THE POLAR FOEHN OF THE VICTORIA VALLEY, ANTARCTICA.

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Hamish A. McGowan* and Johanna C. Speirs
The University of Queensland, Brisbane 4072, Australia.

1. Introduction

Foehn winds have been a key focus of alpine meteorological research for more than a century, most notably in the European Alps. Hann (1866) very early recognised the importance of adiabatic warming of air descending in the lee of a mountain crest as a primary cause of foehn. Hann latter identified the role of latent heat release associated with orographic precipitation as also contributing to the warm and dry foehn winds observed over slopes in the lee of topographic barriers (cited in Drobinski et al. 2007). In recent decades research programmes such as ALPEX (Kuettner 1980), LTEX (Sturman et al. 2003) and MAP (Drobinski et al. 2007) have made significant advances in foehn research through the use of high density observation networks, aircraft, satellite imagery and meso-scale climate modelling. This has provided insight to the thermodynamic characteristics of foehn, foehn interaction with other winds and the role of different mountain and valley geometry in foehn characteristics. The research has been driven by the need to improve forecasting of foehn events and their impact on air quality, snow melt and alpine hydrology, and the severe wind hazard they may present in alpine regions to aviation, communications infrastructure, buildings, forestry and wildfire control.

The majority of foehn research has been undertaken in mid-latitude settings in Europe, North and South America, Japan and New Zealand. In contrast, studies of foehn in high latitude locations are rare, the Antarctic being no exception. Thompson et al. (1971) and Thompson (1972) reported that warm and dry winds monitored in the McMurdo Dry Valleys (MDVs) of Southern Victoria Land, Antarctica originated from the deflection of strong upper level westerly flow down into the valleys. McKendry and Lewthwaite (1990, 1992) believed that these warm winds were foehn in character. However, Clow et al. (1988) and Nylen at al. (2004) stated these winds were either katabatic or of katabatic origin, although Parish and Bromwich (1987) found no evidence of streamline convergence and katabatic flow from the polar plateau into the MDVs, thereby making a katabatic origin unlikely.

In this paper we argue through a case study approach that the warm wind events of the Victoria Valley, the northern most and largest valley of the MDVs are foehn. We offer an explanation for the temperature changes monitored during these events in the valley which may exceed + 40°C.

2. Physical Setting

The Victoria Valley in the largest of the McMurdo Dry Valleys, a largely snow and ice free region of > 4800 km^2 located in the Trans-Antarctic Mountains in southern Victoria Land, Antarctica. The region is bordered by the Trans-Antarctic Mountains to the west and the Ross Sea to the east (Figure 1). The Victoria Lower Glacier occupies the eastern segment of the Victoria Valley system which west of the Victoria Lower Glacier splays into 5 main branches west of Lake Vida (Figure 1). The most northern of these is the upper Victoria Valley, in which lies the Victoria Upper Glacier. The termini of the Victoria Upper and Lower Glaciers are approximately 26 km apart, with melt-water from both in summer draining into Lake Vida in the centre of the Victoria Valley system. The remaining four branches are known as the Barwick, Balham, and McKelvey Valleys and Bull Pass (Figure 1). The surface of the Victoria Valley is largely snow and ice free during summer following the thaw of seasonal snow falls which are < 100 mm water equivalent (Doran et al. 2002a). Surface sediments in the snow and ice free regions of the Victoria Valley system consist of heavily weathered exposures of bedrock, glacial and glacio-fluvial sediments and extensive aeolian deposits. The Olympus Range forms the southern boundary of the valley with peaks exceeding 2000 m, while to the north of the valley the St. Johns Range rises to 1500 m.

The mean annual temperature of the Victoria Valley is approximately -27°C, while summer air temperature maximums of >+5 °C and winter minimums < -60 °C have been recorded at Lake Vida (Figure 1). The mean winter (MJJ) air temperature at Lake Vida is -40°C (Speirs et al. 2008). The wind regime of the MDVs is dominated by topographically channelled valley winds during summer. These develop due to differential surface heating between the low albedo Dry Valley floors and the high albedo cold glacier surfaces to the east, analogous to a sea breeze circulation (McKendry and Lewthaite 1990). During winter the valley experiences lengthy calm periods with localised katabatic winds. Strong west to south-westerly winds with speeds of > 20 ms^{-1} may occur throughout the year

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* *Corresponding author address:* Hamish A. McGowan, Univ. of Queensland, School of GPA, Brisbane 4072, Australia; e-mail: h.mcgowan@uq.edu.au.

with associated air temperature increases of > 40 °C. These mask and/or destroy local circulations and may prevail from several hours to days.

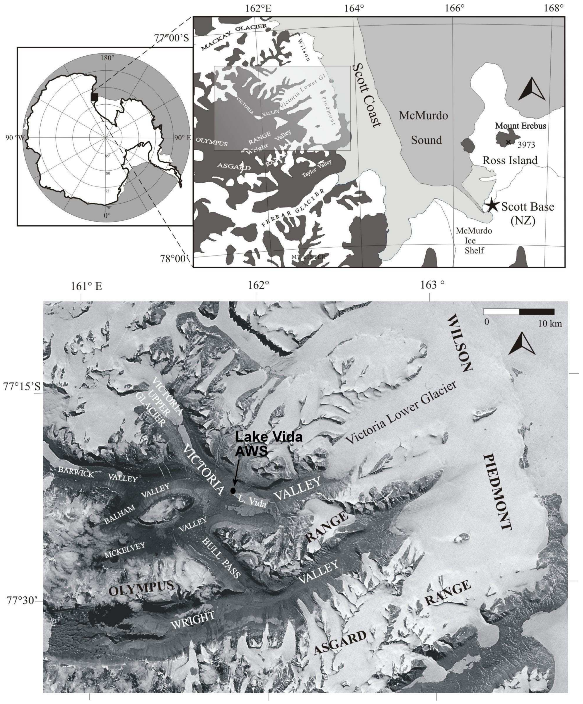

Figure 1. Location map of the study area with the Lake Vida AWS shown on the satellite image of the MDVs in the lower panel.

3. Methods

Meteorological data presented in this study was obtained from automatic weather stations (AWS) operated by the McMurdo Dry Valleys Long Term Ecological Research (LTER) program (Doran et al. 1995). The configuration of these stations is detailed at http://www.mcmlter.org/queries/met/met_home.jsp and in Doran et al. (2002b). The Lake Vida station we present data from here consists of the following sensors: wind speed and direction are monitored by a R.M. Young model 05013 wind monitor with a starting threshold of 1 ms^{-1} (1.1 ms^{-1} vane) and accuracy of 1% of wind speed reading (± 3° of monitored wind direction); air temperature and relative humidity was monitored by a Campbell Scientific 207 probe through until the 1999/2000 season when it was replaced with a Vaisala HMP45C sensor. The Vaisala HMP45C sensor has a reported temperature accuracy of ± 0.2 °C at 20 °C decreasing to ± 0.5 °C at -40 °C and ± 2% over the range of 0 to 90% relative humidity. Relative humidity measurements at temperatures below 0 °C have been corrected to correspond to the relative humidity with respect to ice (Doran et al. 2002b). Air temperature and relative humidity measurements were made at 3 m above the surface, while wind speed and direction were monitored at 3.2 m above the ground surface. These sensors are sampled every 30 seconds with summary statistics logged every 15 minutes.

Barometric pressure field data for different levels and modelled soundings were obtained from the NOAA Air Resources Laboratory FNL archive which is available for the period 1 January 1997 to 31 December 2006. Details of this archive are described by Stunder (1997). Land Surface Temperature (LST) images were derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) MOD11_L2 (level 2) processed product for a swath (scene) with a 1 km spatial resolution. The product is generated using geolocation, cloud mask, quarterly land cover and snow products using the generalised split-window LST algorithm (Wan and Dozier, 1996). The LST algorithm is constrained to pixels with clear-sky conditions at a 99% confidence defined in the cloud-mask. The output file contains LST data, emissivity in bands 31 and 32, error in LST, quality assurance and geolocation data. Emissivity in bands 31 and 32 are estimated by the classification-based emissivity method (Snyder and Wan, 1998) according to land cover types in the pixel determined by the input data in the quarterly land cover product and daily snow cover product.

4. Results

The two case studies presented here were selected to highlight the dramatic increases in air temperature recorded at Lake Vida during foehn. They are both wintertime examples and the warming that occurred was a result of compressional adiabatic warming due to the extremely dry atmosphere over the MDVs at this time of year.

Event 1: 6 – 9 June 2001

The mean sea level synoptic pressure field and 700 hPa geopotential surface for 0600UTC on the 7 June 2001 are presented in Figures 2a & 2b. The 700hPa surface is only slightly higher than the mountain ranges to the south of Lake Vida. Air temperature at this level was -27 °C based on the FNL archive data. Figure 2a shows a low pressure system in the Ross Sea with a central pressure of 972 hPa. This region is climatologically-favoured for the development of cyclonic systems that result in strong pressure gradients over Victoria Land and the MDVs as shown in Figure 2a. Figure 2b indicates that the gradient wind near the ridge crests of the mountain ranges in the MDVs was south-easterly. At 500 hPa (not shown) the wind direction was also south-easterly with an upper level low centred near 175°E, 68°S north-northeast of the field area.

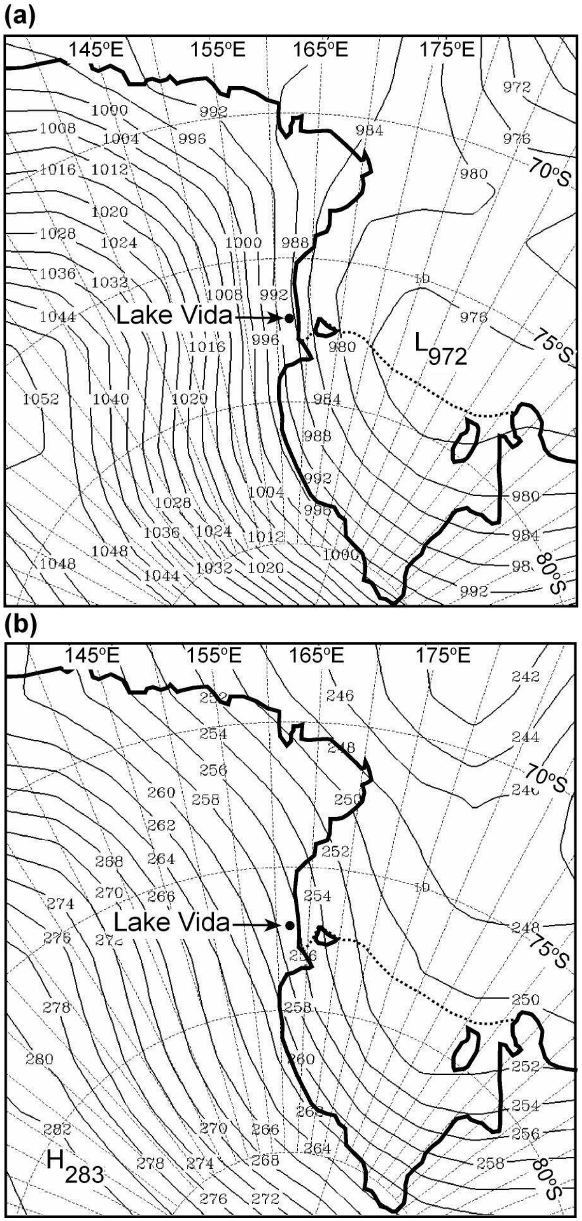

Figure 2. a) Mean sea level pressure field and b) 700 hPa geopotential surface (decametres) for 0600UTC 7 June 2001.

Local meteorological conditions recorded at Lake Vida AWS are presented in Figure 3. These show pre-foehn conditions characterised by a gradual warming of air temperature from -50°C at 1800 New Zealand Standard Time (NZST) (UTC + 12hrs) on the 5 June to -26°C at 1600 NZST on the 7 June – a mean warming of +0.52°C per hour. Foehn onset then caused the air temperature to increase by +27°C in 2 hours with a corresponding increase in wind speed and fall in relative humidity (Figure 3). The wind direction became southerly as air descended the north facing slopes of the Olympus Range (Figure 1) located to the south of the Lake Vida AWS. Air temperature reached a maximum of – 7.3 °C at 1800 NZST 7 June 2001 (Figure 3).

Air temperature at 700 hPa at 1200NZST 7 June was estimated from the FNL archive to have been -27 °C. Warming of this air at the dry adiabatic lapse rate as it descended 2150 m to the floor of the Victoria Valley would have resulted in a warming of approximately +21°C. This estimates a near-surface air temperature of – 6 °C for the foehn, which is close to the monitored -7 to -8 °C at the Lake Vida AWS throughout the event.

Cessation of the event began at 2200NZST on the 8 June with a marked increase in relative humidity and gradual decrease in air temperature referred to as post-foehn conditions in Figure 3. Wind speed decreased to approximately 2 – 3 ms^{-1} and wind direction became variable reflecting a return to local katabatic drainage winds (Figure 3).

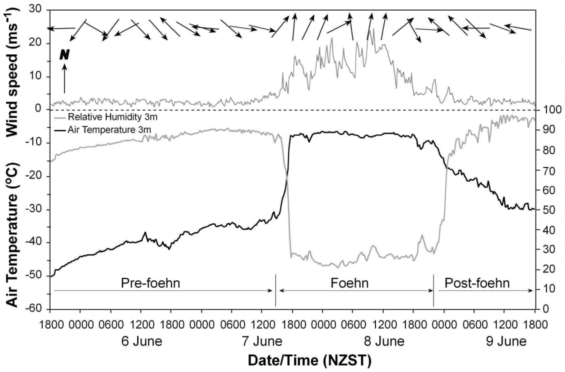

Figure 3. Meteorological conditions recorded by the Lake Vida AWS 6 – 9 June 2001.

Event 2: 31 July - 3 August 2001

Figures 4a and 4b present the mean sea level synoptic pressure field and 700 hPa geopotential surface for 0000UTC 1 August 2001. The mean sea level synoptic pressure field over the MDVs during this event was weak and no cyclonic system(s) were present in the Ross Sea region as reported in Event 1. At 700 hPa the prevailing wind was from the southwest as indicated in Figure 4b circulating a mid-level ridge located north of the field area. This directed a relatively “warm” air mass over the MDVs with an air temperature of approximately -22 °C at 700hPa. Meteorological data from the Lake Vida AWS indicates that the intrusion of this air into the Victoria Valley as foehn occurred twice during this event (Figure 5).

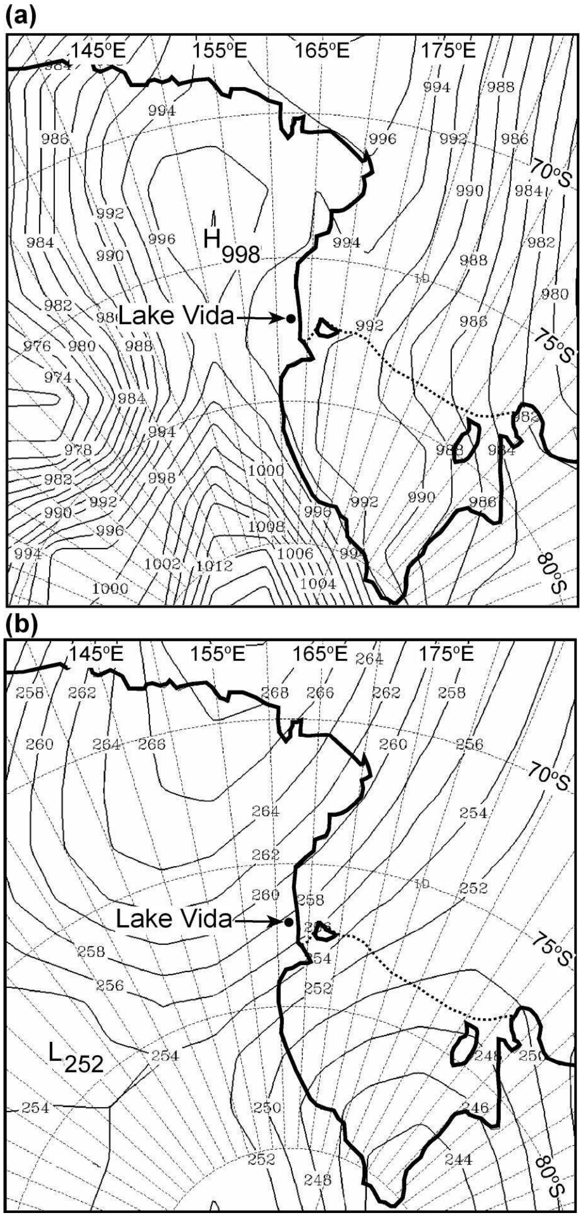

Figure 4. a) Mean sea level pressure field, and b) 700 hPa geopotential surface (decametres) for 0000UTC 1 August 2001.

First, at 1400 NZST 31 July this resulted in a warming of +28 °C in only 30 minutes and was accompanied by an associated fall in relative humidity, while wind speed increased to 5 ms^{-1} (Figure 5). The foehn then decoupled with a return to local katabatic conditions early on 1 August 2001. Foehn onset then occurred for a second time at 2230NZST 1 August causing an increase in air temperature of +32 °C in 30 minutes. A maximum air temperature of +0.2 °C was recorded at 0145NZST 2 August 2001 (Figure 5) by the Lake Vida AWS. This temperature closely approximates that which would have been reached by air descending into the valley from above ridge top at 700 hPa (≈ 2600m), where the temperature was -22°C on this occasion. Namely, by descending 2250 m to Lake Vida the air would have warmed by +22.05 °C once again assuming a dry adiabatic lapse rate. Wind speeds reached 11.5 ms^{-1} before the foehn decoupled and local katabatic winds re-established with air temperatures gradually decreasing (Figure 5).

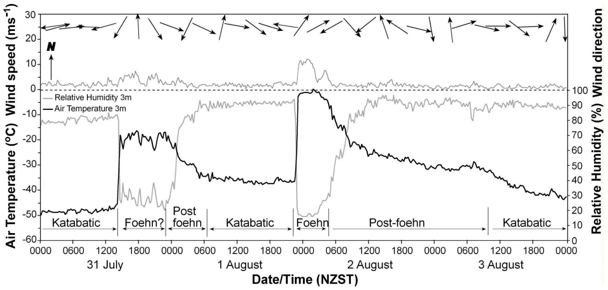

Figure 5. Meteorological conditions recorded by the Lake Vida AWS 31 July – 3 August 2001.

Figure 6 shows MODIS land surface temperatures measured at 0950 NZST July 31 before foehn penetration into the Victoria Valley. LST on the surrounding ridges are 10 to 15 °K warmer than those of the floor of the Victoria Valley, thereby reflecting the influence of the prevailing gradient wind on ridge top temperatures. Valley floor temperatures show no evidence of foehn with the cold LSTs extending east over the adjacent Wilson Piedmont Glacier. Subsequent LST images of this event are not available due to cloud cover.

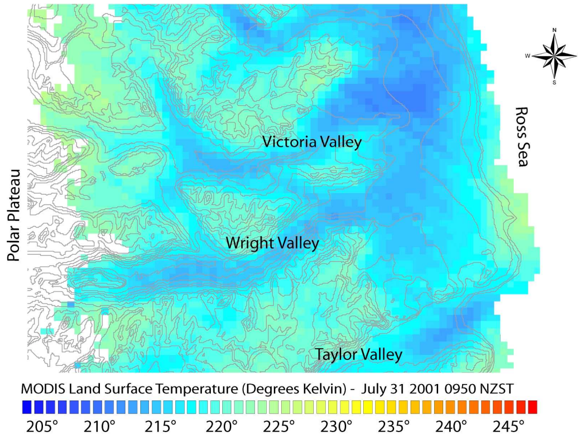

Figure 6. MODIS LST image of the MDVs taken at 0950 NZST July 31 2001.

5. Summary

The MDVs provide a unique environment in which to study the influence of mountain topography on weather and climate. Importantly, the climate of the MDVs is considered susceptible to low amplitude climate shifts (Doran et. al. 2002a) and may therefore exhibit change in response to both natural and anthropogenic forcing of the climate system much sooner than other locations such as, for example, the mid-latitudes. Nylen et al. (2004) concluded that long term changes in air temperatures in the MDVs cannot be understood without detailed knowledge of the regions wind regime.

In this paper we have shown that topographic modification of the prevailing gradient wind and the formation of foehn can produce rapid and dramatic changes in air temperature in the MDVs. Our analysis of the synoptic meteorology of foehn indicates that the majority of these events occur during strong gradient southerly airflow as detailed in the Event 1 case study. These conditions are associated with cyclogenesis in the Ross Sea region. Strong southerly airflow may also develop over the MDVs with the formation of mesoscale cyclones over the Ross Ice Shelf (e.g. Carrasco et al. 2003). Southerly quarter airflow prevails through the troposphere under both of these conditions often up to 500 hPa.

In the second case study, Event 2, coupling of mid-level southerly flow to the surface occurred, while below ridge level weak pressure gradients resulted in light and variable winds. Topographic modification of the south-westerly airstream that had originated north of the Antarctic continent and circulated around a mid-level ridge on this occasion produced dramatic warming at Lake Vida. Our analysis of historical data indicates that these events which may cause wintertime air temperatures to rise above 0 °C in the MDVs are much less common. Such warming reflects the initial warmer temperatures associated with the prevailing ridge-top winds during Event 2 type conditions compared to those reported for Event 1 conditions.

Foehn onset during Event 1 was characterised by a gradual warming trend at Lake Vida over many hours before foehn flushing of the cold air pool and coupling of the foehn to the surface. This resulted in an air temperature increase of +27 °C. We believe that this type of onset may indicate gradual erosion of a wintertime cold air pool that forms over Lake Vida by the descending foehn. This is followed by rapid flushing of the remaining cold air as foehn onset occurs. In Event 2, foehn onset was rapid and may have been due to mountain wave breaking which caused sudden flushing of the cold air pool in the Victoria Valley and rapid foehn onset at Lake Vida.

Future research will aim to use numerical modelling to shed-light on the foehn winds of the MDVs and their interaction with topography and local thermotopographic circulations. This will include study of meso-scale circulation during foehn (unresolved in the FNL synoptic analyses).This research will be combined with planned field observations in 2009 and 2011.

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