the abrupt surface humidity reduction to extremely low levels, and in the presence of a dry band in the middle troposphere in 6.7 μm wavelength 'water vapour channel' satellite imagery. As fine fuels respond to changes in atmospheric humidity on time-scales of the order of an hour, and as fire behaviour becomes increasingly more extreme as fuels become very dry, understanding and forecasting such unusual surface drying events may be important to fire managers. The relation between the lowering of the surface humidity, exchanges of mid-tropospheric dry air with the surface, and the synoptic dynamics of the atmosphere that allowed this process to occur on that day are described.

Introduction

It is well known that low relative humidity is an ingredient that leads to higher fire danger due to the relatively rapid response of fine fuels to atmospheric humidity. Rapid fluctuations in relative humidity, though, have not been addressed extensively in fire weather studies or operations, perhaps partly due to the difficulty of observing such fluctuations and the even greater difficulty in forecasting these. In spite of this, fire managers have for many years been well aware of the threat posed by 'dry air aloft'.

In recent years, however, a small number of studies have begun to emerge that discuss the association of some extreme fire behaviour events with short-period reductions in relative humidity near the surface. Mills (2005a) described the association of mid-tropospheric dry air, clearly visible in 6.7 μm 'water vapour channel' imagery (WVI) from the GMS-5 geostationary satellite with the observed extreme reduction in relative humidity observed at Canberra Airport on the day of the disastrous fires on 18 January 2003, and questioned whether this dramatic reduction in surface humidity may have affected fire behaviour on that day through its effect on fine fuel moisture content (Luke and McArthur 1978, p.88). Mills (2005a)
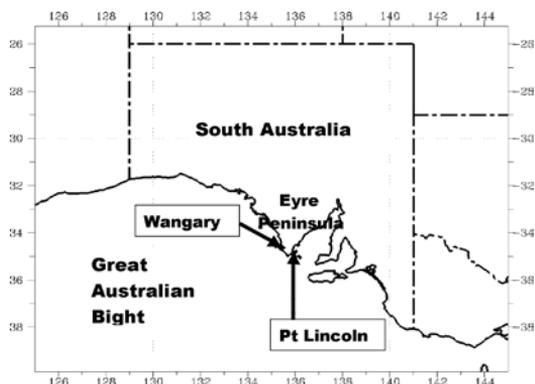
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hypothesised that, once upper-tropospheric vertical circulations had brought dry air into the middle troposphere, dry convective mixing may well have been sufficient to transport this mid-tropospheric air to the surface, while the possible role of frontal circulations was discussed. A follow-up study (Mills 2007), which focussed on the structures of ten easterly changes that were preceded by abrupt reductions in relative humidity, supported the dry convective mixing hypothesis, but also strongly suggested that the ascending branch of the cross-frontal circulation was sufficiently intense to enhance mixing through the entrainment layer. Graham (2003), Charney et al. (2003), Kaplan et al. (2005) and Zimet et al. (2007) relate increases in fire activity with mesoscale drying of the near-surface atmosphere, and the latter three studies associate the observed increased fire activity with the descent of a tropopause fold (large cyclonic potential vorticity, low humidity) to the middle and lower troposphere over the fire, and the subsequent transport of this very dry and high momentum air to the surface. Ninomiya et al. (1985) and Kondo and Kuwagata (1992) describe a dry, gusty wind event over northeastern Japan on a day of enhanced forest fire activity. Both these studies conclude that dry convective mixing led to the entrainment of air from the lower troposphere to the surface, but did point to the role of upstream topography in contributing to downward motion that not only would have caused vertical advection of lower-humidity mid-tropospheric air, but also would have inhibited cloud development and thus enhanced surface heating and consequently dry convective mixing.

On 11 January 2005 a fire near Wangary (see Fig. 1 for locations used in this paper) on the lower Eyre Peninsula (LEP), South Australia (SA), broke containment lines and 'fanned by winds averaging 40 to 50 km/h, with temperatures in the high thirties to low forties and relative humidity less than ten per cent the fire moved rapidly to the southeast towards the North Shields township. A southwesterly wind change arrived over the fire ground around midday causing it to spread northeastward towards the town of Tumby Bay. In a few hours the fire claimed nine lives, destroyed more than 80 homes and damaged many more, killed in excess of 45,000 stock, burnt out around 83,000 hectares of grass and scrubland, and ruined hundreds of kilometres of rural fencing.' (Bureau of Meteorology 2005, hereafter B2005.)

B2005 includes a comprehensive description of the synoptic and subsynoptic meteorology of the day, particularly focussing on the timing of the cool change that passed through Port Lincoln around 0130 UTC*, and noting the strength of the post-frontal winds. In-

* UTC is 10.5 hours earlier than Central Daylight Saving Time, so 0130 UTC is 1200 CDST.

Fig. 1   Locality diagram.

deed, the structure of the front, of which the strong post-frontal winds were part, met the paradigm of the fronts associated with many of the most destructive fire weather days observed in southeastern Australia (Mills 2005b).

A preliminary study of this event by Mills (2005c) noted the dramatic reductions in surface humidity at the Port Lincoln automatic weather station (AWS) site near that fire (see the meteogram in Fig. 2), and also showed an association with a band of dry mid-tropospheric air, identified as a dark band in WVI, over the LEP near the time of the increased fire activity. The similarities between these features in two recent wildfires in Australia that showed extreme fire behaviour and that also led to a number of fatalities prompts several questions about the processes that might lead to these abrupt surface drying events and their frequency of occurrence. First, what were the processes that led to the abrupt surface drying at Port Lincoln on 11 January 2005, and how similar were they to those hypothesised by Mills (2005a) for the Canberra event? Second, how often do such events actually occur, given that they may well go largely unremarked in the absence of a fire? The first aspect is addressed in this paper, which presents a detailed diagnostic study of the 11 January 2005 event over SA, and develops a working hypothesis that may be tested on other events. A companion paper (Mills 2008) presents a preliminary synoptic climatology of such events based on station observations at a number of stations in southern Australia, and makes some attempt at a classification of the particular atmospheric flow structures that lead to these abrupt surface dryings. In the next section a short discussion of the processes that might lead to changes in surface

Fig. 2 Meteogram of 10-minute observations from Port Lincoln Airport AWS, from 1200 UTC 10 January 2005 to 1200 UTC 11 January 2005 showing: (a) wind direction (degrees, black), wind speed (red) and gust speed (green) in knots; (b) temperature (red) and dew-point (green) in degrees C. Note the offset scales for temperature and dew-point.

(a)

(b)
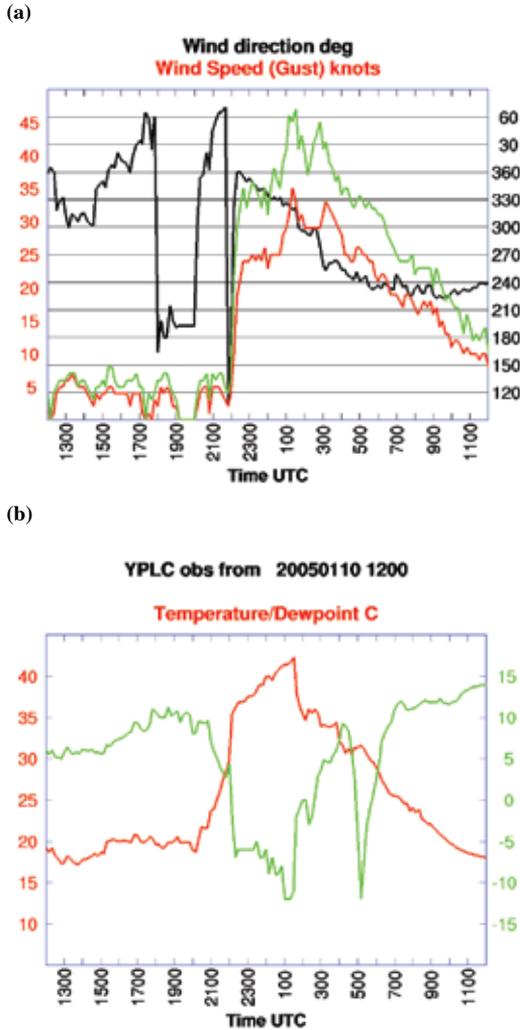
humidity is presented in order to provide some context for the diagnosis of the mesoscale meteorology of the 11 January 2005 event over south-central SA that follows. A particular aspect to be addressed is occurrence of the dark (dry) bands clearly visible in the WVI in this case, and the relation of these to both the tropospheric dynamics of the atmosphere and the observed surface weather.

Processes leading to humidity change at the surface

While the humidity variable that is used in calculating fire danger indices in Australia is relative humidity, the discussions in this paper will address the conservative variables of mixing ratio and dew-point as it is the effects of the near-surface changes in these quantities, as seen in Fig. 2 and in Mills (2005a), on relative humidity, rather than the effects of temperature, that are the primary focus of the study. It is useful to first consider the processes, and the time-scales of those processes, that generate changes of mixing ratio at a point in order to have a basis on which to interpret the synoptic/diagnostic study that follows. The humidity equation can be expressed as:

$$\partial q/\delta t = -V.\nabla q - \omega\, \partial q/\partial p + q_{dia} \qquad …1$$

where the variables have their usual meteorological meaning.

The first two terms on the right-hand side (RHS) of Eqn 1 represent horizontal and vertical advection, while the third term represents diabatic processes which can include turbulent (mechanical or thermal) mixing, condensation/evaporation of water droplets in the free air, and exchanges of moisture between the atmosphere and the underlying surface (evapotranspiration). In the context of the particular case being discussed, condensation/evaporation of free water droplets is unlikely to be relevant, and evapotranspiration is more likely to moisten than dry the low levels, so in the arguments to follow, turbulent mixing is the only diabatic process to be discussed. Several of the individual parameters in Eqn 1 are poorly, or not, observed, and so there is considerable range in possible estimates: however, useful inferences can be drawn.

Horizontal advection is one of the easier terms to scale, given that the horizontal velocity and the humidity fields are perhaps the best measured terms (at least in relative terms), and transport over some hundreds of kilometres in 12 hours is not unreasonable, with clear variations between near-surface and upper-level flow speeds. However, rapid changes in mixing ratio at a point due to horizontal advection are unlikely unless there are very strong moisture gradients present. While such a situation can occur with a frontal passage, in southern Australia this is more likely to lead to an increase in humidity rather than a decrease, although a sharp drying may be experienced with the passage of a central Australian front (Reeder et al. 2000). Accordingly, it might be expected that changes in humidity due to horizontal advection might be relatively steady, and of the order of several hours in most cases.

Vertical advection is rather harder to assess: there are very few reported measurements of downward vertical motion, although descent rates in the middle troposphere of -0.1 m s^{-1} for some hours, and less than -0.4 m s^{-1} for shorter periods, have been reported (May et al. 1990; Nastrom and Warnock 1994; Braun et al. 1997; Koch and Clark 1999). (Much stronger ascent rates, albeit for shorter periods and often associated with moist convection, have been reported). Using numerical weather prediction (NWP) model estimates is problematic as these are model-dependent, and also grid-spacing dependent for the same model, but the Australian Bureau of Meteorology's operational limited area NWP system, LAPS (Puri et al. 1998), 0.375° latitude/longitude grid initialised analyses regularly show subsidence rates of the order of 10-20 hPa h^{-1} ($\sim$0.05-0.1 m s^{-1} in the low to mid-troposphere), while the 0.125° and 0.05° mesoscale versions of the forecast model regularly indicate subsidence rates several times that magnitude, albeit over more concentrated areas. (Note that LAPS is a hydrostatic model, and so does not allow for vertical acceleration.) These magnitudes are of the same order as those reported in the observational studies above, and so subsidence of some 100-200 hPa per 12 hours might be considered not atypical for synoptic-scale vertical advection in the troposphere, and there may be stronger rates associated with frontal or jet circulations, or associated with gravity waves. It must be noted that all these values quoted are essentially Eulerian calculations, yet there is no requirement that a single air parcel necessarily attains these values of vertical motion for the requisite number of hours. Again vertical advection can only cause abrupt changes in mixing ratio at a point if there is also a strong gradient in the mixing ratio, so again significant changes in near-surface mixing ratio due to vertical advection are likely to take place at best over several hours.

Addressing the time-scales for dry convective mixing, Stull (1988, p.120) indicates that the time-scale, t, for mixing in the convective boundary layer is of the order

$$t = a\, H/w^* \qquad \ldots 2$$

where a is a constant of order(1), H is the height of the inversion (top of the mixed layer) and w^* is the convective velocity scale. Estimating H as $\sim$2000-3000 m for summertime afternoon mixed-layer depths in clear-sky conditions in southern Australia, and w^* as $\sim$1-2 m s^{-1} (Stull 1988), the time-scale is $\sim$1000-3000 sec. Thus conservatively, within a time-scale of an hour (3600 sec) full mixing of entrained air from the inversion (entrainment) layer at the top of the mixed layer can occur. Thus, if the air immediately above the mixed layer should dry abruptly, then this change could be realised at the surface in time-scales less than an hour, as postulated in Mills (2005a, 2007).

The meteorology of 11 January 2005 over Eyre Peninsula

The meteogram of 10-minute observations at Port Lincoln Airport AWS for the period 1200 UTC 10 January to 1200 UTC 11 January 2005, is shown in Fig. 2. From about 2000 UTC the temperature begins to climb and the wind settles to a light northeasterly – an onshore breeze. At 2100 UTC the dew-point starts to fall, along with a continuing temperature rise. Consideration of the broad synoptic situation, and the observed light northeasterly (onshore) winds, suggests that a shallow marine layer of air was over Port Lincoln at this time, but it was being eroded by mixing as the boundary layer heated. At 2200 UTC there is an abrupt shift of the wind to the north-northwest, decrease in dew-point, increase in temperature, and increase in wind speed and gustiness. The dew-point dropped further at 0100 UTC, just before the cold front passage, the timing of which is best identified in the thermodynamic variables, although there is a also sharper 20° backing of the wind at that time. Unusually, at 0500 UTC, well after the establishment of the cooler air, there is another deep plunge in dew-point.

In order to place these features in a synoptic context, Fig. 3 shows the LAPS mean sea-level pressure (MSLP) analysis with low-level wind barbs overlaid, and the 300 hPa height/isotach analysis for 0000 UTC 11 January 2005. At the surface a trough of low pressure is across LEP, and extends northwestwards along the western coast of Eyre Peninsula. There is a marked cyclonic shear across the trough, and a band of stronger northwesterly winds to its east marks the pre-frontal low-level jet. At 300 hPa there is a strong trough well southwest of SA, best indicated by the cyclonically-curved 40 m s^{-1} isotach. In addition there is a smaller isotach maximum, with speeds greater than 25 m s^{-1}, north of the main jet streak and extending from the northwestern part of the plotted area to central SA. This local speed maximum appears to be associated with a small short-wave trough, which is better indicated by the cyclonic shift of the plotted wind barbs immediately southwest of this small jet streak than by curvature of the geopotential contours.

WVI (Fig. 4) shows a dark band, indicative of a dry mid-troposphere (see Weldon and Holmes 1991), approaching Eyre Peninsula from the west, and reaching LEP by 2030 UTC – an excellent coincidence with the onset of the marked drying that was observed at Port Lincoln. Interestingly, a second dark band is farther west, and is approaching LEP at 0530 UTC (Fig. 5), approximately the time at which the second surface drying was observed. While the dark band is not vertically above LEP at this time, its approach is intriguing given the second (post-frontal) abrupt drying at Port Lincoln at that time.

Fig. 3 (a) LAPS mean sea-level pressure analysis over-laid with the 0.9943 sigma-level wind barbs; and (b) 300 hPa height/wind analyses with isot-achs shaded light grey between 25 and 40 m s^{-1}, and dark grey for speeds greater than 40 m s^{-1}. Both plots are for 0000 UTC 11 January 2005 and the barbs have their usual meteorological meaning.

(a)

(b)
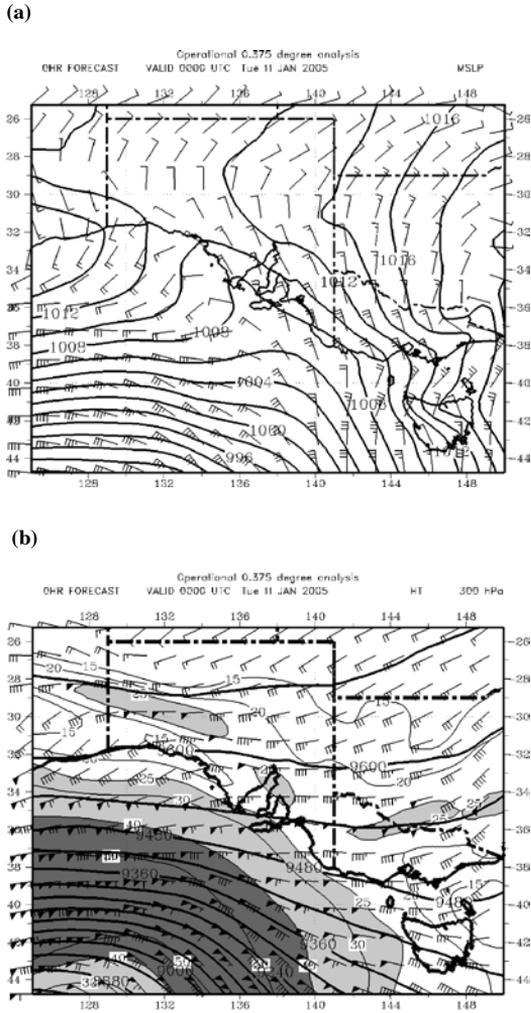
Fig. 4 GMS-5 geostationary satellite water vapour (6.7 μm) channel imagery valid at 1730 UTC (top), 2030 UTC (middle) and 2330 UTC (bottom) 10 January 2005.
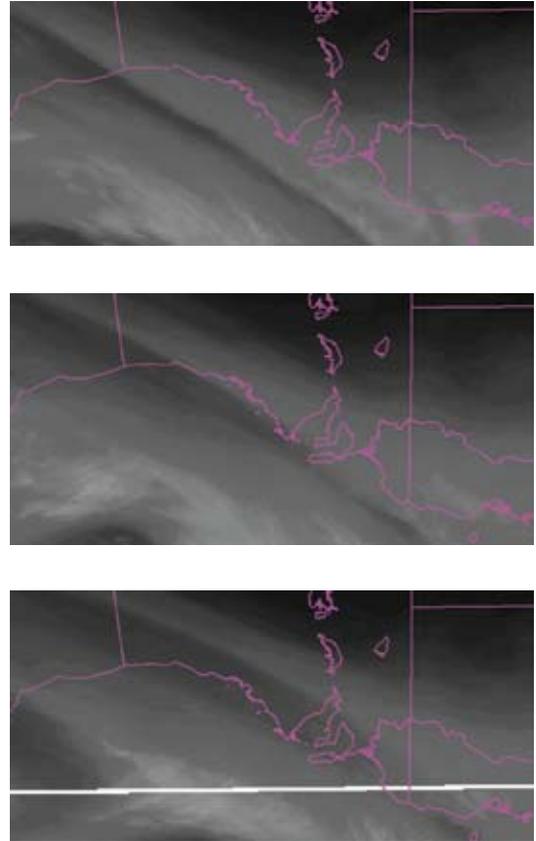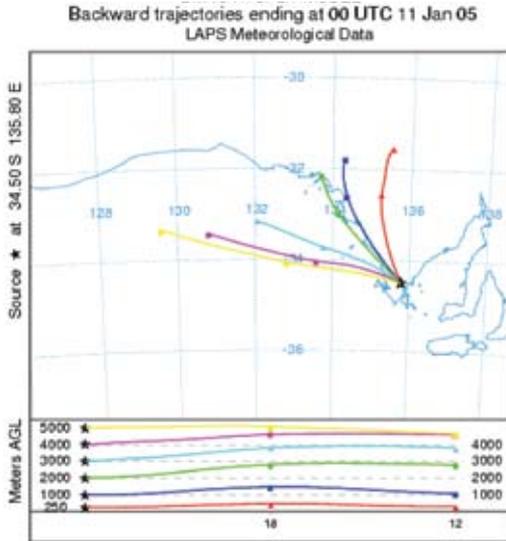

Fig. 5 GMS-5 geostationary satellite water vapour (6.7 μm) channel imagery valid at 0530 UTC 11 January 2005.
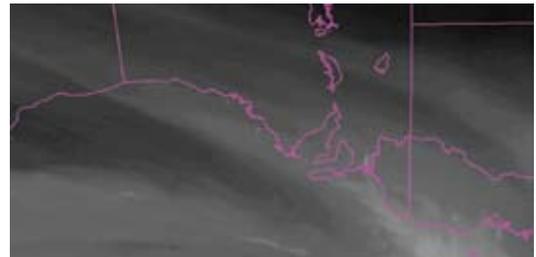
To discuss the relationship between the observed humidity variations at Port Lincoln and the larger and smaller-scale atmospheric circulations we first present backward trajectory plots from a series of points in a vertical column over LEP, using the HYSPLIT (Draxler and Hess 1998) transport and dispersion model, with LAPS forecast fields providing the meteorological input. These trajectories, shown in Fig. 6, might be interpreted as representing the advective terms in Eqn 1 above. The end-time of the trajecto-

ries is at 0000 UTC 11 January 2005. While these trajectories do not include any effect of dry convective mixing, and so must be treated with some reservation for transport through a well-mixed layer, they still provide a useful basis with which to commence this analysis. Below 2000 m, the trajectories originate
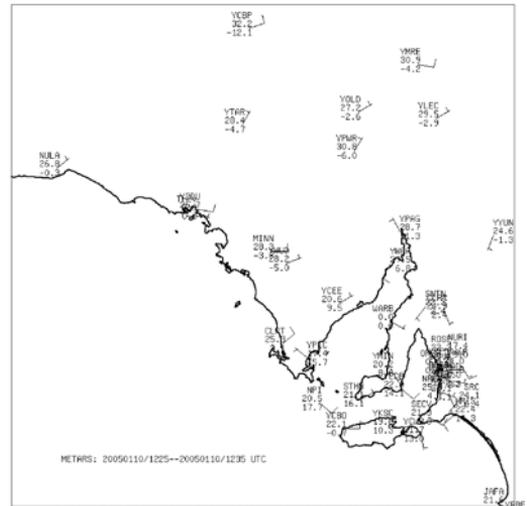
Fig. 6   Twelve-hour back trajectories from the approximate location of Port Lincoln Airport. Note that the end points for the trajectories are marked by the stars, so the vertical profiles in the lower panel show time increasing towards the left.

Fig. 7   Plot of AWS data over South Australia for 1230 UTC 10 January 2005. At each station the wind speed and direction barbs have their usual meteorological meaning, while the station aviation abbreviation, and the temperature and dewpoint (°C) are plotted vertically.

from the north of Eyre Peninsula, where surface dewpoints ~–5°C were observed at 1230 UTC 10 January (Fig. 7), and were as low as –8 to –9°C a few hours earlier. Particularly in the last six hours these trajectories show subsidence. For air parcels ending above 3000 m, the trajectories are from the west-northwest, and those ending at 3000 and 4000 m are subsident, suggesting that the northwesterly upper tropospheric airflow was subsiding towards the middle troposphere above Port Lincoln during the 12 hours prior to the observed surface drying.

Now, returning to the relationship between the vertical motions in the atmosphere and the back trajectory analysis described above, there is a region of deep subsidence seen in the 400 hPa vertical motion field (Fig. 8(a)) to the west of the 300 hPa short-wave trough. In order to relate this subsiding region to divergent circulations, the cross-contour component of the ageostrophic wind is shown in Fig. 8(b) (cf. Fig. 3(b)). The flow over the ocean immediately south of the Australian continent shows strong ageostrophic flow directed towards higher heights, indicative of deceleration of the southern jet streak. While the ageostrophic winds at the entrance to the northern jet streak are not as strong, they are still directed southwards, indicative of acceleration of air parcels in this region. The combination of deceleration and acceleration-induced ageostrophic circulations leads to a conver-

gent zone aligned with the region of subsidence seen in Fig. 8(a). It is a very plausible hypothesis that it is this descending circulation that brings dry air from the upper troposphere down to the middle troposphere and which is manifest as the dark band seen in the WVI in Fig. 4(c). This dynamic process, presented here in Fig. 8 in an Eulerian framework, is consistent with the Lagrangian analysis in Fig. 6, where the upper set of trajectories indicates this descent.

The 850 hPa vertical motion field at 0000 UTC shows a region of subsidence over LEP on the warm-air side of the surface trough (Fig. 9(a)). Figure 9(b) shows the 900 hPa fields of height, vector wind, and wind speed. The area surrounded by the ellipse shows an area of strongly cross-contour, and thus ageostrophic, flow, with the wind barbs directed towards lower geopotential heights indicating acceleration of the flow in this region at the entrance to the pre-frontal low-level jet. Thus the subsidence seen in the 850 hPa vertical motion (Fig. 9(a)) can be interpreted as part of the indirect ageostrophic entrance circulation of the low-level jet (Fig. 3(a)) ahead of the surface front. The subsiding part of the low-level trajectories seen in Fig. 6 can be related to this descent zone, and thus this feature could well have contributed to the surface drying observed at Port Lincoln. While the normal expectation of a direct cross-frontal vertical circulation would lead to the expectation of ascent ahead of

Fig. 8   **(a) LAPS 400 hPa omega (Pa sec^{-1}, negative contours dashed, zero contour suppressed) analysis; and (b) the component of the 300 hPa ageostrophic wind normal to the geopotential contours. Both plots at 0000 UTC 11 January 2005.**

(a)

(b)
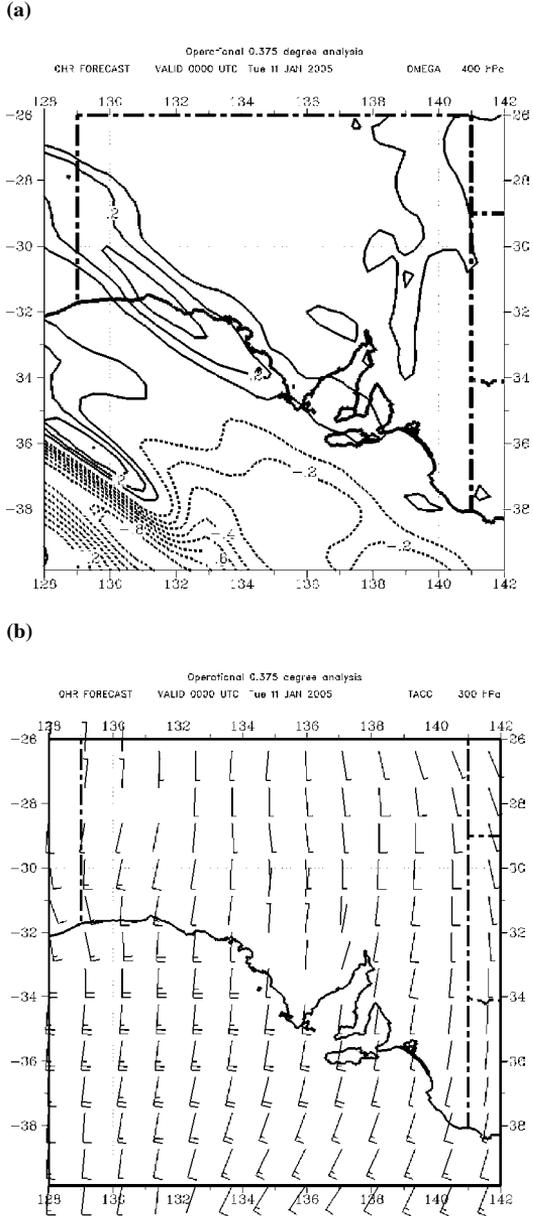
Fig. 9   **(a) LAPS 850 hPa omega (Pa sec^{-1}, negative contours dashed) analysis; and (b) 900 hPa wind vectors at 0000 UTC 11 January 2005, with 900 hPa heights (solid contours at 20 gpm intervals) and wind speeds greater than 15 m s^{-1} (shaded). On the upper panel the thick contour shows the screen-level 8°C dew-point line as an indicator of surface frontal position, while the arrow indicates the descent feature discussed in the text. In the lower panel the ellipse highlights the region of accelerating flow at the entrance to the low-level jet.**

(a)

(b)
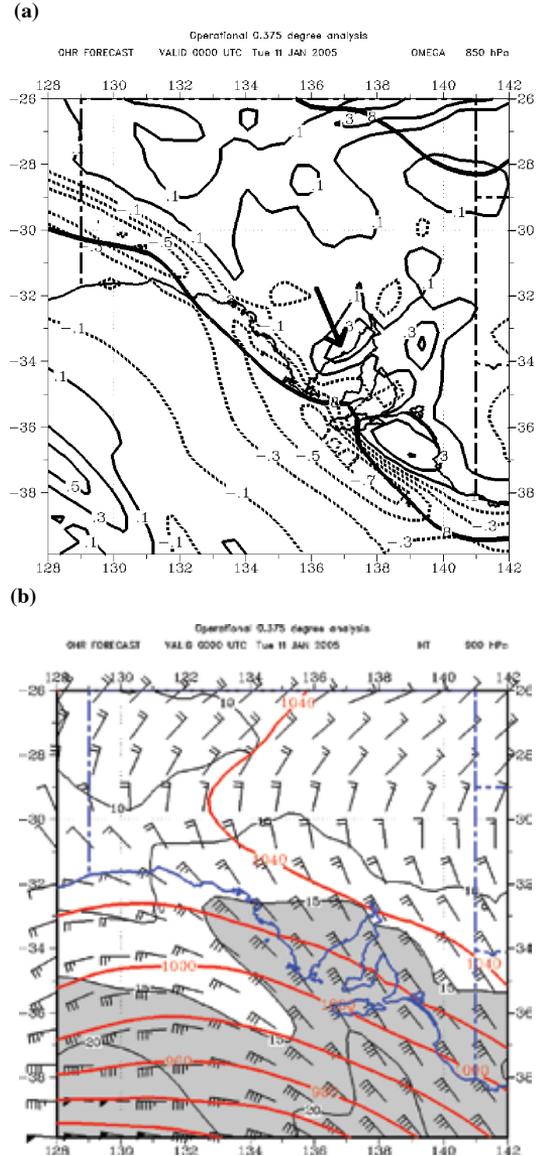
the front, as is seen in the elongated band of ascent in Fig. 9, the low-level acceleration of the flow leads to a mesoscale, rather focussed, region of descent ahead of the ascent band. Schultz (2005) reviews some other published examples of pre-frontal descent, although this mechanism is not included in his discussion.

With surface temperatures above 40°C ahead of the cold front over Eyre Peninsula, the convectively mixed layer would extend to above 600 hPa, as was indicated by Adelaide Airport's 0000 UTC radiosonde

ascent and by NWP model forecast vertical temperature profiles over Eyre Peninsula (see B2005, Figs 7.3.1 and 7.3.2). Each of these profiles shows a very deep mixed layer above a shallow and relatively weak surface inversion. Allowing for only a very small degree of surface heating, dry convective mixing from the surface to well above 600 hPa would be expected. As discussed in the previous section, the time-scale for mixing in such a deep convectively mixed boundary layer is less than an hour (Stull 1988), and at the same time the dry air in the middle troposphere was being advected towards this location, and so it is entirely possible for this dry air to reach the surface by this mechanism.

The second (post-frontal) drying was associated with descending air to the rear of the steeply sloping frontal zone associated with the cold front. Figure 10 shows the 850 hPa vertical motion analysis at 0600 UTC, and the remnant descent associated with the low-level jet entrance (arrowed), the band of pre-frontal ascent, and a band of post-frontal descent along and just inland of the Eyre Peninsula coast can be clearly seen. This band of post-frontal descent at 850 hPa marks the intersection at that level with a deep, sloping band of post-frontal descent, seen in the cross-section shown in Fig.11 (upper), and links with the 300 hPa jet and the descending region there. A tongue of very dry air associated with this sloping frontal circulation is seen in Fig. 11 (lower) (dashed line). The downward slope (towards the northeast) of this dry air associated with the post-frontal descent accounts for the phase difference between the dark band in the WVI (Fig. 5) and the second (post-frontal) surface drying (Fig. 2) at Port Lincoln.

It is also apparent in the cross-sections in Fig. 11 that a marked gravity wave is modelled at the top of the mixed layer just ahead of the cold front, with the upward bulge in the 314 and 316K isentropes directly above the strong upward vertical motion seen at the nose of the front. This structure is essentially the same as that shown by Mills (2007) for the westward-propagating 'easterly changes' through southeastern NSW reported in that paper, and given that the lowest (pre-frontal) surface humidity was observed at Port Lincoln immediately before the frontal passage, it is likely that enhanced mixing due to the disruption of the entrainment layer by the frontal updraft also acted in this case.

Both the pre-frontal and the post-frontal drying showed considerable spatial coherence across SA, lending strength to the arguments implicit above that there was subsynoptic control of the drying observed over LEP. Figure 12 shows the manually inferred time of the pre-frontal and of the post-frontal drying at a number of stations through SA. The author, using meteogram plots similar to those shown in Fig. 2 for each station, assessed these times subjectively. The timing of the pre-frontal drying was assessed as the first 'dip' in the

Fig. 10 LAPS 850 hPa omega (Pa sec⁻¹, negative contours dashed) analysis at 0600 UTC 11 January 2005. The thick contour shows the screen-level 8°C dew-point line as an indicator of surface frontal position, while the arrow indicates the descent centre discussed in the text. The diagonal line shows the position of the cross-section in Fig. 11.
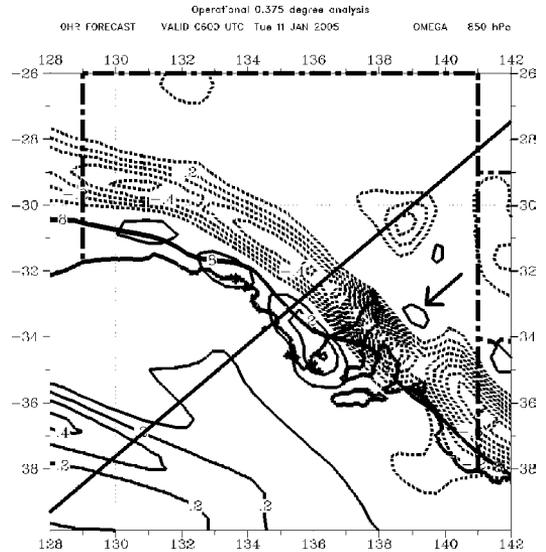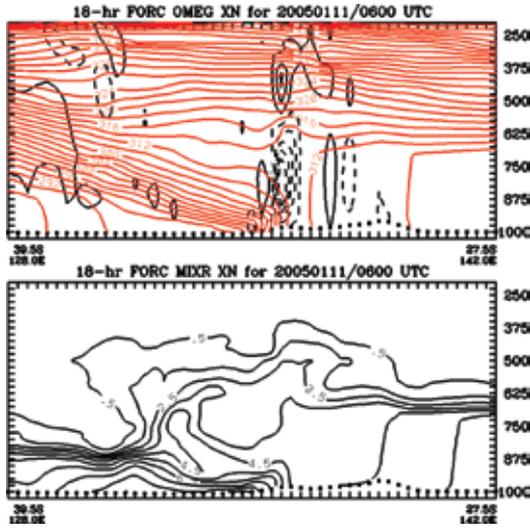

meteogram, rather than the final lowering just before the frontal change, and its timing was generally fairly clear, although at a few stations it was less obvious, and at some, either coastal stations where an onshore flow would have created a shallow inversion, or at the eastern/inland stations where the arrival was after the cessation of daytime heating, it was sometimes difficult to unambiguously determine such a time. In those cases there is either a question mark after the time, indicating some ambiguity, or the time is presented as '****', indicating that no time could be determined. The spatial coherence of the timings is quite dramatic, with the time of onset of pre-frontal drying advancing more rapidly to the east-southeast, consistent with the movement of the dry slot seen in Fig. 4, and a slower movement to the northeast. The post-frontal drying shows isochrones aligned very much with the isopleths of the cold frontal timing (B2005, Fig. 3.8).

Discussion

This current study describes and presents hypotheses as to the processes that led to two periods of abrupt drying of the near-surface atmosphere at Port Lincoln, SA, on 11 January 2005, a day on which extreme fire behaviour was observed over LEP. The first abrupt
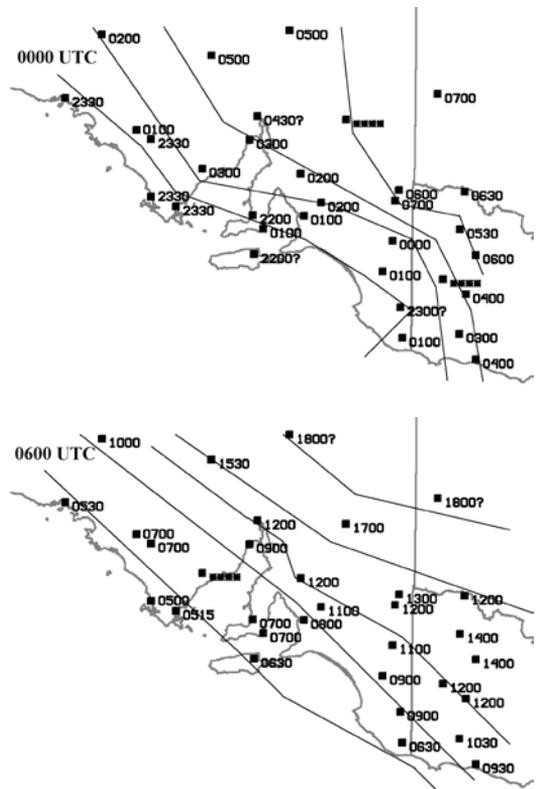
Fig. 11 Cross-sections along the line shown in Fig. 10 from 0.125° meso-LAPS forecast valid at 0600 UTC 11 January 2003. The upper panel shows potential temperature in solid contours, and vertical motion (hPa s^{-1}, contour interval 20, zero contour suppressed) in solid/dashed contours, with negative values (ascent) dashed. The lower panel shows mixing ratio (g Kg^{-1}).

Fig. 12 Upper panel shows time of arrival (UTC on 10 to 11 January 2005) of the first abrupt drying. Lower panel shows UTC time (11 January 2005) of the post-frontal drying. See text for details. In the upper panel isochrones are from 0000 UTC (westernmost) at two-hour intervals. In the lower panels, the isochrones are at three-hourly intervals, with the westernmost isochrone at 0600 UTC.

drying event occurred in a hot, pre-frontal airmass, and it was argued that during what might be termed the preconditioning phase, dry upper-tropospheric air was advected downwards to the mid-troposphere by overlapping upper-tropospheric jet-stream entrance and exit circulations, with this band being marked by a dark (dry) band in WVI. This phase lasted some hours, allowing vertical advection from the upper to the mid-troposphere and horizontal advection from some hundreds of kilometres to the northwest. In the second phase, the development of a very deep mixed layer allowed this dry air in the mid-troposphere to be entrained by dry convective turbulence and mix to the surface with a time-scale of less than an hour. This entrainment is enhanced by the weak static stability of the layer above the mixed layer in this case. Secondary processes that may have enhanced this second phase include lower tropospheric descent associated with the accelerating flow at the entrance of a pre-frontal low-level jet, and enhanced entrainment of the dry air caused by the disruption of the entrainment layer by the strong pre-frontal ascent maximum.

The Canberra event shows many similarities to this conceptual model. Again the dry slot seen in the WVI can be associated with overlapping jet streak descent circulations, although the short-wave trough north of the main jet stream is rather less marked and a mid-

tropospheric front was more evident than for the Port Lincoln case (Mills 2005a). In common with the Port Lincoln case there was a very deep mixed layer with an over-running mid-tropospheric dry slot present. In each case there was further humidity reduction immediately before the passage of the cool change, even though the change at Canberra was propagating westwards and that at Port Lincoln was propagating eastwards. This concept also shows some similarities to that proposed by Kaplan et al. (2005). In that model, based on a study of the event reported by Charney et al. (2003), the authors propose that the conjunction of three vertical circulations associated with (from the upper to the lower troposphere) a transverse jet exit circulation, the vertical circulation associated with a mid-tropospheric front, and the vertical circulation associated with a low-level front all combine to advect dry, upper tropospheric air to the fire location.

The second drying period at Port Lincoln occurred some hours after the first, in the cooler post-frontal airstream. It could also be associated with deep, sustained tropospheric descent associated with the upper jet-wave circulation (also marked as a dark band in the WVI), although the descent was through most of the depth of the troposphere along the downward sloping isentropes that marked the major frontal zone. This descending air reached to within some 100 hPa of the surface, and finally reached the surface through turbulent mixing in the diabatically modified post-frontal boundary layer. Mechanical turbulence associated with the sustained strong post-frontal flow may have contributed to this process. This conceptual model shows some similarity to the description of the kinematics and dynamics that led to abrupt surface drying and enhanced fire behaviour during the Mack Lake fire (Zimet et al. 2007).

While the two Australian cases of abrupt surface drying associated with extreme fire behaviour that have so far been documented constitute a very small sample, the fact that these fires showed such extreme behaviour, and also led to massive social and economic costs, makes the prediction of such events desirable if the postulated link between dry mid-troposphere to dry fine fuels to more active fire behaviour is sustainable. Further, the potential for using WVI to monitor the movement of mid-tropospheric dry air towards a fire site should at least be investigated as an aid in this process. However, dark (dry) bands and areas are routinely seen in WVI as they are associated with the synoptic and sub-synoptic vertical circulations associated with jet/wave circulations in the middle and upper troposphere, while abrupt surface drying events may well either not be associated with their movement, or else go unnoticed because no fire was affected by the surface drying. In order to address these questions Mills (2008) presents a preliminary climatology of abrupt surface drying events at a range of stations in the fire-prone areas of southern and eastern Australia, and discusses their frequency, the upper-tropospheric morphology of any WVI patterns associated with these events, and the contribution of lower-tropospheric stability and/or advections that may provide links between the mid-tropopsheric dry air and the surface.

Acknowledgments

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