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# CASE STUDY OF A PERSISTENT COLD POOL IN THE HELENA VALLEY

**Jeff Johnson - WFO Great Falls, MT**

*[Note: All figures appear only on the web page at http://www.wrh.noaa.gov/ under Technical Attachments]*

## Introduction

Many intermountain basins and valleys in the western U.S. experience cold pools, especially during the winter months. These cold pools can either be diurnal in nature, forming during the overnight hours before scouring out with daytime heating, or persistent, sometimes lasting for many days at a time. Diurnal cold pools typically form in basins and valleys on a clear night, when cold air flows down the slopes of surrounding higher terrain. Daytime heating is usually sufficient to break up this stable layer. Persistent cold pools are not quite as common, and form primarily during the winter months when the lack of sufficient daytime heating cannot break the inversion. Once these persistent cold pools form, it usually takes a mechanism to end the episode, such as a frontal passage, cold air advection aloft, turbulent erosion at the top of the cold pool, or surface heating from below (Bian et al. 2000).

Forecasting the evolution and decay of cold pools remains a challenge, as the physical mechanisms involved in their formation and dissipation have received little study (Whiteman et al. 2000). Additionally, the current resolution of numerical weather models is often insufficient to provide skillful guidance. Since persistent cold pools are often accompanied by periods of low clouds and fog, an extreme safety hazard is posed, especially to aviation and other travel interests.

This study discusses the evolution and eventual decay of a persistent cold pool that formed in the Helena Valley in late December 1999. While both the NGM and AVN MOS guidance proved ineffective in their temperature forecasts (averaging 11-16°C (20-30°F) too warm for high temperatures), it will be shown that the use of synoptic model guidance, a previous case study conducted for the Helena Valley, and the construction of pseudo-adiabatic charts using surrounding observation sites could have helped in forecasting this event.

## Site Location and Climatology

Helena, Montana is located on the south side of an intermountain valley, bounded on the south by the Elkhorn Mountains, on the west by the Rocky Mountains, and on the north and east by the Big Belt Mountains (Fig. 1). The valley is about 55 km (35 nm) long from west to east, and 40 km (25 nm) wide from north to south. The average height of the surrounding mountains rise approximately 915 m (3000 feet) above the valley floor.

During the winter months, diurnal cold pools are quite common as nights are long. These cold pools are usually shallow and break up with daytime heating. Persistent cold pools are not quite as common; however, when accompanied by low clouds and fog, these episodes can paralyze many activities in the valley for days.

## Synoptic Pattern

On December 18, 1999, an upper-level trough rapidly deepened over the northern Rockies, sending an Arctic air mass southward across Montana that night, penetrating the Helena Valley. Next, a strong upper-level ridge began to build over the Pacific Northwest, with a maritime polar surface high eroding the colder Arctic air, beginning on the 20th. Snow fell in the valley between the 19th and 21st, with total amounts generally less than 5 cm (2 inches). Afternoon temperatures on the 20th through 22nd rose above the freezing mark, allowing for partial melting of the snow cover. A mid-level overcast cloud deck remained intact across the valley into the morning of the 22nd, after which the sky cleared.

By the 23rd, the 500 mb ridge along the Pacific Northwest coast had strengthened considerably and extended into the northern Rockies, with only light northerly flow aloft over southwest Montana (Fig. 2). A 1044 mb surface high was centered along the Idaho/Montana border, with strong chinook winds developing along the east slopes of the Rockies. This overall pattern persisted into the 28th, with 500 mb heights continuing to rise over southwest Montana (Fig. 3).

The upper-level ridge rapidly began to break down on the 28th, with strong northwest flow developing aloft over the northern Rockies. The 500 mb height over southwest Montana fell 18 dm between 12Z on the 28th and 12Z on the 29th (Fig. 4). The surface high had retreated into eastern Oregon by the morning of the 29th and weakened to 1030 mb.

## Cold Pool of 23-29 December 1999

A diurnal cold pool developed in the Helena Valley during the nighttime hours of December 23. The temperature at the Helena ASOS (1188 m/3896 feet) was approximately 5°C (9°F) colder than at Rocker Peak (2410 m/7901 feet), the highest reporting station in the area (Fig. 5). Additionally, visibilities of 400 m (1/4 mile) and vertical visibilities of less than 30 m (100 feet) formed over night. Instrument Flight Rules (IFR) were in effect at the Helena airport until 1400 LST that afternoon. The inversion did not break that afternoon, which resulted in a transition from the diurnal cold pool to a persistent cold pool (Fig. 6).

The persistent cold pool strengthened each day, with temperatures in the valley decreasing each day. Temperatures at Rocker Peak were approximately 11-16°C (20-30°F) warmer than temperatures at the Helena ASOS during most of this period (Fig. 7). Low Instrument Flight Rules (LIFR) were observed at the Helena airport each morning and early afternoon through the 28th.

The persistent cold pool in the Helena Valley finally eroded the afternoon of the 29th. Skies remained clear and visibilities had actually increased during the early morning hours of the 29th. By that afternoon, the temperature at the airport climbed to 7°C (45°F), which was 12°C (22°F) warmer than the previous afternoon (Fig. 8).

## Discussion

A. Cold Pool Formation

There were features present to hint that a diurnal cold pool and LIFR conditions would develop during the early morning hours of December 23rd. As previously mentioned, the Helena Valley had received snow the previous few days, with some of the snow melting as afternoon temperatures had climbed above freezing. This helped add moisture to the air mass. Additionally, the mid-level overcast sky that was present had cleared out on the 22nd. The temperature-dewpoint spread remained low and the winds were light. MOS data predicted a minimal temperature-dewpoint spread overnight, along with light winds and clear skies.

These conditions were tested, using a rather in-depth study that had previously been conducted on radiation fog formation in the Helena Valley (see Kieltyka, 1981). This study used five years of data that included 43 cases of radiation fog episodes (winter months only). Rules of thumb were developed as follows:

1) Dewpoint depression of 16°F (9°C) or less at 21Z the previous afternoon
2) Snow cover and/or recent precipitation
3) Clear skies and light winds up to 700 mb

Some interesting notes in Kieltyka's study were that 86 percent of the fog cases had a dewpoint depression of 16°F (9°C) or less at 21Z the previous afternoon, and in 70 percent of the cases, IFR or lower conditions developed.

On December 23, 1999, all the conditions from the study were met. In addition, the synoptic pattern (as previously discussed) showed a strengthening upper-level ridge over the northern Rockies, with a building surface high near the Idaho/Montana border. Both the NGM and ETA models forecast these features well in advance.

B. Cold Pool Continuation

As previously mentioned, once a cold pool is in place, it takes some sort of mechanism to replace the air mass. The models were consistent in forecasting both strengthening high pressure and warming temperatures aloft. Winds aloft were to remain light northerly, and there were no frontal systems or cold air advection in sight. Would turbulent erosion or surface heating be sufficient to scour out the cold pool?

A theoretical model was developed by researchers at the Pacific Northwest National Laboratory in Washington to investigate the turbulent erosion mechanism in the break up of cold air pools (see Bian et al. 2000). This model was applied to cold pools with different atmospheric stratification and topographical cross sections. The researchers concluded that turbulent erosion alone was unlikely to erode a persistent cold pool.

To determine whether surface heating would be able to destroy the cold pool, several factors were considered. First, low sun angles in the winter and blocking from the surrounding mountains only allow for roughly five hours of daytime heating in the Helena Valley. Since LIFR conditions were present on the morning of December 23, surface heating would be delayed. An inversion of approximately 5°C (9°F) from the Helena ASOS to over 1200 m higher (Rocker Peak) was present. Another aspect that should be considered is that the average high temperature in Helena during the latter part of December is -2°C to 0°C (28-32°F), and the temperature in December had not climbed above 15°C (59°F) in the last ten years. Since warming aloft was forecast, it likely would have taken an enormous amount of surface heating to completely scour out the cold pool, which climatologically was unlikely.

Numerical guidance suggested a strengthening inversion for the next several days. Without any mechanism to scour out the cold pool, it would likely continue in the Helena Valley.

C. Cold Pool Destruction

The 00Z 28 December model runs were accurate in rapidly breaking down the upper-level ridge and bringing a return to northwest flow in the 24 to 48 hour forecast period (Figs. 9-10). The 500 mb heights over southwest Montana were forecast to lower from 582 dm at 00Z on the 29th to 564 dm 24 hours later. In response, the surface high was progged to weaken and retrograde west.

Although the NGM MOS did very poorly in temperature forecasts, it did indicate that winds would increase on the afternoon of the 29th, between 5 and 8 m/s (10-15 kts) from a westerly direction. This wind increase in the MOS was seen first with the 12Z 27 December run, and remained consistent in subsequent model runs.
Atop Rocker Peak, the morning low temperature on the 29th was 7°C (13°F) cooler than the previous day (Figs. 11-12). At Nevada Ridge (2113 m/6928 feet), the temperature was 5°C (9°F) cooler. The winds aloft had become northwest and strengthened. The winds at McDonald Pass increased from 5 m/s (10 kts) the evening of the 27th to 15 m/s (29 kts) the morning of the 29th. This cold air advection finally eroded the persistent cold pool that afternoon, as west winds reached 11 m/s (21 kts) and the temperature rose to 7°C (45°F) at the Helena airport (Fig. 13).

## Conclusion

A persistent cold pool affected the Helena Valley for nearly a week in late December 1999. The use of both the NGM and AVN MOS guidance proved highly ineffective in their temperature forecasts for the onset, continuation, and eventual destruction of this persistent cold pool. However, it was shown that using a previous study for fog formation in the Helena Valley, the construction of pseudo-adiabatic charts using surrounding observation sites at different elevations, the use of model synoptic forecasts, and some forecast parameters in the NGM MOS guidance could have aided the forecaster during this event.


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