P2.17 OBSERVATIONS OF STRONG MOUNTAIN WAVES IN THE LEE OF THE MEDICINE BOW MOUNTAINS OF SOUTHEAST WYOMING

Larry D. Oolman[1], Jeffrey R. French[1], Samuel Haimov[1], David Leon[1], and Vanda Grubišić[2]

[1]University of Wyoming, Laramie, Wyoming
[2]Desert Research Institute, Reno, Nevada

1. INTRODUCTION

Strong winds in the atmosphere may be disrupted by mountain ranges creating strong waves and turbulence that are hazardous to aviation and creating damaging surface winds. Flow in complex mountain terrain is not well understood and until the recent development of high resolution remote sensing instruments, observations near the surface have been difficult to obtain.

The University of Wyoming King Air (UWKA) is instrumented for in situ observations, including state variables of temperature, humidity, and winds and has probes for cloud microphysics. It is also instrumented for remote sensing with the Wyoming Cloud Radar (WCR). One upward-pointing and two downward-pointing beams of the radar allow for vertical profiling of clouds and precipitation in the atmosphere as well as dual-Doppler synthesis of the two-dimensional wind below the aircraft. The WCR allows a larger volume to be studied and also allows measurements to be made in regions that are inaccessible by the aircraft due to the low elevations or extreme turbulence. This report will focus on two cases observed during the NASA Orographic Clouds Experiment conducted in over the Medicine Bow Mountains in southeastern Wyoming. The first case on January 26, 2006 evolved rapidly and produced a breaking wave. The second case on February 5, 2006 changed little over the time it was observed and appeared to remain laminar. A companion paper (French et al., 2008) will examine the radar data in more depth.

2. The NASA Orographic Clouds Experiment

The NASA06 field campaign (NASA EPSCoR award NCC5-578, PIs: B. Geerts, J. Snider, D. Leon) was conducted over southeastern Wyoming during January and February, 2006. This project focused on the fine structure of deep wintertime orographic nimbostratus clouds and the processing of aerosols by these clouds. Most of the flights were conducted over the Medicine Bow Range, which extends approximately 160 km along a SSE-NNW line from northern Colorado into southern Wyoming. The highest point of this range in Wyoming is Medicine Bow Peak, which reaches 3650 meters. It is located in the northern portion of the mountain range. In this region, the Medicine Bow Range is about 50 km across. To the west lies the Saratoga Valley and to the east is the Laramie Valley. These high plains valleys have an elevation of around 2000 meters. On the western edge of the Laramie Plains lies the town of Centennial with the Rock Creek Ridge to the north of the town and Sheep Mountain to the southeast. Both have an elevation of over 3000 m. The eastern flank of both these features is fairly steep with a slope of about 15%.

3. January 26, 2006

Prior to the noon flight on January 26, 2006, scientists for the NASA06 project noted that clouds were developing considerably over the mountains. On the final leg of the flight, a rapidly developing wave cloud was noted to the east of the Medicine Bow Mountains over the Laramie Valley. This was captured on the forward facing camera aboard the aircraft (Fig. 1).

A 700 hPa map from the 18 UTC NAM run on January 26 is presented in Fig. 2. A trough had passed through the night before. A weak short wave can be seen passing through central Wyoming. The winds are westerly at 15 m s^{-1}. Stronger winds associated with the jet stream are seen to the east over the Great Plains.

**Corresponding author:* Larry D. Oolman, Dept. 3038, 1000 E. University Ave., Laramie, WY 82071; e-mail: ldoolman@uwyo.edu

Fig. 1: Photograph of a wave cloud captured from the video camera aboard the Wyoming King Air on Jan 26, 2006. The aircraft was at an altitude of 5200 m, 1500 m above Medicine Bow Peak and 3200 m above the valley floor.

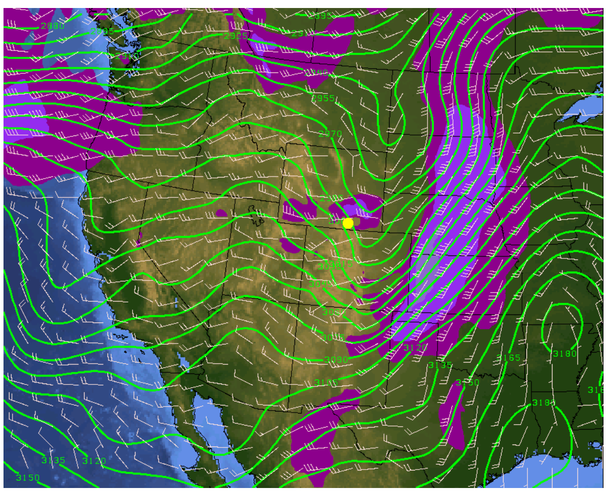

Fig. 2: **700 hPa map for 18 UTC 26 Jan. The heights are contoured in green with an interval of 15 m. Regions with wind speeds above 15 m s^{-1} are shaded with violet hues. The shading interval is 5 m s^{-1}. The flight location is indicated by the yellow dot near the center of the image.**

The flight track is shown in Fig. 3. The track is aligned nearly along the direction of the wind. The vertical wind speeds are indicated by the color of the track. Downdrafts are shown in read and updrafts are shown in blue. A strong wave can be seen to the northeast of Centennial, with speeds ranging from 6 m s^{-1} up to 4 m s^{-1} down.

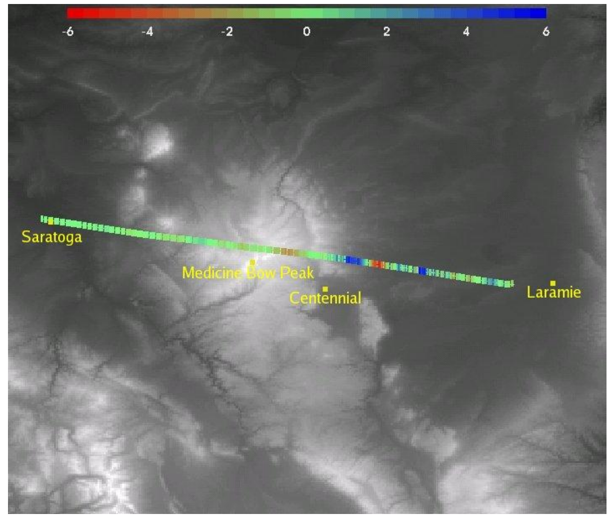

Fig. 3: Flight track for 21:54-22:08 UTC on Jan 26, 2006. The gray image shows the altitude of the underlying topography. The colors indicate the vertical wind speed measured by the aircraft with the scale shown at the top of the figure.

A sounding taken with the King Air near Saratoga is shown in Fig. 4. An inversion can be seen just below ridge top at around 675 hPa. The maximum winds of about 18 m s^{-1} occur below this level. Above 440 hPa, the winds become weak and northerly, establishing a critical layer with respect to the lower winds and the orientation of the Medicine Bow Mountains. This may contribute to the development of a wind storm. The Froude number, estimated from this sounding, is 0.8, which also suggests that a wind storm may be possible.

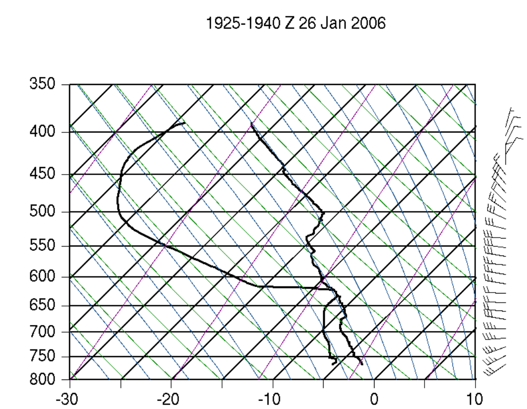

Fig. 4: Aircraft sounding taken between 1925-1940 UTC on Jan 26, 2006.

The King Air flew three legs passes through this wave. The vertical Doppler velocity measured by the WCR from two of these passes is shown in Fig. 5. The second pass was displaced to the south and is not shown.

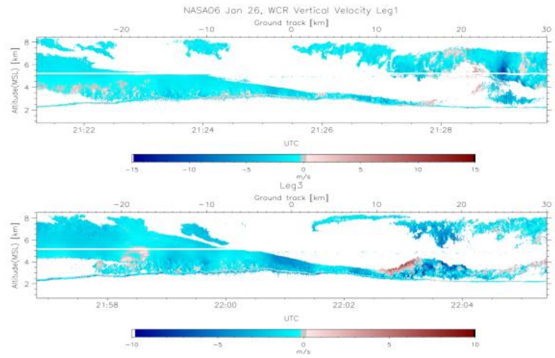

Fig. 5: Vertical Doppler velocity from the first and third passes on Jan. 26. The scale varies from 15 m s^{-1} down (dark blues) to 15 m s^{-1} up (dark red). The scale at the top of each plot is the distance from the GLEES research station, just below the summit of Medicine Bow Peak. The white line passing through the center of each plot is the dead zone of the radar at flight level.

On the first pass, centered at 21:25 UTC, there is a strong downdraft of 9 m s^{-1} measured by both the UWKA and the WCR at around 25 km from the GLEES research station. The King Air measured a peak updraft of 12 m s^{-1} upwind of this feature that is not seen by the WCR because the radar signal was too weak. The returns from the WCR below flight level are also weak.

The third pass was flown about 35 minutes after the first one. By this time (bottom panel of Fig. 5) a low level wave can be seen with the peak downdraft at 18 km. This is upwind of the location during the first pass. The radar returns are also stronger. This is probably due to the winds being strong enough to carry blowing snow. Using the data from the two downward beams, a dual-Doppler synthesis of this wave was done. The technique is described by Leon et al. (2006) and Damiani and Haimov (2006). The top panel of Fig. 6 shows the vertical wind speed. The bottom panel shows the horizontal wind speed. Low level winds exceeding 35 m s^{-1} are observed feeding into the wave. Beyond the crest of the wave, small scale vortices of several hundred meters are observed indicating that this wave was breaking and generating turbulence.

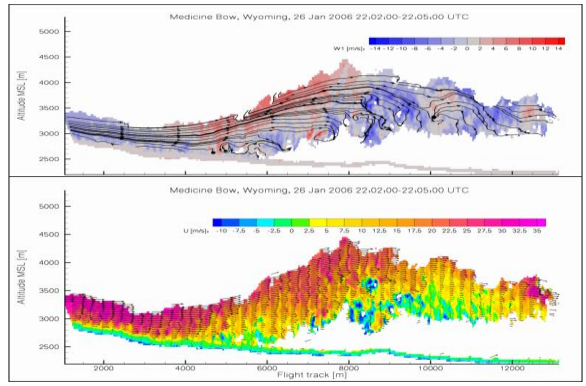

Fig. 6: Results of the dual-Doppler synthesis for the wave identified during the third pass. The top panel shows the vertical wind speeds and the streamlines. The bottom panel shows the component of the horizontal wind in the plane of the flight track and the wind vectors.

4. February 5, 2006

On February 5, 2006 a flight was scheduled to capture a rapidly moving snow band propagating across Wyoming. Fig. 7 shows the 700 hPa NAM analysis from 12 UTC on this day. As on the Jan. 26 case, a trough had passed through the area prior to the flight and a weak approaching short wave created clouds over the mountains.

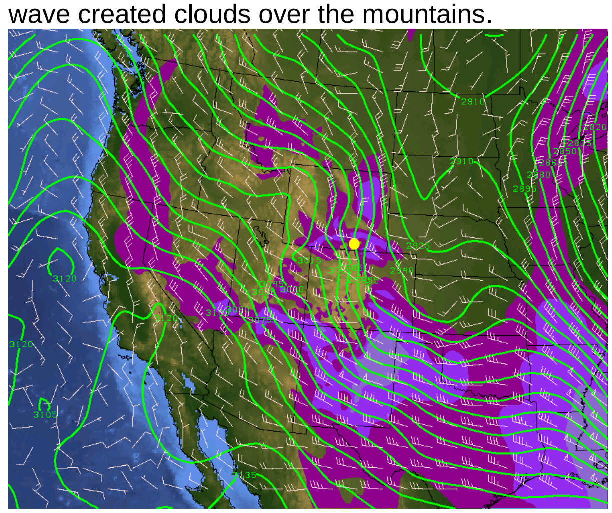

Fig. 7: 700 hPa map for 12 UTC 05 Feb. The heights are contoured in green with an interval of 15 m. Regions with wind speeds above 15 m s^{-1} are shaded with violet hues. The shading interval is 5 m s^{-1}. The flight location is indicated by the yellow dot near the center of the image.

On this day the wave remained fairly steady for duration of the flight. Four passes were flown through the wave. One of the flight tracks is shown in Fig. 8. The winds were more northerly on this day and the southeast end of the flight track extends over Sheep Mountain. A wave pattern can be seen in the Centennial Valley, which lies between Centennial and Sheep Mountain. Updrafts and downdrafts of 4 m s^{-1} were measured at the flight level of 4200 meters.

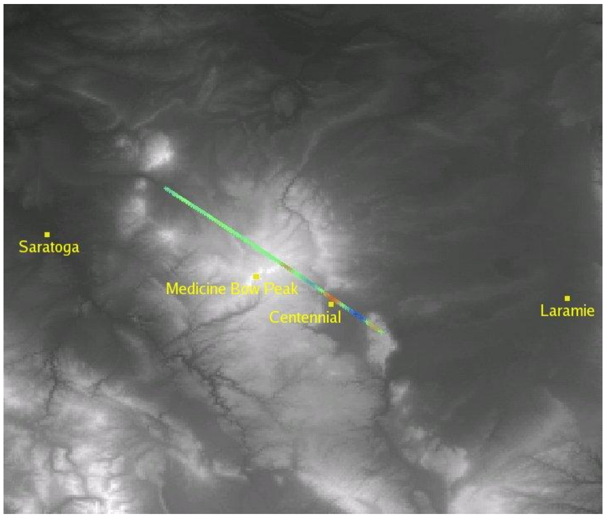

Fig. 8: Flight track for 1443-1451 UTC on Feb 5, 2006. The gray image shows the altitude of the underlying topography. The colors indicate the vertical wind speed measured by the aircraft with the scale shown at the top of the figure.

A sounding taken near Saratoga shows an inversion capped at 720 hPa. Another stable layer exists near mountain top between 690 and 660 hPa. The winds are strongest at low levels peaking at 19 m s^{-1}. The winds near the top of this sounding become northerly. The Froude number estimated for this sounding is 1.05, which would indicate a strong possibility of waves, but the likelihood of breaking waves is less.

The single-Doppler analysis of the four passes is presented in Fig. 10. There are two waves evident with a wavelength of 12 km. The magnitude of the vertical wind speeds remain less than 10 m s^{-1}. The flow appears to remain laminar except for turbulence generated near the ground. During the hour that these observations were made, there is little change in these features.

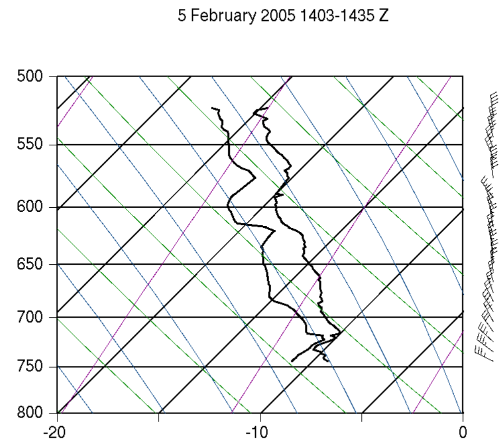

Fig. 9: Aircraft sounding taken between 1403-1435 UTC on Feb 5, 2006.

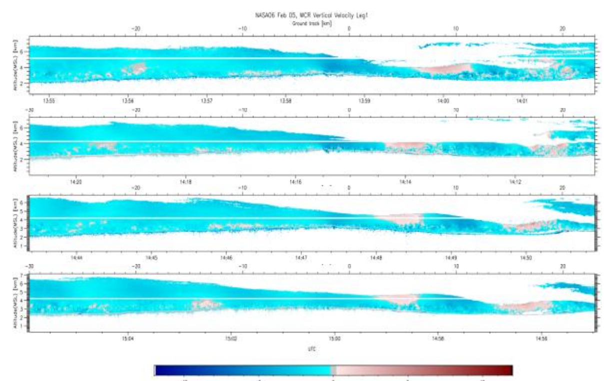

Fig. 10: Vertical Doppler velocity from Feb 5.

5. Acknowledgments

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6. References

Damiani, R. S., S. Haimov, 2006: A high resolution technique for fixed multiantenna airborne radar. *IEEE Trans. Geoscience and Remote Sensing,* 44, 3475-3489.

French, J. R., S. Haimov, L. Oolman, V. Grubisic, and D. Leon, 2008: Airborne radar observations of breaking waves/rotors in the lee of the Medicine

Bow Mountains in SE Wyoming, USA. *Preprint 13th Conf. Mtn. Meteorol.,* Am. Meteorol. Soc., Boston, MA.

Leon, D., G. Vali, and M. Lothon, 2006: Dual-Doppler analysis in a single plane from an airborne platform. *J. Atmos. Ocean. Tech.,* **23**, 3-22.