XX.Y OPERATIONAL DETECTION OF AN OROGRAPHIC HEAVY SNOWFALL EVENT IN EASTERN IDAHO

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1. INTRODUCTION

The 26 November 2005 snowstorm was a significant snowfall event in eastern Idaho. Trained weather spotters and local media outlets reported snowfall amounts of 25 to 38 cm (10 to 15 inches) east and south of the city of Pocatello. Lighter snowfall amounts 3 to 10 cm (1 to 4 inches) occurred near the Pocatello Regional Airport. This observational study describes the evolution of the 26 November 2005 event using state-of-the-art Geographic Information Systems (GIS) scenes of temperature, moisture, wind, radar, and precipitation data sets. This manuscript will explore the mesoscale aspects of the event, particularly, orographic mechanisms contributing to significant localized snow accumulations in the Lower Snake Plain near Pocatello and the Pocatello Range.

2. TOPOGRAPHY

The domain of eastern Idaho is illustrated in Figs. 1a and 1b. The major feature is the Snake River Plain, ~250 km long from the Magic Valley to the Upper Snake Plain and ~100 km wide. A fishhook terrain depression (z ~ 1.5 km contour) is superimposed on the plain. The Central Mountains, Eastern Highlands, and Southern Highlands bound the plain and vary in elevation from z ~ 2.1 to 3.8 km. Three tributary valleys, oriented from northwest to southeast and downstream of the Central Mountains, empty onto the Arco Desert and Upper Snake Plain. Regional topographic variability leads to differences in atmospheric pressure, temperature, wind, cloudiness, and precipitation (Wendell 1972; Cate 1977; Andretta and Hazen 1998; Andretta 1999; Carter and Keislar 2000; Andretta 2002; Stewart et al. 2002; Andretta and Wojcik 2003; Andretta 2005; Andretta 2006). The region of study is in the Lower Snake Plain from Aberdeen (z ~ 1.34 km) to between Pocatello (z ~ 1.36 km) and Downey (z ~ 1.48 km).

3. DATA SOURCES

This study utilizes National Oceanic and Atmospheric Administration (NOAA) geostationary (GOES 10) infrared (4 km resolution) imagery (Band 4: 10.2 to 11.2 µm) for detection of low-level clouds. The 1200 UTC 26 November 2005 maps at mandatory levels of 250 mb, 300 mb, 500 mb, 700 mb, 850 mb, and surface were from the NOAA SPC archives. The Forecast Systems Laboratory (FSL) disseminates Aeronautical Radio, Inc. (ARINC) Communications, Addressing, and Reporting System (ACARS) meteorological data from commercial aircraft to users. This paper uses ACARS temperature and wind profiles across southern Idaho based on take-off from (1533 UTC) and landing to (2012 UTC) the Boise Air Terminal (KBOI), west of the domain (Fig. 1a).

The University of Utah collects many meteorological observations, *Mesowest*, across the western United States (Horel et al. 2002). This study uses 114 mesonet sites in the domain (Fig. 1a). The potential temperature, wet bulb temperature, and relative humidity data sets are calculated using an Inverse Distance Weight (IDW) scheme from *ESRI ArcGIS Spatial Analyst* mapping software.

This study uses the single Weather Surveillance Radar 1988 Doppler (WSR-88D) Level II and Level III

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products from the National Climatic Data Center (NCDC) online repository. Data originate from the WSR-88D KSFX Radar Data Acquisition (RDA) (dish symbol: Fig. 1b) located ~10 km northeast of Aberdeen. The temporal frequency of radar data is every 5 minutes (Volume Coverage Pattern (VCP) 11) with a reflectivity to rainfall (Z-R) convective relationship ($Z = 300 \cdot R^{1.4}$). Data sets in this paper include Vertical Wind Profiles (VWP), Base Reflectivity (BR) and Base Velocity (BV) at 0.5^o and 1.5^o, and Low-Level (LL) Composite Reflectivity. The Digital Precipitation Array (DPA), a blend of radar bin and rain gauge data, are collected in hourly grids. During convective events like this study, radar-estimated precipitation approximates gauge-measured values (Klazura et al. 1999). An (hourly) snowfall grid is extracted from the DPA grid and a liquid water to snowmelt conversion table (NOAA 1997).

4. UPPER AIR ANALYSIS: MANDATORY LEVEL OBSERVATIONS

The NOAA SPC objective analysis (valid at 1200 UTC 26 November 2005) is illustrated in Fig. 2. The 250 mb (Fig. 2a) and 300 mb (Fig. 2b) maps show a negatively-tilted open wave trough over Washington, Oregon, and Idaho with a powerful northwest 130 to 200 knot jet on the backside of the trough. Winds on the front side were much lighter (30 to 50 knots), suggesting a digging system. A 300 mb local temperature *maximum* (-44 ^{o}C) occurred over northern Utah indicating a tropopause depression over northern Utah. There was a local *minimum* in the 300 mb divergence fields (-3 to -5 x 10^{-3} s^{-1}) over southern Idaho, suggesting a vertical circulation with ascent below this level. Fig. 2c displays the 500 mb pattern with moist onshore flow and cold air advection over Idaho. At 700 mb in Fig. 2d, there was a neutrally-tilted broad open wave trough over eastern Idaho. The 850 mb trough (Fig. 2e) was aligned across western Wyoming and eastern Utah with temperatures between -2 and 2 ^{o}C across most of Idaho. The surface map (Fig. 2f) indicated a surface front meridionally oriented across western Wyoming and trailing back into central Utah. A surface low (~1003.6 mb) was situated over west-central Wyoming. These synoptic signatures resembled the Type COLD heavy snow synoptic pattern Fig. 3a (Andretta and Wojcik 2003) and the Type A SPCZ synoptic pattern Fig. 3b (Andretta 2002).

5. MESOSCALE ANALYSIS: SATELLITE, SURFACE, AND RADAR OBSERVATIONS

5.1 *Satellite*

The NOAA GOES 10 infrared satellite imagery animation (Fig. 4) shows the cloud field evolution associated with the SPCZ. Following the passage of the cold front (1145 and 1445 UTC), there was a region of post-frontal clearing and subsidence (black area) in the Snake River Plain (brown oval). By 1745 UTC, cloud bands associated with the low-level convergence zone and precipitation developed in the Upper Snake Plain. From 2045 to 2323 UTC, the zone and cloud cover spread slowly into the lower plain and dissipated by early evening.

5.2 *Mesowest*

The *Mesowest* observational animations are shown for potential temperature, wet bulb temperature, and relative humidity in Figs. 5a, 5b, and 5c, respectively. In Fig. 5a, the colder isentropes were initially centered in the Magic Valley and Lower Snake River Plain (284 to 287 ^{o}K) but spread eastward during the event. In particular, from 1500 to 2100 UTC, note the large potential temperature gradients along a line from American Falls to Blackfoot. A warm anomaly was evident just north of Chubbuck, just downwind of the American Falls Reservoir, where water temperatures were 3.8 to 4.1 ^{o}C, or about 5 to 6 ^{o}C warmer than the air blowing across the lake. There were local maxima in the wet bulb temperature fields (Fig. 5b) following the Snake Plain near Chubbuck and Rigby. As Fig. 5c shows, during the afternoon, dry air (RH < 70 %)

advected from the Central Mountains to the Upper Snake Plain along the back edge of the SPCZ.

5.3 *WSR-88D KSFX Wind Profiler*

The KSFX WSR-88D Vertical Wind Profile (VAD) from 1140 to 1230 UTC (Fig. 6) indicated a disorganized and sheared flow from the surface to 24K feet MSL. The profiler between 1440 and 1529 UTC showed a more organized flow with southwest flow near the surface veering to northwest flow at 12K feet and backing to west flow up to 17K feet MSL. From 1740 to 1830 UTC, the profiler indicated organized flow with southwest flow near the surface veering to northwest flow at 13K feet and backing to westerly flow up to 18K feet MSL. The VAD from 2039 to 2129 UTC indicated organized flow with southwest flow near the surface veering to northwest flow at 20K feet MSL. The upper-level flow decreased in speed from 20 knots to 10 knots versus earlier time series. From 2338 to 0029 UTC, there was sheared flow with southwest flow near the surface veering to northwest flow at 15K feet (warm air advection) and backing to west flow to 20K feet MSL (cold air advection). These temporal trends suggested a destabilizing lower troposphere.

5.4 *WSR-88D KSFX Reflectivity and Velocity*

At 1200 UTC, the KSFX 88D Base Velocity charts at 0.5^o (Fig. 7a) and 1.5^o (Fig. 7b) indicated northwest flow across the Arco Desert and Upper Snake Plain. The *Mesowest* data showed the low-level jet (20 to 30 knots) oriented zonally in the Magic Valley. The KSFX 88D Base Reflectivity charts at 0.5^o (Fig. 8a) and 1.5^o (Fig. 8b) depicted scattered to numerous light to moderate snow showers (15 to 30 dBZ) across the Upper Snake Plain. A similar snow reflectivity pattern is in the KSFX 88D Low-Level Composite Reflectivity chart (Fig. 9). At 1500 UTC, the KSFX 88D Base Reflectivity charts depicted an expanding region of light snow (15 to 25 dBZ) across the Upper Snake Plain. A convergence zone formed across the Snake Plain, with multiple snowbands *parallel* to the Central Mountain tributary valleys, *parallel* to the low-level wind in the VAD profiles, and *perpendicular* to the radial velocity zero isodop (Carpenter 1993; Niziol et al. 1995). These bands were L (length) ~ 50 to 70 km long and W (width) ~ 5 to 10 km wide and were aligned parallel to the 700 mb northwesterly steering flow.

In the late morning (1800 UTC), the KSFX 88D Base Velocity charts at 0.5^o (Fig. 7a) and 1.5^o (Fig. 7b) displayed channeled northwest flow across the Upper Snake Plain with a serpentine-shaped zero isodop (grey region) from Rexburg to Atomic City to just south of the KSFX RDA tower (dish symbol), forming low-level wind confluence (Γ-shaped symbol) (Brown and Wood 1987). The surface mesonet winds superimposed on the KSFX 88D Base Reflectivity at 0.5^o (Fig. 8a) and 1.5^o (Fig. 8b) and Low-Level Composite Reflectivity (Fig. 9). confirmed these Doppler radial winds. The reflectivity charts portrayed several bands of light to moderate snow showers (15 to 25 dBZ) aligned perpendicular to the eastern foothills of the Snake Plain, from Swan Valley to Mud Lake and near Arco (Andretta and Hazen 1998; Andretta 2002). Snowbands appeared more fibrous and curvilinear versus earlier times, on the order of L (length) ~ 60 to 80 km x W (width) ~ 5 to 10 km. By 2100 UTC, the *Mesowest* data showed channeled northwest flow (20 to 25 knots) at the exit regions of the tributary valleys and a westerly low-level jet (20 to 30 knots) in the Magic Valley. This valley jet aided in strong upslope flow and enhanced vertical motions along the western foothills of the Pocatello Range (east of Pocatello). The numerous moderate to heavy snow showers (25 to 40 dBZ) which were earlier south of the Arco Desert had coalesced into a large solitary band along a line from Minidoka to American Falls to Pocatello. Pocatello Regional Airport (KPIH) reported blizzard conditions between 1720 and 2305 UTC with moderate to heavy snow, winds over 25 knots, and visibilities below 0.5 statute miles. A local cyclonic gyre (yellow "X" symbols: reflectivity charts) developed along the back edge of the large snowband. This band remained nearly stationary over the Pocatello area for several hours producing light to moderate snow, a prolonged period of snow accumulations, and marked the peak intensity of the SPCZ. As the reflectivity animations indicate, the highest radar returns (30 to 45 dBZ) were situated from Aberdeen to Pocatello.

By 2330 UTC, the KSFX 88D Base Velocity charts at 0.5^{o} (Fig. 7a) and 1.5^{o} (Fig. 7b) revealed confluent flow with a diffuse zero isodop (grey region) extending from Rexburg to Pocatello. The KSFX 88D Base Reflectivity maps at 0.5^{o} (Fig. 8a) and 1.5^{o} (Fig. 8b) depicted an echo-free region in the Snake Plain with scattered to numerous light snow showers (15 to 30 dBZ) along the eastern walls of the Upper and Lower Snake Plains. However, the KSFX 88D Low-Level Composite Reflectivity (Fig. 9) indicated a decrease in coverage and intensity of the echoes, especially over the Upper Snake Plain. As drier air intruded further into the Upper and Lower Snake Plains during the late evening, the SPCZ and orographic upslope flow weakened and eventually dissipated over the Southern Highlands. The event ended at 0400 UTC on 27 November 2005.

5.5 *WSR-88D KSFX Precipitation and Derived Snowfall*

The KSFX 88D Digital Precipitation Array (Fig. 10) animation shows the evolution of the hourly precipitation fields during the snowfall event. Likewise, the derived Snow Amount animation is illustrated in Fig. 11. The precipitation and snowfall bands closely followed the spatial evolution of the radar reflectivity fields. One salient feature (at 2100 UTC) was the liquid precipitation 0.23 to 0.30 cm (0.09 to 0.12 inches) and snowfall 2.3 to 3.0 cm (0.9 to 1.2 inches) maxima near the American Falls Reservoir. These maxima were spatially correlated with large temperature gradients from American Falls to Blackfoot (see Section 5b).

5.6 *ACARS Soundings*

The ACARS soundings for Boise Air Terminal (KBOI) (ascent - 1533 UTC) and (descent - 2012 UTC) are displayed in Figs. 12a and 12b. The Boise sounding at 1533 UTC indicated the low-level temperature inversion with a moist adiabatic lapse rate from 850 to 525 mb. Estimated low-level dewpoint depressions were small implying a region of CAPE and subsequent convection between 800 and 600 mb. Fig. 12a indicates a deep layer of post-frontal northwest flow from 900 to 500 mb. The Boise sounding at 2012 UTC revealed a dry adiabatic lapse rate between 875 and 750 mb. Fig. 12b shows a vertical shear zone with 700 mb north (330 to 350 ^{o}) flow and northwest (300 to 325 ^{o}) flow below this level, possibly an indicator of the boundary layer wind convergence zone. The low-level jet (25 to 35 knots) was clearly evident from 850 to 700 mb in both soundings. The temperature profiles revealed a well-defined cold (-12 to -16 ^{o}C) layer between 750 and 650 mb, necessary for the dendritic growth of ice crystals and large snowflakes (Stewart 1985; Pobanz et al. 1994; Baumgardt 1999).

6. CONCLUSIONS

This study documented a significant snowfall event in eastern Idaho that occurred on 26 November 2005. The region of heavy snowfall was localized in the Lower Snake River Plain with amounts varying from between 3 and 10 cm (1 and 4 inches) near the Pocatello Regional Airport to between 25 and 38 cm (10 and 15 inches) east and south of the city of Pocatello. This snowfall event was driven by two principal forcing mechanisms consisting of a mobile zone of orographically-induced boundary layer convergence in the Snake River Plain and a zonally oriented low-level jet in the Magic Valley. The WSR-88D and *Mesowest* observations were crucial in analyzing the formation, persistence, and dissipation of several snowbands associated with the SPCZ. Over a period of about 12 hours, these SPCZ snowbands formed in a moist neutral and unstable lower troposphere, aligned themselves roughly parallel with the 700 mb northwesterly steering flow, and moved slowly down the Snake River Plain.

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