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Fire danger anomalies associated with foehn-like winds in southeastern Australia

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Abstract: In southeastern Australia the synoptic archetypical severe fire weather day is that of the dry "cool change", or coastally modified cold front. Less well known, however, are synoptic cases that occur in connection with the topography of the eastern Australian mainland and Tasmania, which can also lead to abrupt spatiotemporal changes in fire weather variables that ultimately result in locally elevated fire danger rating. Some of these cases are associated with cross-mountain flows, mountain wind waves and foehn-like occurrences, the latter of which are characterised by warm, dry winds on the lee side of mountain ranges.

In this paper we consider two foehn-like occurrences over parts of the southeast Australian mainland. In particular we focus on the Gippsland region of Victoria and the south coast of New South Wales. The events of interest are characterised by regional warming and drying at times when surface winds place the regions in the lee of significant topography. The warming, drying and strong and/or gusty winds lead to regional, statistically significant, anomalies in fire danger rating. The events presented here all resulted in McArthur Forest Fire Danger Rating at or above the 95th percentile, for the particular region and time of year.

The events considered in the present paper occurred on 19 and 20 September 2008, and 27 October 2008. While these events may not have caused the extremes of fire danger rating that have been experienced in southeastern Australia, they are worthy of examination due to the magnitude and rapidity of the changes in fire weather they caused and the fact that they produced fire danger ratings that were statistically anomalous when compared to climatological values. On 20 September 2008, the rapid onset of foehn-like conditions resulted in a transition in fire danger rating from 'Low' to 'Very High' within 25 minutes, while on 27 October 2008, the onset of foehn-like conditions resulted in a transition in fire danger rating from 'Low' to 'Very High' within 36 minutes, with fire danger rating eventually reaching an 'Extreme' value of 62.

The foehn-like occurrences are analysed based on observational data and the results of a numerical weather prediction (NWP) model. The numerical weather model suggests that the foehn-like events occurred in connection with partial orographic blocking of relatively moist lower-level winds and large-scale mountain waves. As such, the two events presented qualify as significant foehn occurrences. The observational analyses provide an initial step in discerning regions that are prone to foehn occurrence, while the numerical modelling provides more detailed information on the processes involved in the manifestation of foehn conditions at the surface. Knowledge of the extent and frequency of foehn occurrences in southeastern Australia, in addition to knowledge of the physical mechanisms that cause them, will assist in the development of more complete bushfire risk management models.

Keywords: *Foehn winds, bushfire, fire weather, fire danger, numerical weather modelling, risk modelling*

1. INTRODUCTION

The potential for the occurrence and development of bushfires is dependent upon the interaction of fuels with variables such as air temperature, atmospheric dryness and wind speed. By combining these variables with information on fuel type and drought effects, a number of fire danger rating systems have been devised around the world, each reflecting the different climates and fuel types in which they are employed (e.g. Forestry Canada Fire Danger Group, 1992). Typically these fire danger rating systems produce a numerical index that relates to the chance of a fire starting in a particular fuel, its spread and difficulty to control and the damage it is likely to cause (Chandler et al., 1983). Despite the differences in their design and implementation, all fire danger rating systems generally agree that warmer, drier and windier conditions result in higher fire danger levels. Understanding the synoptic processes through which changes in temperature, relative humidity and wind speed can occur is therefore an important problem and the development of synoptic models to assist in forecasting these changes is a key requirement in improving bushfire control and bushfire risk modelling.

In this paper we discuss synoptic cases that occur in connection with the topography of the eastern Australian mainland and Tasmania that can result in locally elevated levels of fire danger. In particular we discuss cases associated with cross-mountain flows and foehn-like occurrences, the latter of which are characterised by warm, dry winds on the lee side of mountain ranges; the warmth and dryness of the air being due to adiabatic compression of the air descending the mountain slopes. While some knowledge about Australian foehn winds does exist, there appears to be very little formal knowledge about the extent to which the foehn effect applies over Australia's mountainous regions, the mechanisms behind it and how it might affect local fire danger levels.

In other parts of the world, the foehn effect occurs in the vicinity of many mountainous regions and has been linked with elevated wildfire risk. Particular examples include the autumn foehn (Santa Ana) in southern California, the north foehn in Switzerland and foehn winds in New Zealand and parts of Asia.

Commonly, three observational criteria are used to distinguish foehn conditions at stations in the lee of mountains: surface winds blowing from the direction of the mountains, an abrupt rise in air temperature in the lee of the mountains and an accompanying reduction in atmospheric moisture. Characteristic cloud formations also often accompany foehn occurrences, e.g foehn wall, foehn arch (Sharples, in press).

Genuine foehn occurrence, however, has been attributed to two main mechanisms: In the first, moist air forced to ascend a mountain barrier cools, ultimately resulting in condensation and precipitation. The precipitation removes much of the moisture from the air and the latent heat of condensation warms the air mass. The drier air is then warmed further by adiabatic compression as it descends the lee slope (Whiteman, 2000). In the second, moist low-level air is blocked by a mountain barrier with drier upper air flowing down to replace it in the lee. As the drier air from above descends the lee slopes it is warmed by adiabatic compression (Seibert, 1990; Ustrnul, 1992) The second mechanism typically occurs in association with a vertically propagating lee mountain wave (Drechsel and Mayr, 2008).

We present a study of two foehn-like events that occurred over southeastern Australia on 19 and 20 September 2008, and 27 October 2008. The meteorology of the events is analysed using data from a number of automatic weather stations and the atmospheric dynamics of the events are investigated using output from a mesoscale numerical weather model. In particular, the model output is used to ascertain whether either of the two foehn mechanisms contributed to the foehn-like conditions recorded in the surface observations. Based on the analyses we discuss the results and their implications for bushfire risk modelling in southeastern Australia.

2. CANDIDATE EVENTS, DATA & METHODS

On 19 September 2008 relatively warm and dry conditions were observed over the Gippsland region of Victoria and the NSW south coast in connection with strong winds from the north-northwest and northwest, respectively. On 20 September 2008 winds remained strong but shifted to a general westerly flow. The NSW south coast region in the lee of the mountains then experienced abrupt warming and drying with temperatures in excess of 25^{o}C and relative humidity falling below 10%. On both the 19 and 20 September 2008 regionally elevated fire danger was observed in connection with the local warming and drying.

Regional warming and drying over the Gippsland and NSW south coast regions was also observed on 27 October 2008. With winds from the north-northwest, temperatures over the Gippsland region rose to above 30^{o}C by mid-morning, while relative humidity fell to around 15%. Later in the day, as the winds shifted to a

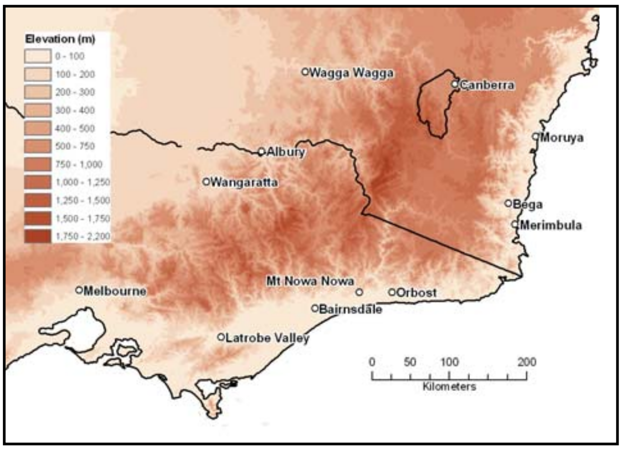

Figure 1. Map of southeastern Australia showing the locations of the automatic weather stations used in the study and the underlying topography.

more westerly flow, temperatures on the south coast of NSW rose to around 35 ^{o}C and relative humidity fell to around 10%.

To facilitate a more in-depth analysis of the foehn-like events described, observational data from a number of automatic weather stations were obtained from the Bureau of Meteorology. The data included measurements of temperature, relative humidity, dew point and wind speed, direction and gust. The position of these stations in relation to the major topographic features of the southeast Australian mainland can be seen in figure 1. In addition, to investigate whether the foehn-like conditions occurred in connection with either of the two accepted foehn mechanisms discussed in the introduction, we modelled the atmospheric dynamics surrounding the two events using the MesoLAPS mesoscale numerical weather model (Puri et al., 1998).

3. RESULTS

In this section we provide a more detailed account of the meteorology of the two candidate events. In particular we focus on the evolution of temperature, relative humidity and wind observations at lee stations compared with those at windward stations during the candidate events. In addition we discuss the atmospheric dynamics associated with the event on 19 and 20 September 2008, as given by the MesoLAPS model.

3.1. 19 and 20 September 2008

Conditions along the Gippsland coast during the evening of 18 September 2008 were characterised by prevailing northwesterly to northeasterly winds. In northwesterly synoptic-scale flows the combination of the lee-trough and the land-sea temperature contrast acts to produce a markedly northeasterly flow along the Gippsland coast (Huang and Mills, 2006). Temperatures were observed to rise after sunset at Mt Nowa Nowa and Bairnsdale, with a complementary decrease in relative humidity. The time series of temperature and relative humidity at Mt Nowa Nowa and Bairnsdale along with that of the upwind station at Wangaratta can be seen in figure 2. The relatively warm and dry conditions persisted along the Gippsland coast for the remainder of the day with temperatures and relative humidity of around 16^{o}C and 31-43%, respectively, in contrast to conditions encountered upwind where temperatures and relative humidity were approximately 8-15^{o}C and 60-99%. Figure 3a shows the resultant differences in the McArthur Mark 5 Forest Fire Danger Index (FFDI). A localised region of elevated FFDI can be seen along the Gippsland coast, immediately in the lee of the ranges. For September-October an FFDI of 27 near Bairnsdale is just above the 95th percentile (Dowdy et al., 2009). Observations of temperature and relative humidity at Moruya also exhibited anomalous maxima and minima on 19

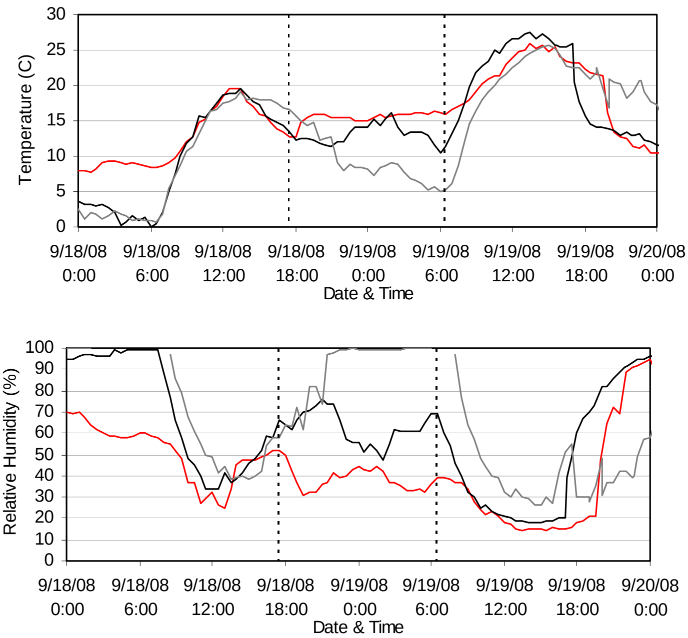

Figure 2. Time series of temperature and relative humidity at Mt Nowa Nowa (red), Bairnsdale (black) and Wangaratta (grey). The dashed vertical lines indicate the period when foehn-like conditions were most pronounced.

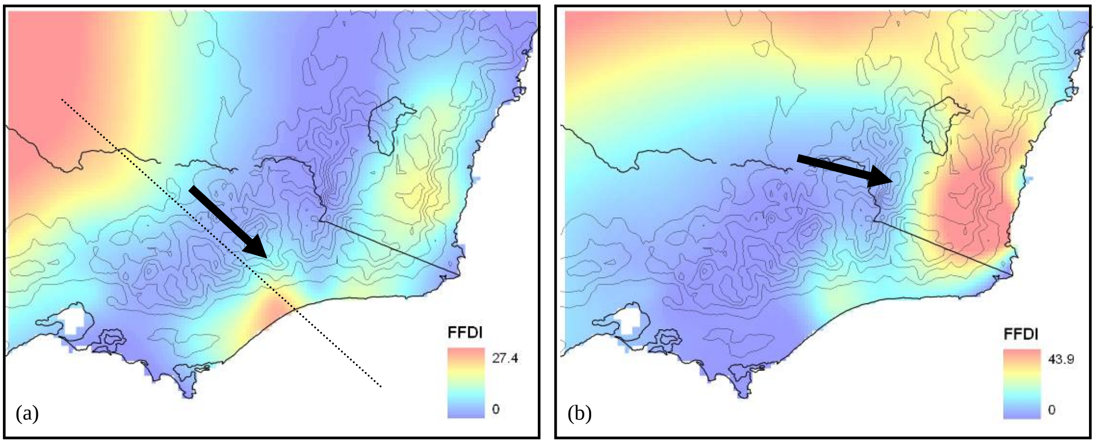

Figure 3. Interpolated surfaces of McArthur Mark 5 Forest Fire Danger Index (FFDI) for (a) 1400 hours, 19 September 2008, and (b) 1500 hours, 20 September 2008. The arrows indicate the synoptic wind direction and the dotted line in panel (a) approximately indicates the cross section used in figure 5.

September. These can be seen in figure 4a, while the associated changes in FFDI can be seen in figure 4b. These features coincide with brief instances of strong winds from between west and north-northwest.

On the following day (20 September 2008) at around midday the south coast of New South Wales experienced a change in wind direction from between northeast and east to between west and northwest, with an associated increase in wind speed gusting to over 60 km h^{-1}. Coincident with the wind change, temperatures exhibited an abrupt increase of approximately 8-12^{o}C in less than an hour. By contrast, the temperatures on the upwind side of the mountains at Wagga Wagga only increased by about 2^{o}C. Complementary decreases in dew point temperatures of the order of 15-21^{o}C were also observed, with relative humidity falling from 79% at 12:00 to 8% at 14:22. Relative humidity at Wagga Wagga, while falling to around 20%, did not match the extreme lows recorded at lee stations along the coast; the rate of decline did not match the sharpness of the decline at the lee stations either. The effect of the localised warming and drying on FFDI can be seen in figure 3b. An FFDI of 44 over the region is above the 99th percentile for that time of year (Dowdy et al., in press). The evolution of the abrupt warming and drying at Moruya can be seen in figure 4a. The sharpness of the changes at Moruya, for example, resulted in a significant and rapid increase in FFDI from around 1.3 (Low) to 24.5 (Very High) within an hour (figure 4b). In fact, the change in FFDI classification from ‘Low’ to ‘Very High’ took place in less than 25 minutes, between 12:35 and 13:00 hours.

The MesoLAPS output in figure 5 indicates the existence of a topographically-induced, vertically propagating gravity wave at a time when the foehn-like conditions were observed over the Gippsland coast. Vertical cross-sections of vertical velocity (figure 5a), and potential temperature and projected wind vector (figure 5b), exhibit definite buoyancy wave structure, while the streamlines (isentropes) in figure 5b suggest that the foehn-like conditions were associated with partial blocking of relatively moist lower-level air on the windward side of the mountains, with drier upper air flowing downslope in the lee to replace it.

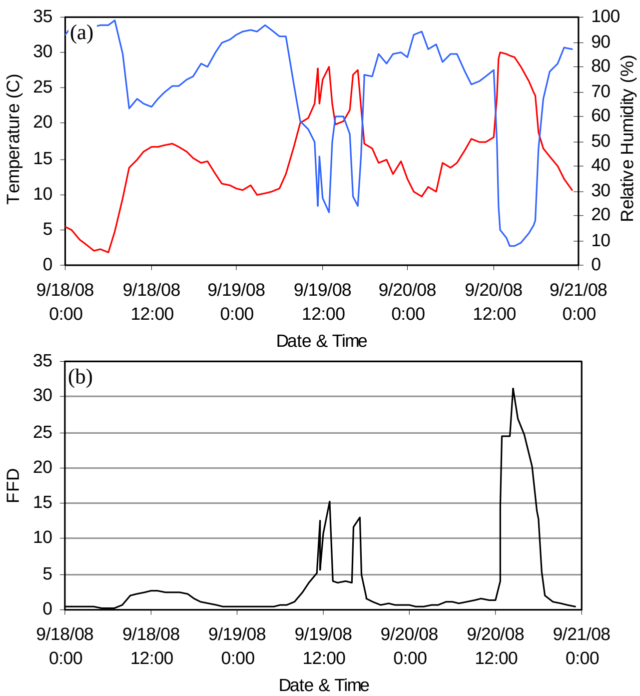

Figure 4. (a) Temperature (red) and relative humidity (blue) time series, and (b) FFDI time series for Moruya, 18-21 September 2008.

3.2. 27 October 2008

Foehn-like conditions were again observed on 27 October 2008, occurring in two stages; in the morning with north-northwesterly winds over the Gippsland region and in the afternoon with more westerly winds over the southern NSW coast. Interpolated surfaces of forest fire danger rating can be seen in figure 6. Figure 6a shows that FFDI on the Gippsland coast was around 30, which is at the 95th percentile of October-November FFDI for the region (Dowdy et al., in press).

Similarly, the FFDI surface in figure 6b shows a region of elevated fire danger rating, with an FFDI of about 35, which is above the 97th percentile for October-November over the region (Dowdy et al., in press). In fact, the FFDI at Bega increased from 4.5 (Low) to 28 (Very High) within 36 minutes from 09:30 to 10:06, and eventually reached an 'Extreme' value of 62.

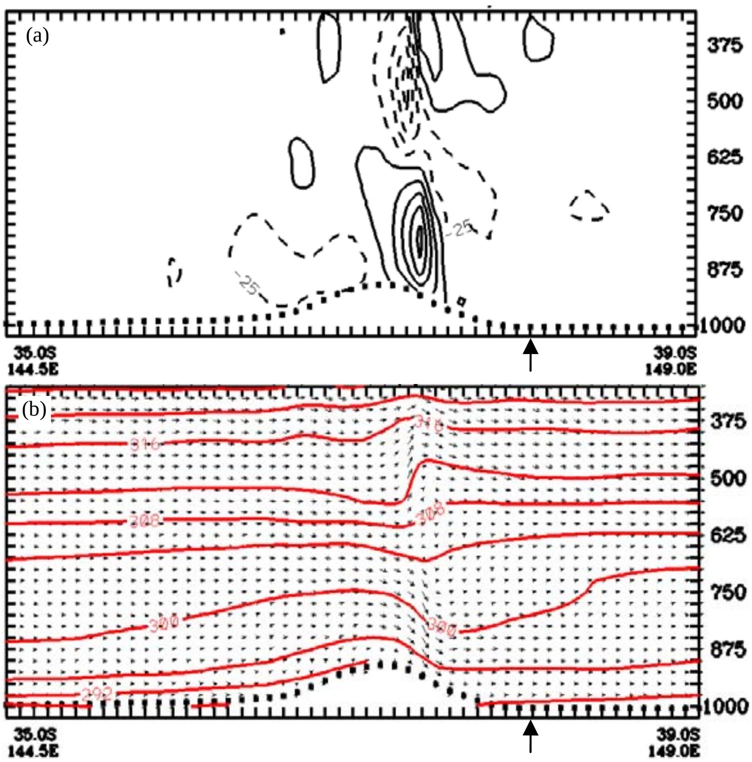

Figure 5. MesoLAPS output for 0700 19 September 2008. The vertical scale is height in pressure coordinates (hPa). (a) Vertical cross-section of vertical velocity isopleths (hPa h^{-1}), (b) Vertical cross-section of potential temperature isentropes (K) and projected wind vector. (See figure 3a for cross section). The arrows indicate the approximate position of the coast.

The evolution of the event can be seen in figures 7a and 7b. At Orbost the temperature increased from around 17°C at 03:30 to 32°C at 10:56. The maximum temperature of 32°C is approximately 12°C warmer than the average for Orbost for October-November. A similar rise in temperature was also observed at Mt Nowa Nowa, which attained a daily maximum of 27°C before noon. About three hours after the sharp temperature increase at Orbost, the temperature trace for Bega exhibits a significant increase from 13°C at 05:30 to 32°C at 10:06. The temperature at Bega then continues to increase to a maximum of 36°C, approximately 14°C above the average maximum temperature for October-November. By contrast, changes in temperature at Albury, on the upwind side of the mountains, exhibited neither the magnitude nor the rates observed in the lee.

The relative humidity time series for Orbost and Bega in figure 7b exhibit changes that complement the changes in temperature just discussed. Relative humidity over the Gippsland fell to around 15%, while on the

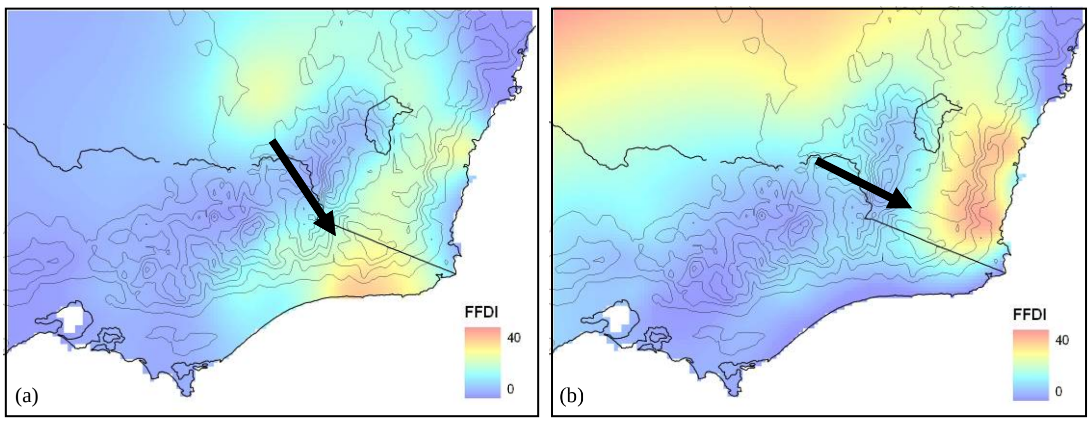

Figure 6. Interpolated surfaces of McArthur Mark 5 Forest Fire Danger Index (FFDI) for (a) 11:00 (b) 15:00, 27 October 2008. Arrows indicate the synoptic wind direction.

NSW south coast relative humidity fell to as low as 11%. The changes in relative humidity were shown to be largely driven by changes in the available atmospheric moisture, as indicated by dew-point time series (not shown). At Orbost dew-point fell to 2.5°C, while at Bega it fell to 1.6 °C. These figures indicate an influx of significantly drier air in the lee of the mountains, and are in contrast to those recorded on the upwind side at Albury where dew-point remained at 6-8°C.

The 500 hPa level vertical velocity field at 09:00, 27 October 2008, as modeled by MesoLAPS, can be seen in figure 7c. A region of descending air is evident over the Australian Alps to the north and northwest of Orbost at a time when Orbost was experiencing relatively warm and dry conditions. A region of upper-level ascending air can be seen in the immediate lee of the mountains, over Orbost. This again indicates the existence of a topographically-induced, vertically propagating buoyancy wave over the affected region.

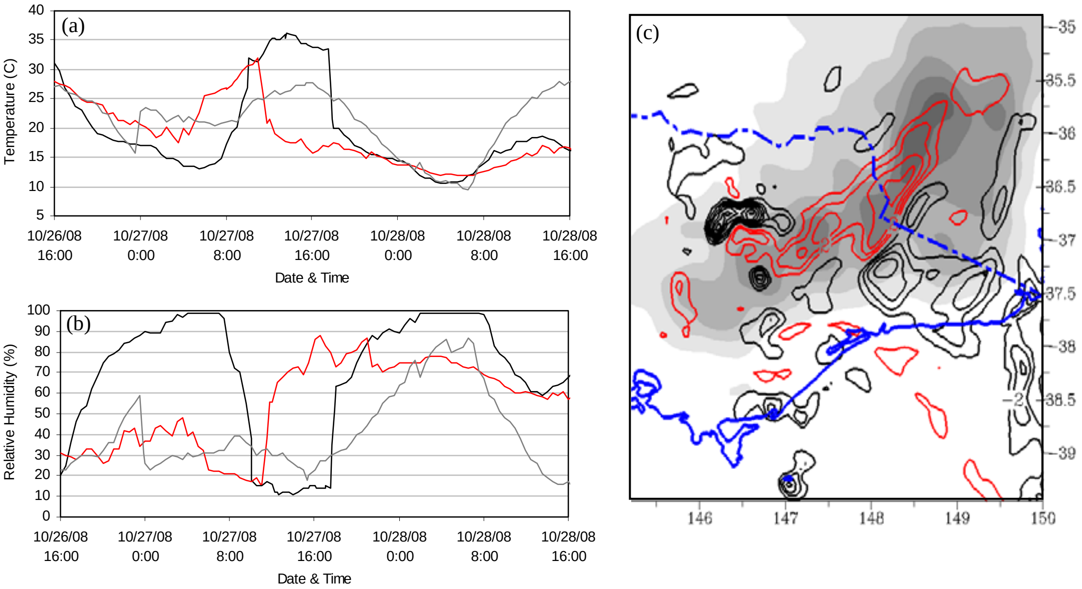

Figure 7. (a) Time series of temperature at Orbost (red), Bega (black) and Albury (grey), (b) Time series of relative humidity at Orbost (red), Bega (black) and Albury (grey), (c) MesoLAPS output for 09:00, 27 October 2008, showing vertical velocity (Pa s^{-1}) at the 500 hPa level. Red contours indicate indicate descending air, black contours indicate ascending air.

4. DISCUSSION AND CONCLUSIONS

The analyses presented above confirm the existence of regional anomalies in fire danger rating, in the lee of the main mountain ranges of southeastern Australia, consistent with foehn occurrence. Fire danger rating was shown to be at or above the 95th percentile for the two events presented. Particular regions shown to be affected included the Gippsland region and the southern New South Wales coast.

NWP modelling, using MesoLAPS indicated a connection between foehn-like conditions and partial orographic blocking of relatively moist low-level air on the upwind side of the mountains and subsidence of drier upper-level air in their lee. The NWP fields also indicated the presence of topographically-induced atmospheric waves in connection with foehn-like conditions. These waves originated with the descent of upper-level air above or slightly upstream of the ridge top and extended into the lee of the ranges as broad-scale, vertically propagating gravity waves. As such, the two events on 19 and 20 September, and 27 October 2008 qualify as genuine and significant foehn occurrences, driven by the second foehn mechanism discussed in the introduction. Enhanced mixing-down of drier upper air through wave breaking in the lee may also have been a contributing factor to these events, though it was not possible to identify such features with the hydrostatic model used.

The results also suggest that the existence of foehn conditions at the surface is dependent upon the interaction of the mountain wave features with other atmospheric structures such as inversions. On 19 September 2008 the foehn conditions intermittently experienced at Moruya (figure 4a) did not manifest in the surface observations at Merimbula nearby. Other stations in the lee of the topography may have been protected from the downward-propagating dry air by a shallow marine inversion, with the onshore flow of cooler marine air being assisted by the lee trough in the surface pressure field. Hence, the absence of foehn conditions in the surface observations at a particular station does not mean that they cannot occur somewhere in the surrounding area, as the processes that develop surface inversions can vary widely over small geographic areas. Hence, the presence of wave structures in model fields and satellite imagery over regions in southeastern Australia indicates the probability of foehn-like conditions occurring in some localities in that region.

Foehn occurrence over southeastern Australia has significant implications for modelling bushfire risk, as their features can result in the accelerated drying-out of wildland fuels, more intense fire behaviour and increased spotting potential. As such, foehn occurrence can seriously compromise fire-fighter safety and suppression efforts. The abrupt transition of conditions that occur with the onset of foehn winds has significant implications for fire-fighting. Sudden changes in weather conditions have often been associated with loss of containment of bushfires and fire-fighter fatalities (e.g. Cheney et al., 2001). In this context, it is interesting to note that current Australian bushfire risk management frameworks do not formally account for foehn winds as drivers of bushfire risk, and the likely effects of foehn winds are not generally allowed for in alternate or ‘worst case’ scenarios. From the point of view of risk modelling, the study presented above already indicates that the Gippsland and NSW south coast regions should be considered as having higher bushfire risk when synoptic flows align with certain parts of the topography. As investigation into these types of events continues, it will be possible to assign probabilities to these regions, which relate the likelihood of elevated bushfire risk due to foehn occurrence (cf. the ‘Red Flag’ system in the U.S.).

Foehn occurrence also has bearing on prescribed burning and hazard reduction strategies. The events presented occurred during a period typically set aside for hazard reduction burning. Thus, effective bushfire risk management, particularly concerning prescribed burning, in regions prone to foehn occurrence requires a proper appreciation of the precursor conditions for foehn winds and their likely (spatiotemporal) effect on fire danger levels. In particular, prescribed fires or wildfires that have not been sufficiently extinguished have significant potential to flare up and become problematic if impacted by foehn conditions. Improved knowledge and forecasting of foehn events will therefore allow agencies to better anticipate the resources required for prescribed burns, particularly during the mop-up, blacking-out and patrol phases.

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