INVESTIGATING THE ROLE OF THE HUT POINT PENINSULA TERRAIN AS IT RELATES TO A MODERATE NORTHEAST WIND EVENT AT MCMURDO, ANTARCTICA

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1. INTRODUCTION

Hut Point Peninsula extends 22 km south of the Erebus Ice Tongue of Ross Island, Antarctica (Fig. 1). It is 2 to 4 km wide across its southern two-thirds. A ridge of 200 to 400 m above Mean Sea Level (MSL) runs along the middle of the peninsula.

During the late austral summer and early fall, McMurdo is usually free of snow. The dark volcanic soil is effective at maintaining warmer 2-meter air temperatures than the air over the Ross Ice Shelf east of the peninsula. When surface winds are light and skies mostly clear, the temperature at McMurdo is typically 5º to 10º C warmer than the nearby ice shelf.

In the absence of a significant pressure gradient, weather conditions in McMurdo during this time of year are often favorable for outdoor work and recreation. The sustained wind averages10 KT or less. The mean low temperature is -11º C, and the high is -6º C.

Occasionally, periods of moderate east to northeast winds (true direction) occur during quiet synoptic conditions. These regimes are marked by sustained surface wind speeds of 15-22 KT lasting at least 6 hours. Gusts range from 26 to 31 KT. The onset of these wind events is rapid. Falling temperatures and modest surface pressure rises are common.

Between 17 UTC and 19 UTC,19 FEBRUARY 2023, the observed sustained wind at McMurdo increased from 9 KT to 18 KT from the northeast. It remained in the 15 to 20 KT range until 12 UTC, 20 FEB. Associated with the onset of wind was a temperature drop of 3º C in 2 hours. The temperature remained near -11º C most of the day. The wind chill temperature reached -22º C at times.

These wind speeds are well below those reported during the strong southerly wind events of the late austral winter and early spring (colloquially referred to as *Herbies*). However, there are typically more outdoor station operations during the late summer than in late winter and early spring. These operations include the use of tall cranes for the loading and offloading of large ships. Operations must be suspended when the surface wind speed reaches 25 KT. Other outdoor work and recreation are still ongoing in late February as well. Personnel must be adequately prepared for cold wind chill temperatures.

The NPP Antarctic Weather Forecasting Handbook (NIWC, 2022-23) offers a few rules of thumb for forecasting “McMurdo moderate easterly winds” but does not contain specific cases. It also does not explore what role, if any, the terrain of Hut Point Peninsula might play in shaping this regime.

NPP forecasters who have deployed to McMurdo during all seasons have anecdotally noted the occurrence of this wind regime being more common in late summer and fall. Along with the forecasting handbook, they note a diurnal cycle in which the wind speed at McMurdo increases between 0500 and 0900 Local Time (LT). The wind subsides below 10 KT at times ranging from mid-afternoon through midnight.

This work explores 4 cases from the late summer and early fall of 2023 which fit this pattern. Composite synoptic charts of basic meteorological parameters are constructed to help forecasters recognize the large-scale weather patterns associated with this weather regime. Skew-T Log-P diagrams and possible airmass source regions are also provided.

The 19 FEB – 20 FEB case is presented in more detail, including high-resolution Numerical Weather Prediction output from the Antarctic Mesoscale Prediction System (AMPS) Weather Research and Forecasting model (WRF). This model output, coupled with NPP Automated Weather Station (AWS) surface and McMurdo upper-air observations, show that the increase in wind occurs immediately past and downstream the Hut Point Peninsula ridge (Fig. 2). Newly available, high-resolution vertical cross-section output across Hut Point Peninsula is examined to better understand the interaction between terrain and the (initially) light easterly flow.

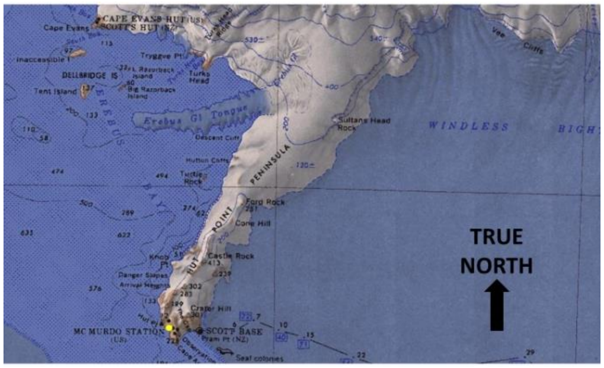

Figure 1. Southern Ross Island focused on Hut Point Peninsula. Ridge of 200-400 m above MSL lies along center of peninsula.

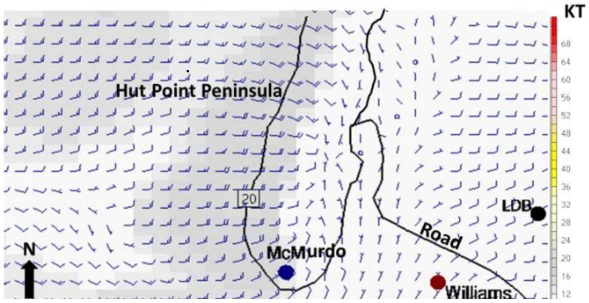

Fig. 2. AMPS WRF 0.89 km resolution surface wind (KT) for southern third of Hut Point Peninsula, valid 15 UTC 19 FEB.

2. SYNOPTIC OVERVIEW OF CASES

Four similar cases from late summer and early fall of 2023 were selected using the following, somewhat subjective criteria from observations from McMurdo:

1. Peak sustained wind of 18 KT or more
2. Sustained wind of 14 KT or more lasting at least 6 consecutive hours
3. True wind direction remains within 30º to 90º sector
4. Event beginning defined as first observation with increase in wind (less than 10 KT to at least 14 KT).
5. Event ending defined as last observation before wind decreases below 10 KT.
6. Diurnal component: event must begin between 0500 and 0900 LT and end by midnight of same day. (Eliminates persistent moderate east-northeast wind regimes lasting 24 hours or more)

The cases matching these criteria are (UTC dates) 19-20 FEB, 6-7 MAR, 7-8 MAR, and 9-10 MAR. 18 UTC was used to compute the composite charts, as the beginning of each event was between 17 UTC and 19 UTC.

The composite synoptic charts of the 4 cases show a quiet weather pattern across the Ross Island region. Present in the lower through mid-troposphere are above-average geopotential heights (Figs. 3-4) over eastern Antarctica and the Ross Sea, and near-average heights across much of the Ross Ice Shelf. Slightly below-average temperatures are noted across the extreme western Ross Sea from Ross Island to Cape Adare (Fig. 5).

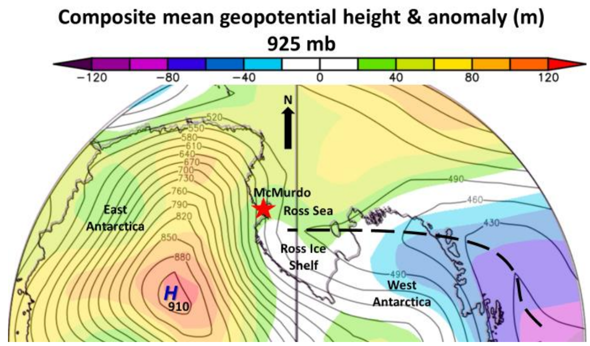

Fig. 3. Height contours (solid black lines, 30-meter increments) and anomalies compared to 1991-2020 mean values (image).

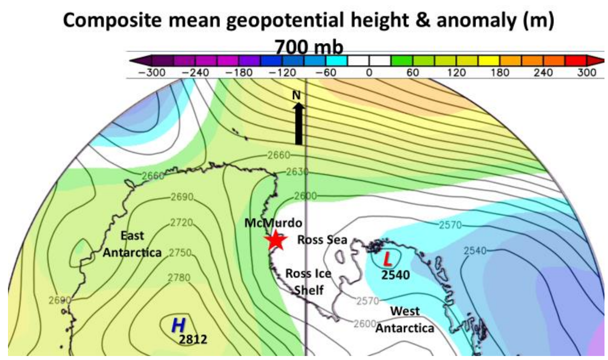

Fig. 4. As in Fig. 3.

The tight temperature and geopotential height gradient between the Transantarctic Mountain range and eastern Antarctic plateau coincides with abnormally strong surface winds there. These winds become an anomalously strong downslope flow through the glaciers of Terra Nova Bay (Fig. 6). This may account for the cool anomaly over the extreme western Ross Sea (Fig. 5), as cold air from the eastern Antarctic plateau gets transported through glacial gaps in the mountains.

The web-based National Oceanic and Atmospheric Administration (NOAA) HYSPLIT model was used to estimate the airmass source region for each case. A single backward trajectory was computed for an air parcel ending at 50 meters AGL at McMurdo 24 hours prior to the onset of cold, breezy conditions. Archived 00 UTC runs from the 0.25º resolution GFS were used to run HYSPLIT. Each run used the default model vertical velocity.

Fig. 7 shows these backward trajectories. In all but one case (7-8 MAR), the trajectories crossed the southern portion of Windless Bight and Hut Point Peninsula.

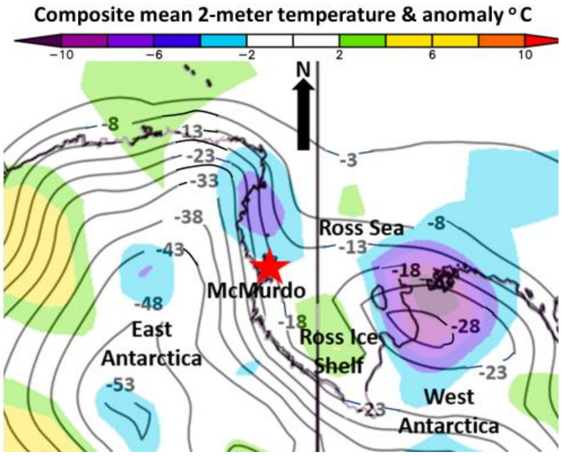

Fig. 5. Temperature contours (solid black lines, 5º C increments) and anomalies (image).

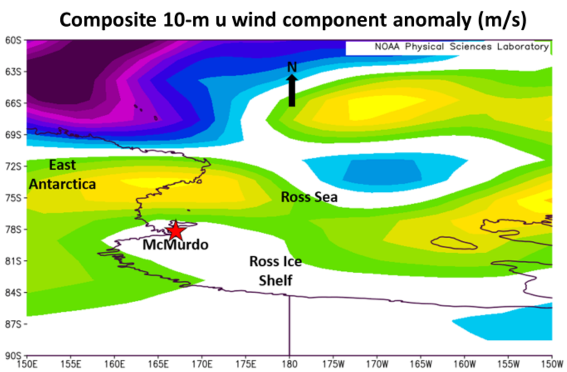

Fig. 6. Positive values indicate above-average westerly wind component.

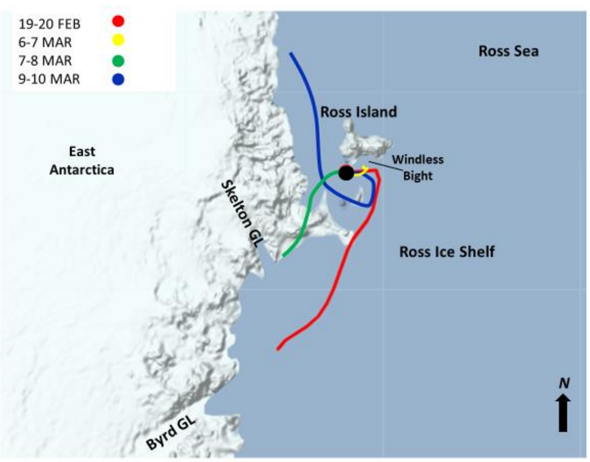

Fig. 7. 24-hour backward trajectories for 4 cases.

The 00 UTC Radiosonde observations from McMurdo show similar temperature and wind profiles for all 4 cases (Figs. 8-11). Each temperature profile has a well-mixed layer through approximately 50 m AGL. This mixed layer is strongly capped by a 50 to 100 m layer where the temperature increases between 4º and 6º C. Above this narrow layer of peak static stability lies a larger layer with more typical lapse rates.

In all but the 7-8 MAR case, the strongest wind speed occurs approximately 100 m AGL. (The 7-8 MAR moderate wind event ended earlier than the others, shortly after the observation was taken). In all cases, the wind speed diminishes above 100 m. The flow aloft has a significant westerly component above the 925 mb constant pressure level, except for the 9-10 MAR case (Fig. 11), where this westerly component does not occur until the 800 mb level.

At the time of these upper air observations (13 LT), cold air had been spilling over the higher terrain of Hut Point Peninsula into McMurdo for at least 6 hours. For the 19-20 FEB case, there was only a 2º C temperature difference between McMurdo and the Willie Whiteout AWS site.

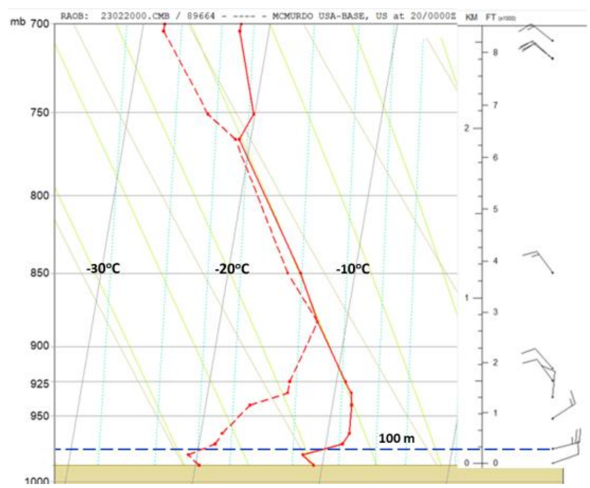

Fig. 8. Skew-T Log-P diagram below 700 mb. Mandatory and significant vertical level plots of temperature (solid red line, º C), dewpoint (dashed red line), and wind vectors (standard barbs, KT) from 00 UTC, 20 FEB. McMurdo Station elevation is 34 meters above MSL.

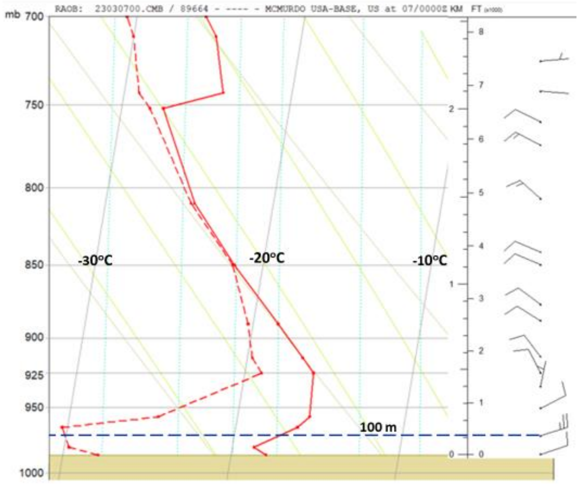

Fig. 9. As in Fig. 8.

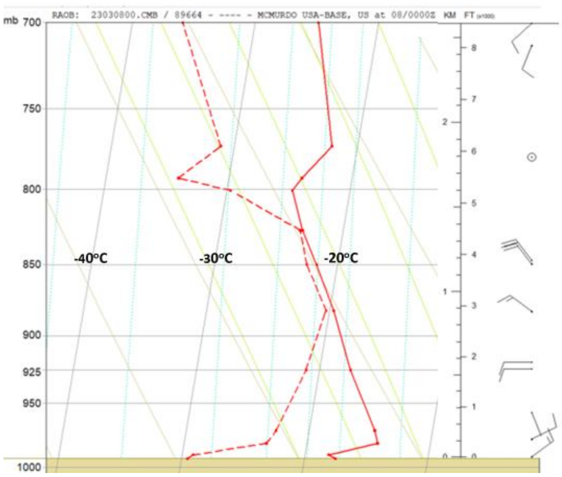

Fig. 10. As in Fig. 8

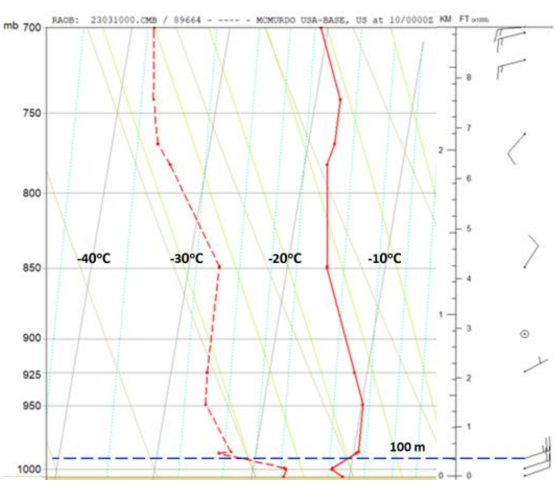

Fig. 11. As in Fig. 8.

3. SYNOPTIC OVERVIEW OF 19-20 FEB CASE

The AMPS surface wind simulation (Fig. 12) shows a quiet synoptic pattern across the Ross Island region at 17 UTC, 19 FEB. The nearest synoptic scale cyclone (968 mb central pressure) is centered near Cape Colbeck. A very weak, sub-synoptic scale cyclone (989 mb) is located on the cyclonic shear side of the Byrd Glacier outflow channel. The Ross Ice Shelf Airstream (RAS) is well east of Ross Island. This simulation fits well with the composite charts shown in the previous section.

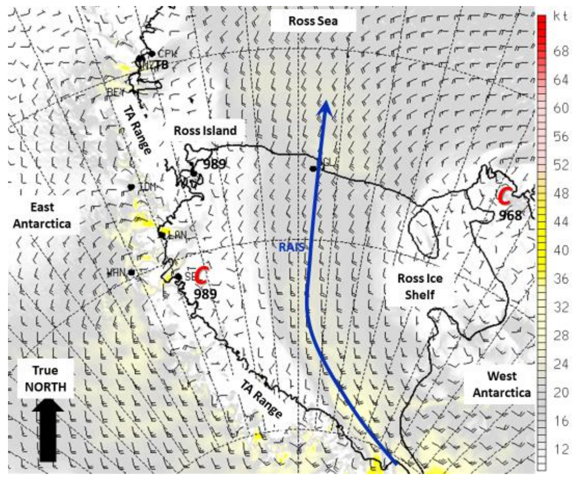

Fig. 12. 00 UTC, 19 FEB AMPS 2.67 km surface wind vectors (standard barbs, KT) and speed (image). Forecast valid 17 UTC, 19 FEB. Circulation centers and RAS core highlighted. MSL pressure maxima and minima labeled (mb).

4. MESOSCALE OVERVIEW OF 19-20 FEB CASE

The AMPS 0.89 km resolution output valid at 17 UTC (Fig. 13) shows a mesoscale cyclone near the southwest coast of Ross Island and a weak ridge near White Island. The pressure difference between these two features is 2 mb. (For a sense of scale, Ross Island is approximately 75 km/47 miles from east to west and north to south at its widest points). To help assess how accurate this model run is, the observed surface wind observations from 4 AWS sites are plotted with the NWP model output in Figures 13-15.

The wind forecast (Fig. 13) for 17 UTC (06 LT) at Willie Whiteout and McMurdo is excellent for direction and speed. The model solution is 8 KT too low at Ford Rock and 18 KT too low at Tent Island. The direction is 60º off at both sites.

At 21 UTC (10 LT), the mesoscale cyclone over McMurdo Sound 4 hours before has nearly dissipated (Fig. 14). The wind forecast at McMurdo, Ford Rock, and Tent Island is excellent. The forecast wind direction at Willie Whiteout is correct but the speed is 8 KT too strong.

At 00 UTC, 20 FEB (13 LT), the temperature at McMurdo has bottomed out at -11^o C. The pressure is 1.4 mb higher since the event began. Fig. 15 shows the plume of stronger winds from the ridge of Hut Point Peninsula westward for 30 km. The AMPS wind forecasts at McMurdo, Ford Rock, and Tent Island are excellent. The forecast wind direction at Willie Whiteout is correct but the speed is 7 KT too strong.

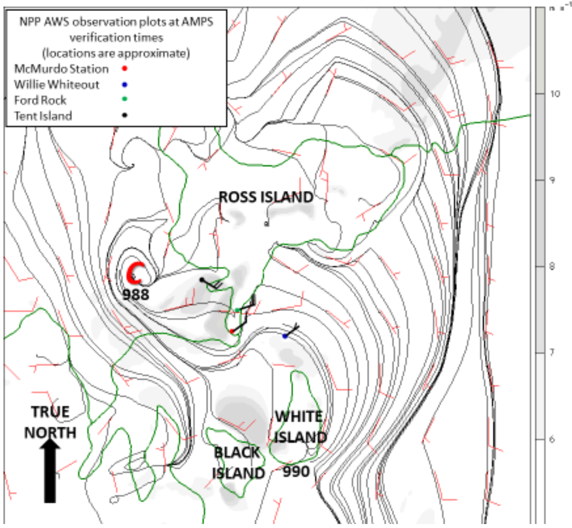

Fig. 13. 00 UTC, 19 FEB AMPS 0.89 km surface wind vectors (red barbs; KT), speed (image; m/s), and streamlines. Forecast valid 17 UTC, 19 FEB. Circulation centers highlighted. Local MSL pressure maxima and minima labeled (mb). Select AWS wind observations plotted using standard black barbs (KT).

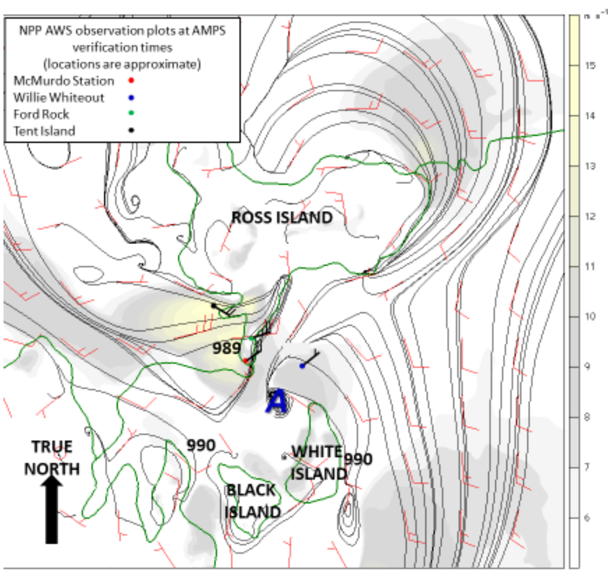

Fig. 14. As in Fig. 13 except 21 UTC, 19 FEB.

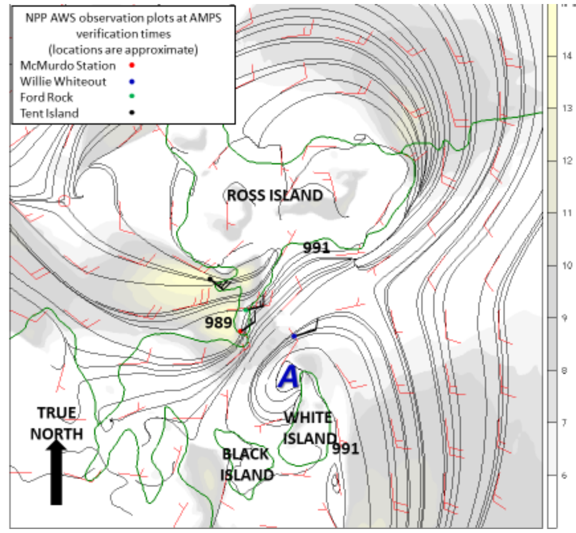

Fig. 15. As in Fig. 13 except 00 UTC, 20 FEB.

5. ANALYSIS OF AMPS VERTICAL CROSS-SECTION FROM 19-20 FEB CASE

In the surface wind simulation shown in Fig. 2, the light northeast to east flow east of Hut Point Peninsula abruptly increases to 15 to 20 KT near the ridge and downstream. Much has been written about flow over high terrain. Pertaining to the weather in and around Ross Island, multiple publications have explored the cases of strong southerly flow interacting with the relatively high terrain of upstream Minna Bluff and Black Island. The highest terrain of these features exceeds 1 km above MSL. However, the author is unaware of any published work that directly deals with the flow of statically stable air over Hut Point Peninsula.

Assuming an overly simplified triangle shape resulting from a vertical plane cutting east-west through the peninsula, the terrain slope on either side of Hut Point Peninsula would have 0.2 meters rise per horizontal distance of 1 meter. This is an angle of 11^o relative to a horizontal plane at the surface. Can such modest terrain help to increase wind speed when exposed to orthogonal flow near and downstream of the peninsula?

Prior to May 2023, only a north-south oriented vertical cross-section (line 2 in Fig. 16) from Mt Erebus through Black Island was routinely available to AMPS users. The AMPS team of the University Corporation for Atmospheric Research/National Center for Atmospheric Research added an east-west cross-section (line1 in Fig. 16) through the southern tip of Hut Point Peninsula, including the McMurdo area, at the beginning of May.

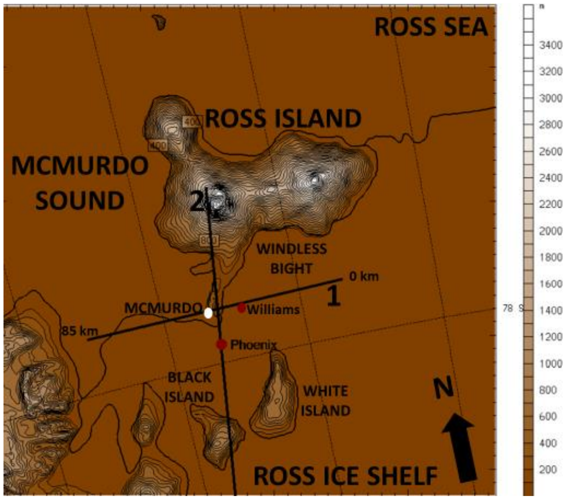

Fig. 16. Map of AMPS vertical cross-sections and model topography (meters). Cross-section 1 is used in this paper.

Fig. 17b shows plotted AMPS output from a vertical cross-section valid at 12 UTC (01 LT), 19 Feb. This is 6 hours prior to the onset of moderate winds at McMurdo. Also plotted are the measured wind vectors from the McMurdo RAOB at this time. The model and observed data show east winds from 5 to 15 KT in the lowest 0.6 km AGL. The flow above 1 km is from the west at 5 to 10 KT.

In addition to relative humidity, Fig. 17a shows the horizontal and vertical components of the modeled circulation wind vectors oriented along the east-west plane. There is narrow ribbon of stronger winds within the lowest 1 km of the lee slope of Hut Point Peninsula. The maximum easterly wind component here is 10 m/s. The maximum vertical component, oriented downslope, is 117.2 cm/s.

At 15 UTC (0400 LT), cold, very shallow, statically stable air east of Hut Point Peninsula is no deeper than the higher terrain of Hut Point Peninsula (Fig. 18). Having more rapid cooling of the near-surface air over the Ross Ice Shelf compared to the lee side of the peninsula is common during light wind regimes. The east wind component is so light, and the depth of the coldest air so shallow, that the leeside of the peninsula is effectively shielded from the core of coldest air.

At 17 UTC (0600 LT), the AMPS simulation has cooling of 1 to 2 K in the layer between 100 and 500 meters above MSL east of Hut Point Peninsula over the last 2 hours (Fig. 19). The 270-266 K isentropes now envelope the entire model terrain. These isentropes closely follow the leeside terrain.

An easterly component of speeds between 12-24 KT (light green shading) extends from above the crest of the model terrain (0.5 km above MSL) to 35 km downstream. Another narrow wind maximum is located within 250 meters above the surface 5 km east of the peninsula. This is an hour before the surface wind increases at McMurdo and the surface temperature begins to quickly cool.

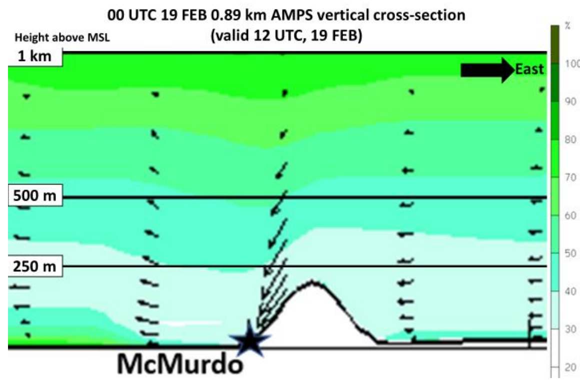

Fig. 17a. Circulation vectors (black arrows; horizontal component in m/s, vertical component in cm/s) and relative humidity (image).

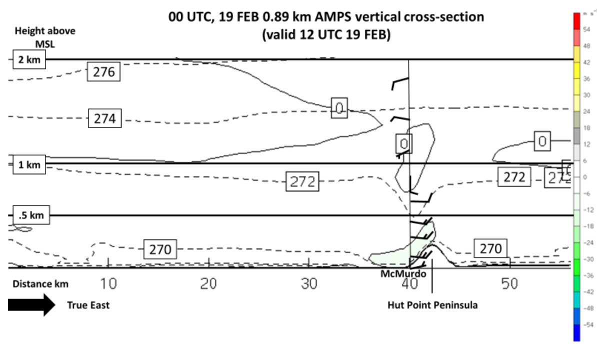

Fig. 17b. Potential temperature (dashed lines, K), cross-section wind speed component (solid lines and image, m/s). Wind from east is negative, west is positive. 12 UTC, 19 FEB McMurdo RAOB wind vectors plotted as standard barbs (KT).

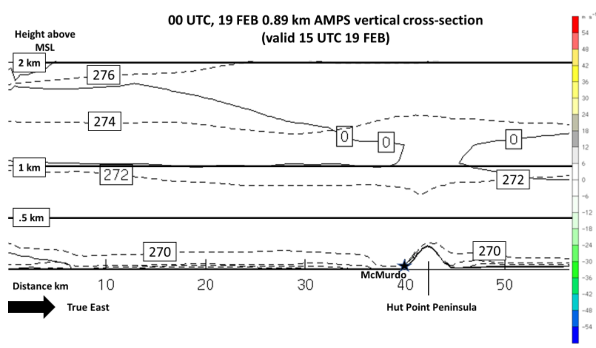

Fig. 18. As in Fig. 17b except no RAOB winds.

Between 17 UTC and 19 UTC (0600 and 0800 LT), the observed surface temperature at McMurdo has fallen 3º C to -10º C. The measured sustained northeast wind is 18 KT. Fig. 20 shows the model solution having a small easterly wind component maximum of 24-36 KT from just west of the terrain crest to 5 km downstream of McMurdo.

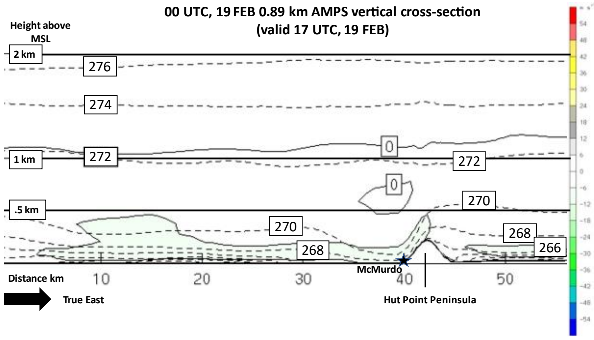

Fig. 19. As in Fig. 17b except no RAOB winds.

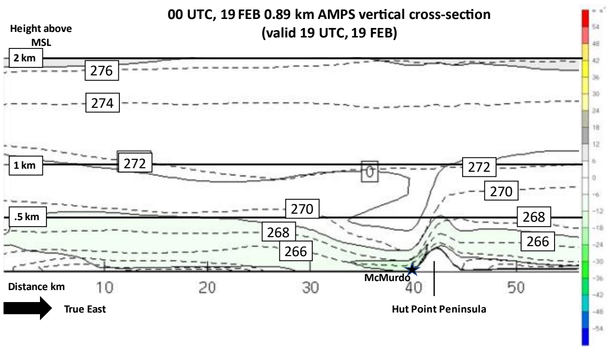

Fig. 20. As in Fig. 17b except no RAOB winds.

The same cooling rate noted between 15 UTC and 17 UTC has continued through 19 UTC within the same layer east of the peninsula. As this cold, dense air continues to spill westward over the higher terrain, the isentropes remain tightly packed and sharply angled along the modelled terrain leeside slope.

At 22 UTC (11 LT), the cold airmass over and east of Hut Point is at its greatest depth of 0.75 km. (The 268 K isentrope is used as an estimate of the upper bound of the cold airmass). The easterly component wind maximum of 24-36 KT along the leeside slope of the peninsula ridge has expanded downstream 9 km (Fig. 21). This forecast vertical potential temperature and wind profile match well with the 00 UTC, 20 FEB observed conditions at McMurdo (Fig. 22).

The forecast circulation wind vectors for 00 UTC (Fig. 23) have a similar pattern to that of 12 hours before (Fig. 17a). However, the magnitudes are larger. The maximum horizontal speed has increased from 10 to 14.4 m/s. The vertical component (downward over the leeside of the peninsula) has increased from 117.2 cm/s to 204.3 cm/s. As was the case at 12 UTC, the simulation has this downward component confined to the lowest 500 m of the troposphere.

Qualitatively, this case bears some resemblance to a high-resolution NWP simulation in Sun and Sun (2015). Their case number 4 discusses the Bernoulli equation as it applies to a modest downslope wind event for steep terrain with a height of 2 km above MSL. In their example, the plotted vertical cross-section isentropes and streamlines share the general characteristics of those modelled in this case.

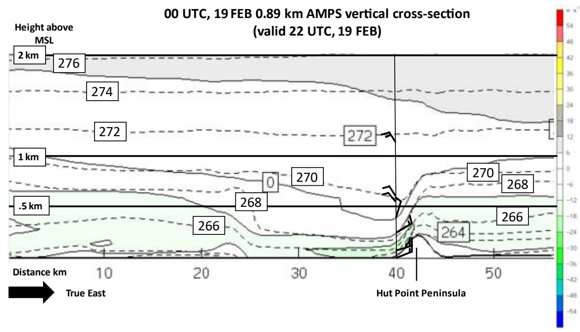

Fig. 21. As in Fig. 17b except RAOB from 00 UTC, 20 FEB.

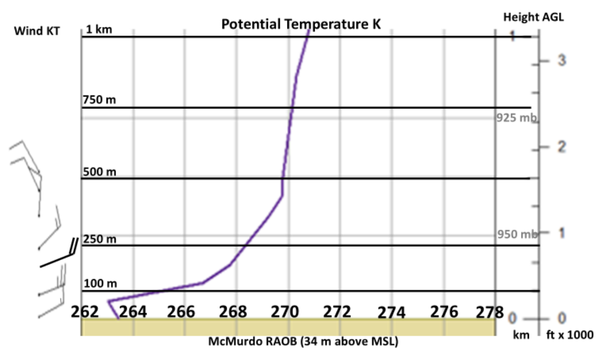

Fig. 22. Observed McMurdo potential temperature and wind profile from 00 UTC, 20 FEB. Bold wind plot is from Crater Hill AWS, approximately 260 meters above MSL near McMurdo.

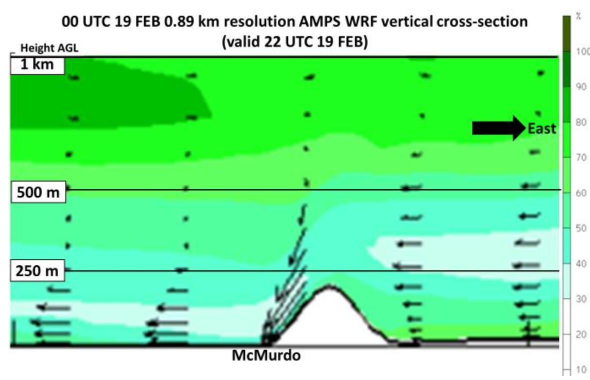

Fig. 23. As in Fig. 17a.

6. SUMMARY

Four cases classified within the moderate east to northeast wind regime at McMurdo are analyzed for commonality. This regime is characterized by a rapid increase in wind speed and corresponding decrease in temperature between 05 and 09 LT. The sustained wind remains in the 15 to 22 KT range for at least 6 hours. A temperature decline of 3^{o} to 4^{o} C and station pressure increase of 1 to 3 mb are common during the first 6 hours.

Composite synoptic charts of the lower through mid-troposphere show above-average geopotential heights over eastern Antarctica and the Ross Sea, and near-average heights over the Ross Ice Shelf. With little height gradient over the western Ross Ice Shelf, the RAS remains far east of Ross Island.

Above-average surface wind speeds between the Transantarctic Mountains and interior eastern Antarctic Plateau drive strong downslope winds through the glaciers of Terra Nova Bay into the western Ross Sea. This flow correlates with a surface cool temperature anomaly from Ross Island to Cape Adare. Modelled backward trajectories show airmass source regions ranging from Byrd Glacier to Windless Bight, to the western coast of McMurdo Sound 24 hours prior to the arrival of cold air in McMurdo.

The 19-20 FEB case is modeled well by the 0.89 km resolution AMPS WRF. This qualitative assessment is based primarily on the wind verification of select model forecast points and nearest available AWS sites near and on Hut Point Peninsula. The 00 UTC 20 FEB McMurdo RAOB is used to verify the vertical potential temperature and wind profiles against the model's vertical cross-section through the southern portion of the peninsula. Here again, the model performed well.

Although Hut Point Peninsula is relatively small with shallow terrain, the AMPS WRF high-resolution output suggests that important interactions may occur within the lowest 500 meters of the troposphere. A few hours prior to the onset of moderate winds reaching the surface of McMurdo, NWP output shows the oft-present, extremely shallow, statically stable, cold airmass east of the peninsula being blocked by terrain. The observed and modelled flow during this time is from the east 5 to 15 KT in the lowest 500 m above MSL, becoming westerly 5 to 10 KT above 1 km.

As the event begins, modelled cooling of up to 1 K per hour occurs within the layer between 100 and 500 m above the surface of the Ross Ice Shelf immediately east of Hut Point Peninsula. As the depth of this cold, stable airmass begins to exceed the 200 to 400 m terrain of the peninsula, some of this relatively dense air "spills" over the terrain and accelerates westward down the lee slope.

The combination of light east wind and cold air spilling over the highest terrain appears to create a potential temperature profile favorable for intensifying downslope wind. As the surface wind speed increases and the temperature cools at McMurdo, the AMPS solution shows a 100-200 m deep easterly wind component maximum of 24 to 36 KT developing within the equally narrow zone of highly sloped, packed isentropes. This maximum begins within a kilometer downstream of the terrain peak and extends westward 5 to 10 km.

The wind maximum may be driven by the Bernoulli principle. (This assumes that the associated thermodynamic processes are largely adiabatic). The modest acceleration of the downslope wind occurs as relatively light east wind upstream from Hut Point Peninsula becomes squeezed into an increasingly narrower vertical channel bounded by a shallow, strong temperature inversion that closely follows the leeside slope.

7. FUTURE WORK

The author has offered a possible qualitative explanation for the moderate wind event of 19-20 FEB. It is based on limited data and NWP output from one case. A quantitative analysis of this, or similar cases, is needed to better understand this type of weather regime. Such studies could include model sensitivity experiments.

It is unclear why this regime has a diurnal cycle. The onset of cold wind on the leeside of Hut Point Peninsula during the early morning coincides to the diurnal minimum temperature cycle. Yet, quiet synoptic conditions this time of year do not often yield such results. There also needs to be some means of maintaining sufficient depth of cold air east of the peninsula to maintain the strong static stability along the leeside slope.

ACKNOWLEDGMENTS

I am grateful to the AMPS team at UCAR/NCAR, especially to Kevin Manning, for so quickly setting up the Hut Point Peninsula vertical cross-section used in this work.

I would also like to thank Paul Gulli, Lead Forecast Specialist for NPP, for recounting his experience with moderate northeast wind events in McMurdo.

8. REFERENCES

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