Wind Flow Reversal around the Black Hills of South Dakota

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AWOC Winter IC4.3 Microclimate Exercise

Overview: The Black Hills have several effects on western South Dakota's weather, such as higher snowfall in the northern hills due to the upsloping northwesterly winds, and warmer temperatures in the eastern foothills from downsloping westerly winds. Under certain conditions, the Black Hills can cause wind flow reversal on the lee side: areas of eastern Wyoming and the South Dakota plains will have westerly winds, while areas in the lee of the Black Hills will have light easterly winds. One condition necessary for this to occur is weak low-level winds. Another ingredient is a stable atmosphere, further preventing winds from moving over the Black Hills. Therefore, with weak winds and a stable atmosphere, Froude numbers of less than one are expected in these situations. Winds are forced to move around the hills rather than over, and they subsequently wrap around the northern and southern hills, turning easterly.

Topography: The Black Hills are located mainly in western South Dakota, with the northwestern portion in eastern Wyoming. Rapid City sits at the lee of the Hills, with an elevation around 3000 feet. Climbing steeply from Rapid City, the Black Hills reach an elevation around 7000 ft. Areas to the west of the Black Hills are of higher elevation (4000 to 5000 ft) than those east of the Black Hills (2000-3000 ft); however, the Black Hills are tall enough compared to the west to have an effect on the westerly flow over or around the hills.

Example Case: December 6, 2011

The northern plains were under an upper-level ridge, providing stable atmospheric conditions. Stability is shown in the 12 UTC sounding from Rapid City (KUNR), with temperatures generally increasing with height up to 600 mb (Fig. 1). The wind profile shows weak low-level westerly winds, with stronger northerly winds aloft.

Figure 2 displays the high resolution topographic image of KUNR's county warning area with the 18 UTC surface observations overlaid. Over much of the area, winds have a westerly component. However, winds in the Rapid City area are easterly. It has been noted that this phenomenon usually occurs late morning through midday, when winds have picked up enough for a noticeable effect, yet the atmosphere hasn't mixed out completely and conditions are still stable.

A local program at KUNR uses the North American Model (NAM) every six hours to predict several weather variables and calculate the Froude number. Figure 3 shows the 18 UTC forecast for December 6th at Rapid City. The Froude number at 18 UTC was 0.25, which is much less than one, and would be expected for a scenario that causes winds to flow around a barrier and reverse direction. As the atmosphere mixed in the afternoon and evening, winds in Rapid City were forecast to increase and become westerly. The increase in wind speed would increase the Froude number, ending the wind direction reversal.

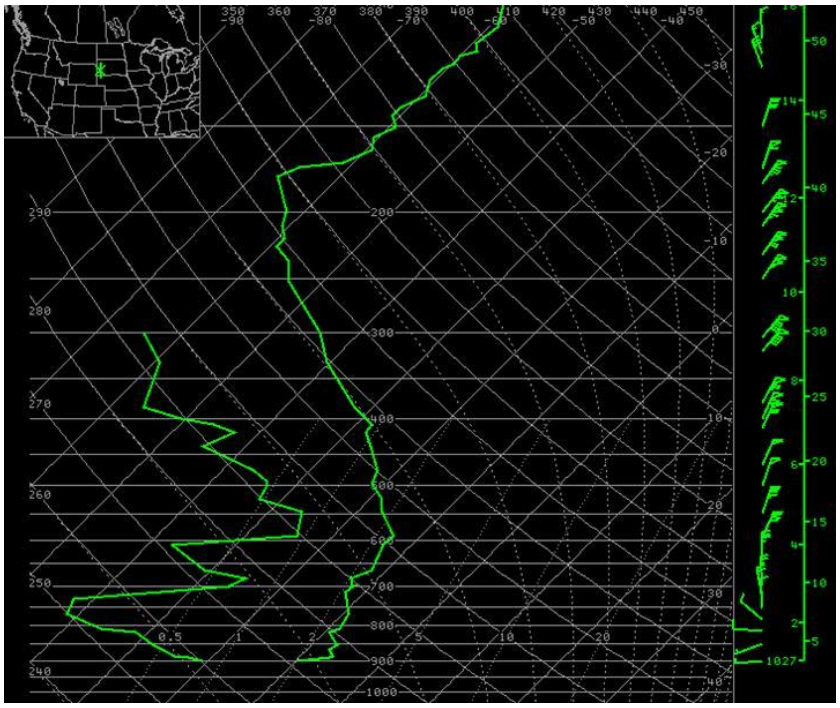

Fig. 1. 12 UTC sounding from KUNR showing stability and light westerly winds in the lower levels.

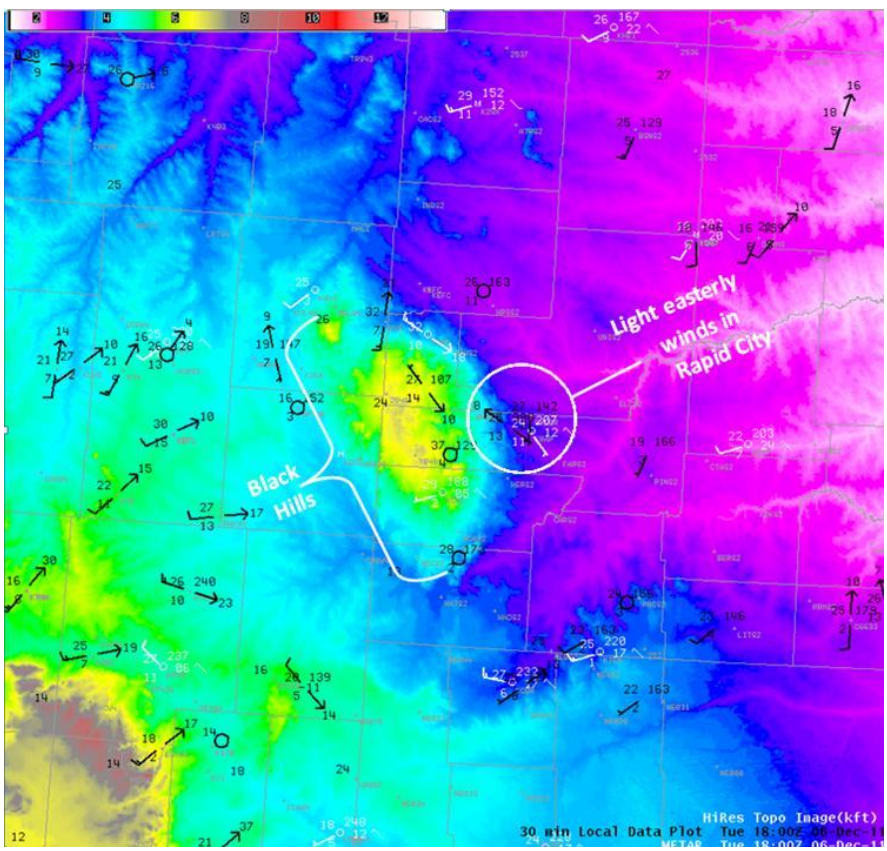

Fig. 2. High-resolution topographic image of Rapid City's warning area with 18 UTC surface observations.

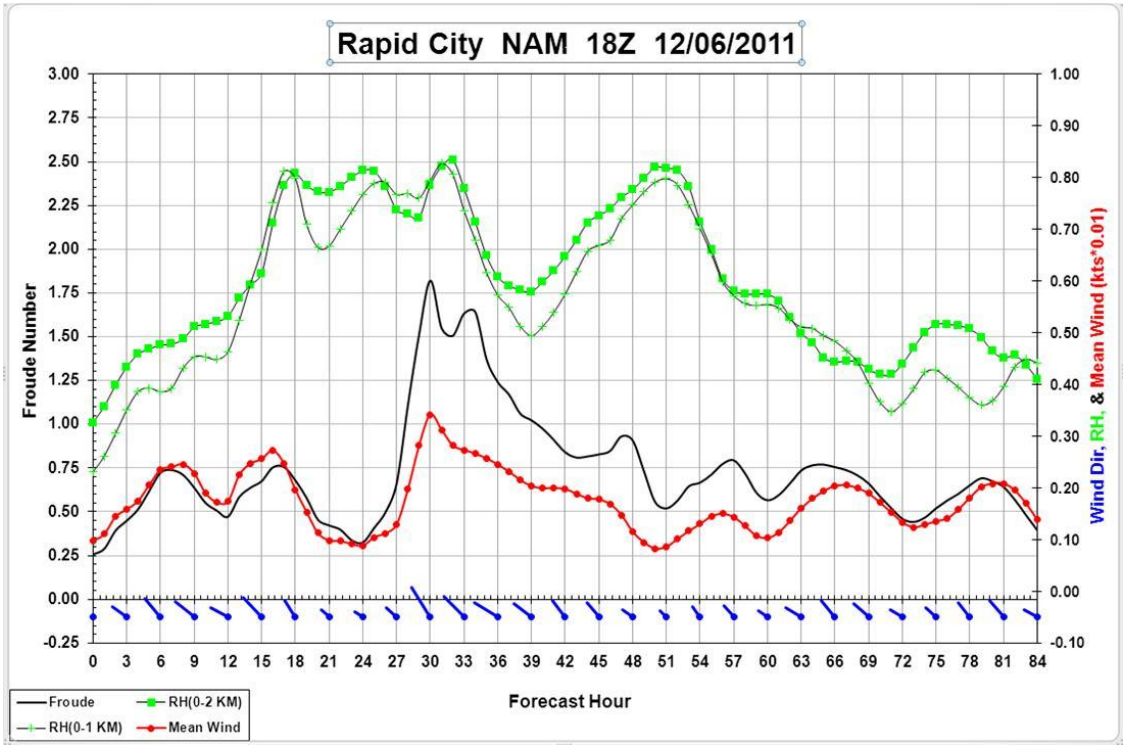

Fig. 3. 18 UTC NAM forecast of several weather variables and the calculated Froude number from a local program at KUNR.