Rare Freezing Rain Event in the Little Colorado River Valley on 25 January 2006

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1. Introduction

Freezing precipitation events are very rare across northern Arizona. There are several reasons for this. First, there is normally not a source of cold air readily available. Second, the sun angle never gets too low due to the low latitude of Arizona and the relatively higher sun angle. Therefore, the boundary layer will inevitably warm quickly during the morning and early afternoon hours. Finally, strong pre-frontal winds often scour out the boundary layer over this topographically diverse terrain, thus not allowing for the temperature stratification conducive to freezing rain. That being said, one freezing rain event did occur during the morning hours of 25 January 2006. The impact of this storm was quite substantial; the freezing rain left a glaze of ice on various major roadways across the Little Colorado River Valley (hereafter LCRV). Portions of Interstate 40 near Holbrook, along with State Highways 61 and 77 were closed temporarily due to the ice. There were numerous vehicular accidents during the morning hours as people drove to work or began their travels, with several fatalities and injuries reported due to the weather.

This technical attachment will summarize the two known processes through which freezing precipitation can occur in section 3. In section 4, the synoptic environment from the morning of 25 January in the LCRV will be presented. Finally, using the available data, a description of why freezing rain occurred in the LCRV will be given in section 5.

2. Methods and Data

Model data and surface weather observations were archived and examined using the Weather Event Simulator (WES). Data related to the injuries and fatalities were obtained from news accounts appearing in newspapers and e-magazines. No hard references with the exact number of injuries and fatalities were available.

3. Two Freezing Precipitation Processes Summarized

There are two freezing precipitation processes that have been thoroughly researched. The first case, and the one most known, involves a freezing air mass at the surface with a melting layer aloft. As snow falls from the freezing layer above, it encounters this melting layer. Heat from this layer causes the snow to melt, thus producing either partially melted snowflakes or raindrops. These particles leave the melting layer and start falling through the second, surface-based freezing layer, where they either refreeze into solid particles or become supercooled liquid drops. These supercooled droplets, when they come into contact with the cold surface of the Earth, freeze on contact. There are a variety of synoptic situations where this particular process (called the “classic” case) can play out. Robbins and Cortinas (1998) not only explain many of these scenarios, but they also provide a history of the research done on this particular freezing precipitation process.

As research in the formation of freezing rain continued, it was found that roughly 30% of freezing precipitation events did not have a melting layer aloft. Basically, supercooled water droplets fell through a subfreezing atmosphere without freezing into a solid state. Huffman and Norman (1988) dubbed this new process the “supercooled warm rain process”, or SWRP. In their research, they concluded a majority of these events occurred when cloud top temperatures were between 0^{o}C and -10^{o}C, and when “there are too few ice nuclei available to create solid hydrometeors”.

4. Synoptic Environment on 25 January 2006

Figure 1 highlights the terrain features of northern Arizona along with the LCRV. The high terrain of central Arizona can act very much like a blocking mechanism during a northeast wind event keeping the cold air in the valleys, much the same way as cold air damming affects the eastern United States along the portions east of the Appalachian Mountains. The importance of this will be explained later in the technical attachment.

Shown in Figure 2 is a satellite/lightning/surface observations/model composite overlay valid at 0600 UTC 25 January 2006. A closed 500 hPa low was situated just west of northern Baja California, with a shortwave ridge east of Arizona. A diffluent region aloft was evident over northern Mexico and southeast Arizona, with significant moisture and cloudiness over this area. Lightning strikes, which are rare for the late January time frame, could be seen over northern Mexico due to convective activity. This underscores how unstable the air mass was in northern Mexico. In the northern portions of Arizona, skies were mostly clear during the early morning, as had been the case for the entire night (not shown).

At the surface (Figure 3), high pressure was centered over northwest Colorado at 0600 UTC, with low pressure over southwest Arizona. This setup was also prevalent during 24 January (not shown). Given the placement of the isobars, a fairly tight surface pressure gradient can be seen across northern Arizona. This type of surface pressure gradient results in a low-level northeasterly flow regime that advects cold air from the snow covered regions of Colorado into northern Arizona. This flow pattern helps to accentuate the already strong surface-based inversions seen in the LCRV from the previous day. Indeed, surface observations seen in Figure 2 showed subfreezing to near freezing temperatures across most of northern Arizona. The air mass was also quite dry over the region as surface dewpoints during this time were around -18^{o}C. Observations in western New Mexico and southeast Arizona were quite warm, with temperatures ranging from 7^{o}C to 14^{o}C. These warmer temperatures would eventually make their way northward.

At 0900 UTC, the satellite/ surface observations /lightning composite (Figure 4) suggests the 500 hPa closed low had moved slightly to the northeast. Convective activity had now spread north onto the Arizona/Mexico border, with cloud tops as cold as –53°C. Another area of clouds existed over extreme western New Mexico, with cloud top temperatures exceeding -50°C. However, no lightning strikes were being registered in this area at this time. Surface temperatures for the sites across northern Arizona were mainly at or below 0°C, with the exception of St Johns, where the temperature increased to 10°C. This temperature was significantly warmer than at 0600 UTC when the surface temperature was at -2°C. The wind had also increased to 16 knots, and the direction changed to the southeast. The surface dewpoint at St Johns increased from -17°C to -9°C in three hours as well. The warmer air at the surface that was seen 0600 UTC over southeast Arizona and southwest New Mexico had advected northward with the convective activity, although no precipitation was reported at St Johns during the last three hours.

A 1200 UTC satellite/lightning/surface observations/model composite shown in Figure 5 identifies a significant expansion and northward push of moisture from the 0900 UTC (Figure 4) time frame. RUC model surface dewpoints were 0°C to 4°C over southeast Arizona. Isolated lightning strikes could be seen over zone 18, corresponding to northern Gila County. It is quite rare for lightning to develop in the early morning hours over east-central Arizona during late January, which gives credence to how unstable the air mass was at this time. Moderate to strong 700 hPa flow at 35-knots, impinging upon the eastern Mogollon Rim and White Mountains, was enhancing the overall synoptic scale lift, thus aiding in the formation of thunderstorms. Figure 6 depicts the KFSX radar imagery at 1157 UTC with lightning plot and surface observation overlay. The image shows the area of convective activity beginning to move across the higher terrain of the Mogollon Rim and the White Mountains, however, precipitation had not yet been recorded on the ground at Show Low. It was noted the surface temperatures at Show Low and Winslow were -8°C and -6°C, respectively. Thus, the cold and dry air mass at the surface remained firmly entrenched over the LCRV at this time.

Surface observations for 1300 UTC (Figure 7) showed the surface temperature in Show Low had risen to 3°C, with high reflectivity returns and lightning strikes that occurred to the northwest of the city. Further north at the ASOS in Winslow, the surface temperature of -9°C continued to show the surface-based cold air mass had remained intact. Figure 8 highlights the northward expansion of the precipitation as of 1330 UTC. Light rain showers were being reported in the 1400 UTC observation at Show Low, while the temperature cooled slightly to 0°C. Although no surface observation data is available for Holbrook, radar reflectivities imply at least light precipitation was falling over the LCRV. Cloud top temperatures from the infrared satellite image valid at 1330 UTC (Figure 9) of -30°C to -40°C suggest ice crystal formation within these clouds. The composite reflectivity image in Figure 10 shows another area of precipitation moving over the high terrain and was about to move into the LCRV. Thunderstorm activity continued to be isolated after 1400 UTC over east-central Arizona as lift was very weak. Another image of composite reflectivity (Figure 11), valid at 1429 UTC, shows a continued northward progression of light scattered precipitation moving across east-central Arizona and into the LCRV. However, the area of precipitation that fell across the LCRV was enough to glaze area roadways with ice. Indeed, the Flagstaff office received its first report of freezing rain from local spotters right around 1425 UTC, although freezing rain likely was occurring prior to these reports.

5. LCRV freezing rain process explained

A cross-section of the terrain on the LCRV floor from Winslow to St Johns is given in Figure 12. The ASOS at St Johns sits at 5723 feet above sea level. As shown in the diagram, the LCRV gently slopes lower as one progresses west, with the ASOS at Winslow being 4886 feet above sea level (837 feet lower than St Johns).

The LCRV began the night under mostly clear skies with dewpoints around -18^{o}C and light winds. As a result, radiational cooling was maximized during the entire night, which further strengthened the surface-based cold air mass already in place. As mentioned earlier in this paper, the surface temperature at St Johns jumped to 10^{o}C at 0900 UTC, an increase from -2^{o}C at 0600 UTC. The rise in temperature occurred with a sudden increase in wind speed, while the direction changed to the southeast. Referring to Figure 4, cloud top temperatures in western New Mexico were noted to be colder than -50^{o}C, but no lightning strikes had been reported. It is possible convective activity was occurring in this area (although radar observations were nearly non-existent from this distance) and as a result, an undetected outflow boundary was likely produced from one of the convective cells. Figure 12 illustrates that since St Johns was closer to the outflow boundary, and also sits somewhat higher than the rest of the LCRV, the warm air and relatively strong winds from the outflow were the most likely contributors that caused the erosion of the cold surface air. This allowed for the rapid increase in St Johns' surface temperature. Presented in Figure 13 is a conceptual diagram of the outflow moving past St Johns and heading west towards Winslow. As this warm boundary continued west, the colder air at the surface would become deeper and more dense, thanks to the gently sloping terrain. At some point, the warm air would not have been able to erode the cold surface air, and at that time, would begin riding over it, much in the way warm air glides over cold air in a warm frontal process. Following this logic, this outflow boundary would have led to the formation of the melting layer aloft. Given the sparse nature of data across the LCRV, it is not known how far west and north this outflow traveled.

The other necessary ingredient, the snow which fell through the melting layer, arrived after 1300 UTC with the northward advance of the warm and moist air mass from southeast Arizona. This air mass was able to produce early morning thunderstorms as far north as east-central Arizona. These thunderstorms progressed northward and crossed over the Eastern Mogollon Rim and the White Mountains, eventually moving into the LCRV. As pointed out in Figure 9, the cloud top temperatures were less than -30^{o}C during the precipitation process over the LCRV, indicating that ice crystals were in great numbers in the uppermost sections of the clouds. These ice crystals, falling through the cloud, would form into snowflakes via the processes of aggregation and riming. Figure 14 shows a conceptual image of the light snow falling through the melting layer, and then through the surface-based cold layer, over the LCRV. Although the storms weakened considerably once they moved into the LCRV, the light snow that did fall through the melting layer was enough to coat area roadways with ice.

6. Summary

A rare freezing rain event occurred during the early morning hours of 25 January 2006 over northern Arizona's LCRV. It was discovered there were three main contributors that played a role in this event. The first was northeasterly flow at the surface from the day before that helped to reinforce the low-level temperature inversion already over the LCRV. The second member involved was the clear skies and dry air at the surface. This allowed for the maximum amount of radiational cooling over the LCRV to occur during the night time hours, as this event occurred just before sunrise. The final contributor to the LCRV freezing rain event involved a warm and unstable air mass east of a closed upper level low over Baja California. Unseasonably strong convection likely caused an outflow boundary over western New Mexico, which traveled northwestward into the LCRV and over-ran the cold surface air mass that was already in place. Several hours later, another round of convection moved northward over the Eastern Mogollon Rim and White Mountains and into the LCRV. As cloud top temperatures were colder than $-30^{o}C$, light snow was most likely the first precipitator. Given the two known freezing rain processes previously discussed in section 3, the LCRV case was consistent with the "classic case", and conceptual diagrams were given (Figures 13 and 14) illustrating the warm outflow and how the melting layer had formed over the LCRV. Although the convective activity weakened as it traversed the LCRV, sufficient light snow fell into the melting layer, and through the surface-based freezing layer, to produce supercooled water droplets. This led to the formation of ice on area roadways across the LCRV.

7. Acknowledgements

The author would like to thank Michael Staudenmaier, Science and Operations Officer at WFO Flagstaff, for his knowledge, guidance, and patience while this technical attachment was written and reviewed. Special thanks goes to Brian Klimowski, Meteorologist in Charge at WFO Flagstaff for his generous comments in making this paper better.

8. References

Huffman, George J. and Gene Alfred Norman, Jr. 1988: **The Supercooled Warm Rain Process and the Specification of Freezing Precipitation.** *Monthly Weather Review*: Vol. 116, No. 11, pp 2172-2182.

Robbins, Chris C. and John V. Cortinas, Jr. 2002: **Local and Synoptic Environments Associated with Freezing Rain in the Contiguous United States.** *Weather and Forecasting*: Vol.17, No. 1, pp 47-65.

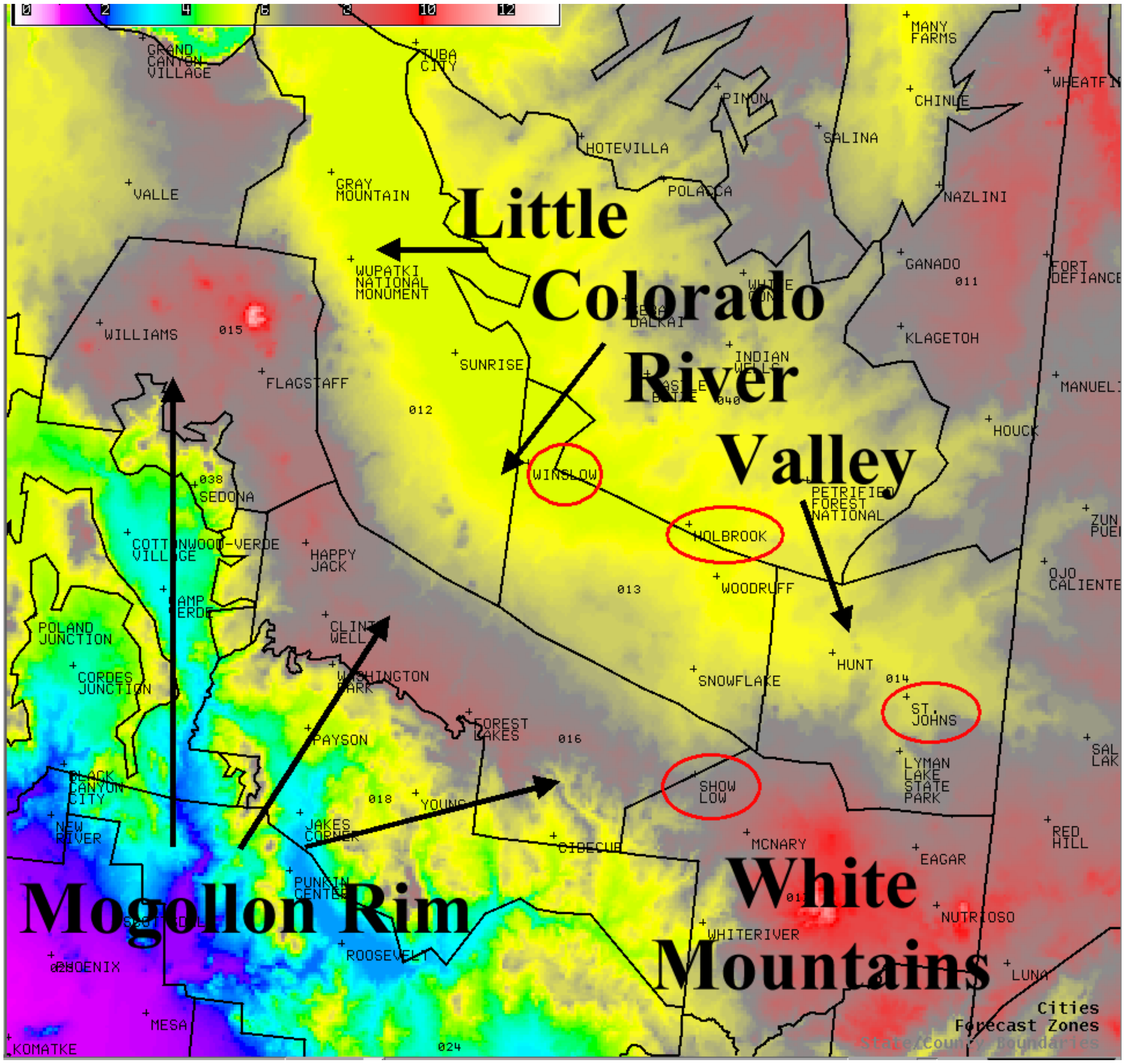

Figure 1. Topographical map showing locations of the Little Colorado River Valley, Mogollon Rim, and the White Mountains in Flagstaff’s CWA. Green colors represent valley locations, while red indicates the high terrain. Cities circled in red are used as reference points in this paper.

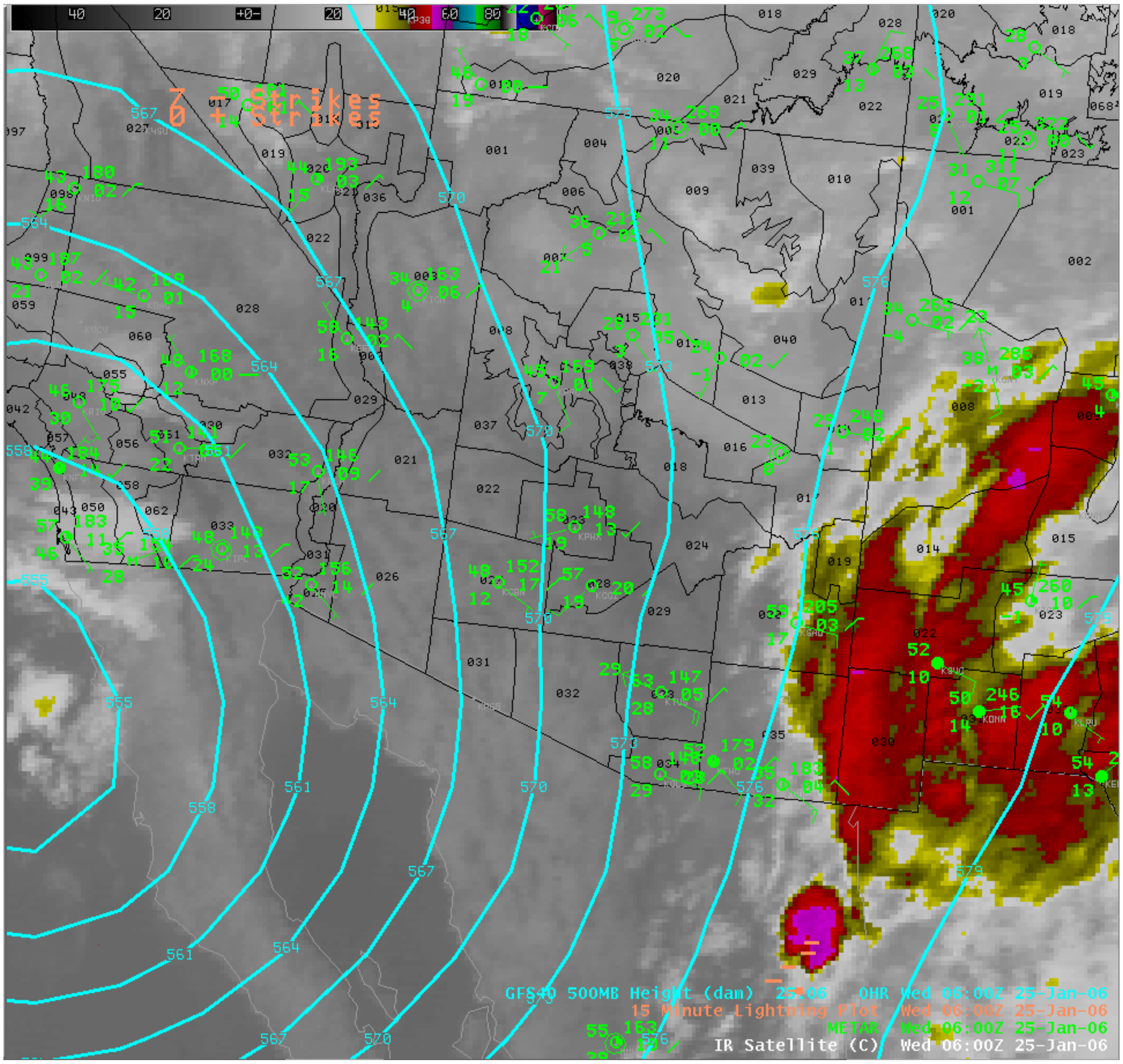

Figure 2. Infrared satellite imagery with GFS 500 hPa heights (aqua, solid), 15-minute lightning plot (orange), and surface observation (green) overlay for 0600 UTC 25 January 2006.

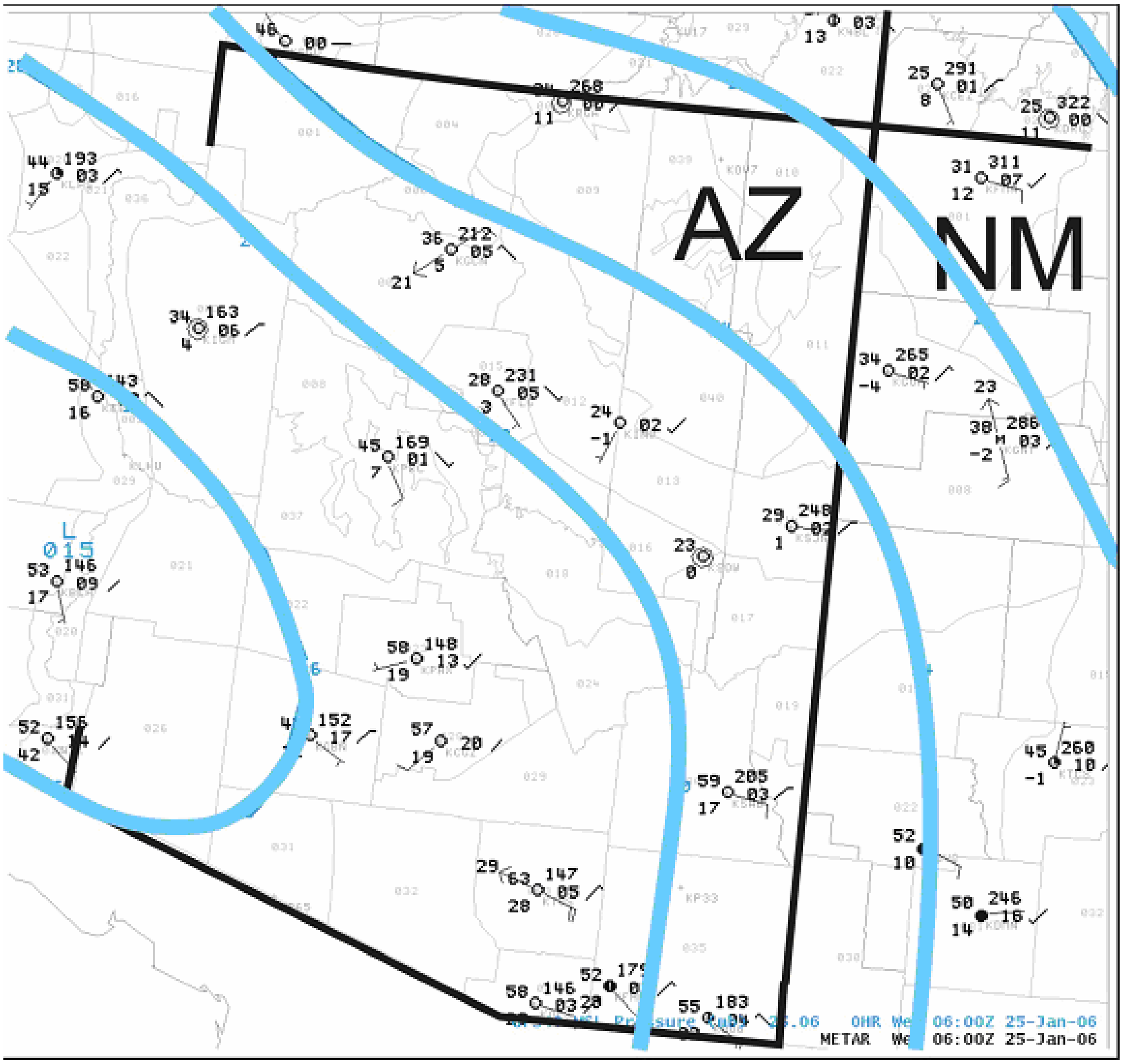

Figure 3. GFS40 surface pressure (blue, solid) with surface observation (black) overlay at 0600 UTC 25 January 2006.

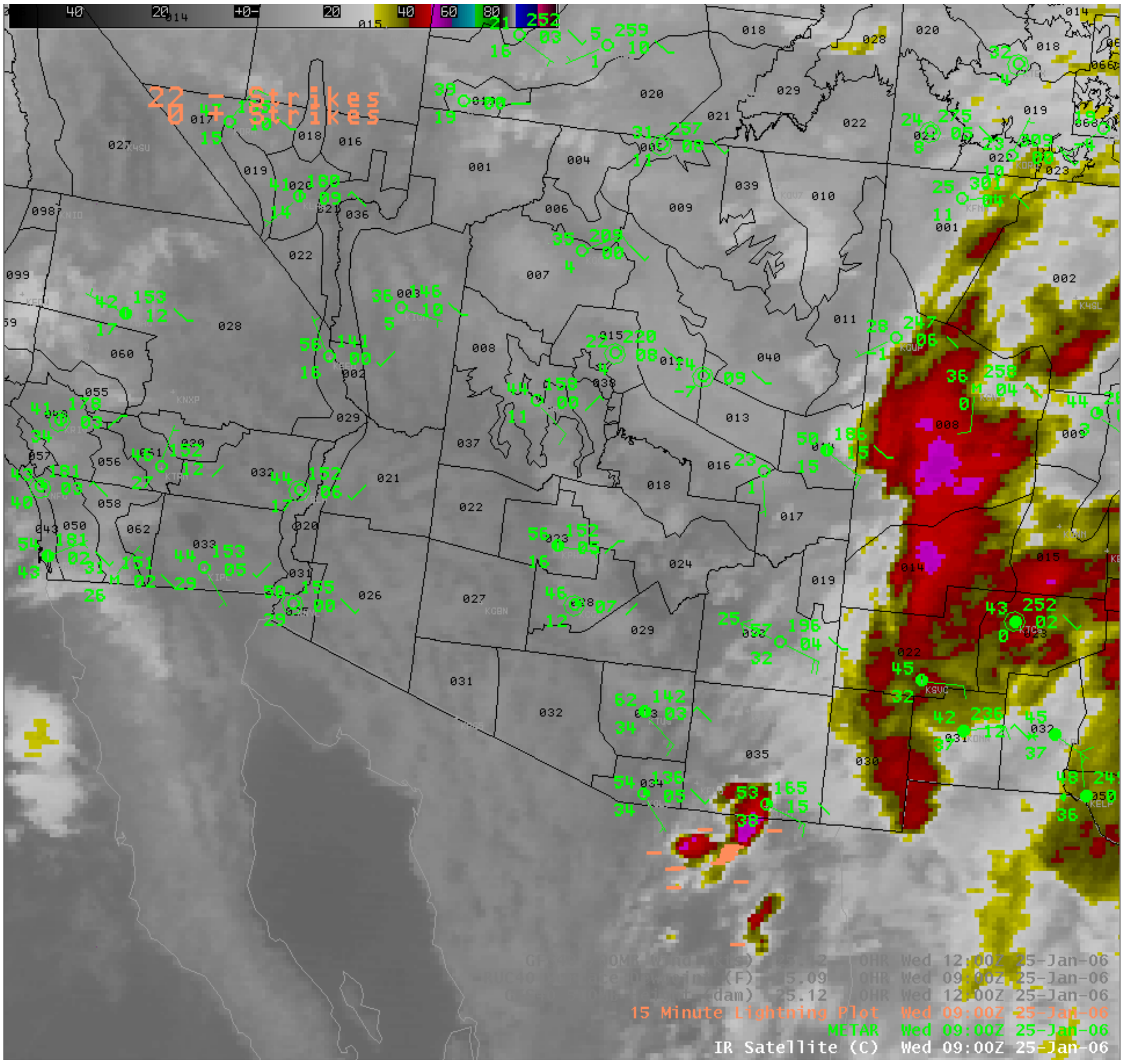

Figure 4. As in Fig. 1 but 15-minute lightning plot and surface observations at 0900 UTC.

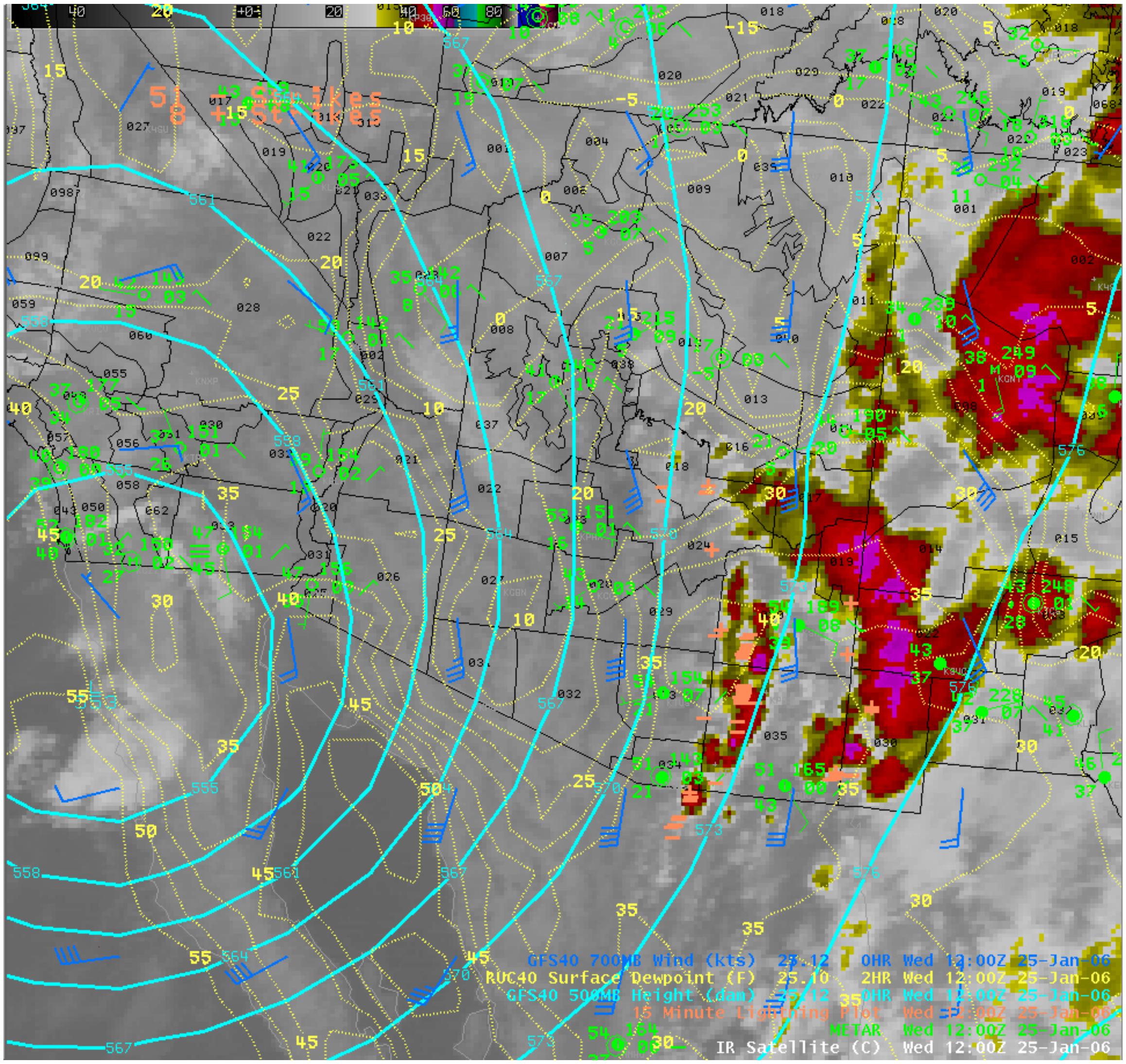

Figure 5. As in Fig. 1 but at 1200 UTC, with RUC40 surface dewpoint (yellow, dashed) and GFS 700 hPa wind (dark blue, barbs) overlay.

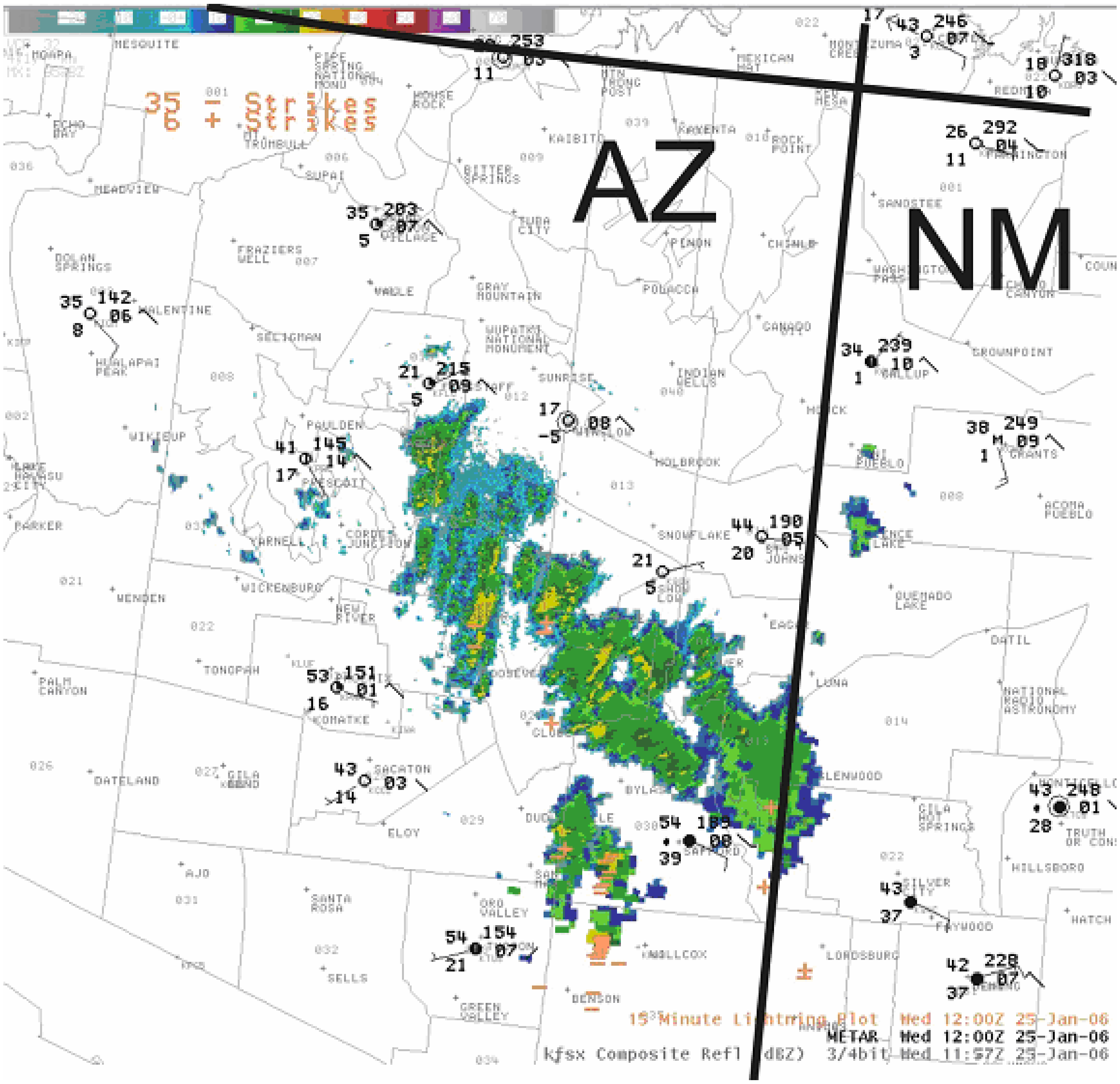

Figure 6. 1157 UTC KFSX composite reflectivity radar with 1200 UTC surface observations (black) and 15-minute lightning plot overlay (orange).

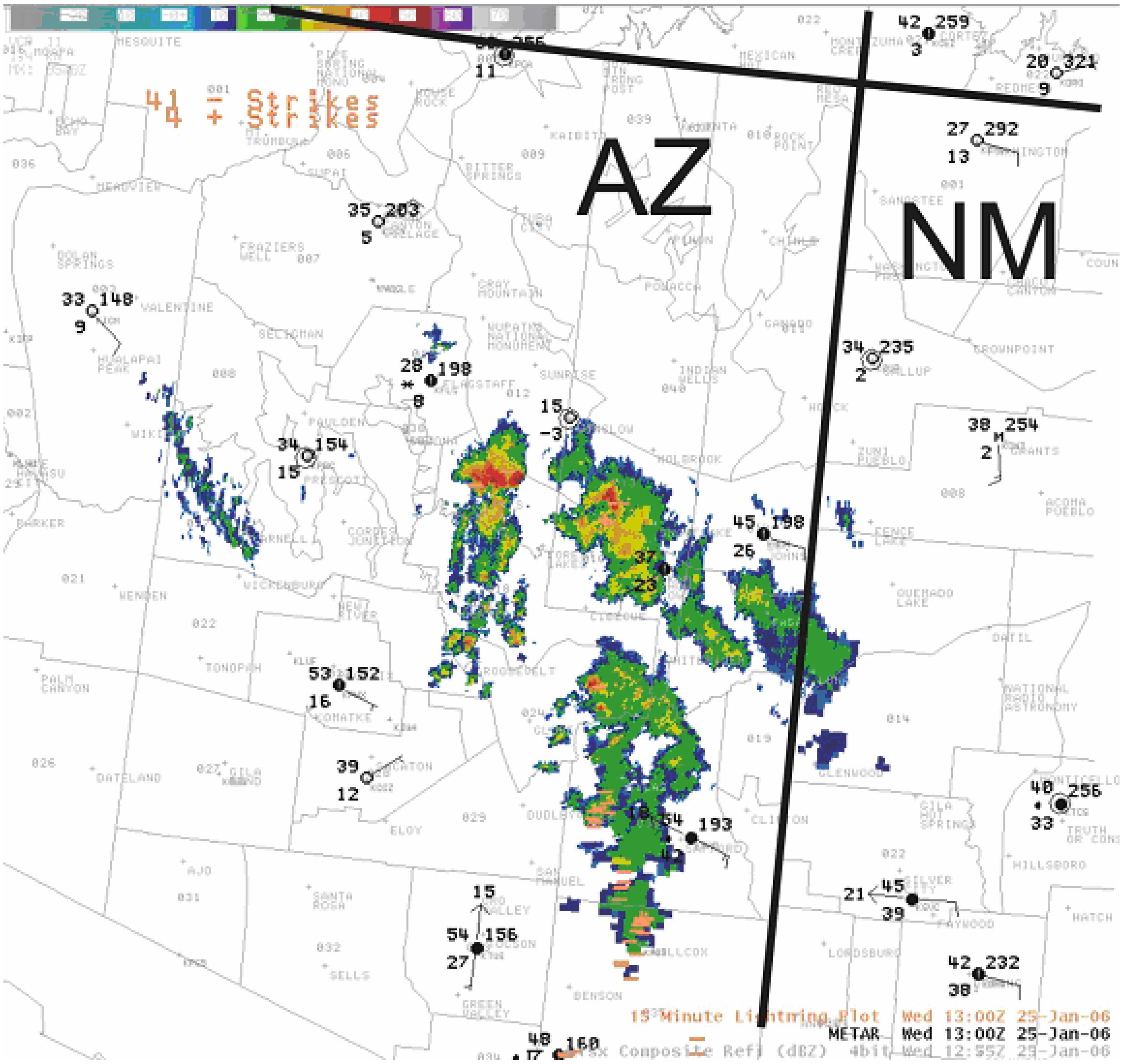

Figure 7. As in Fig. 6 but composite reflectivity at 1255 UTC, with surface observation and 15-minute lightning plot overlay at 1300 UTC.

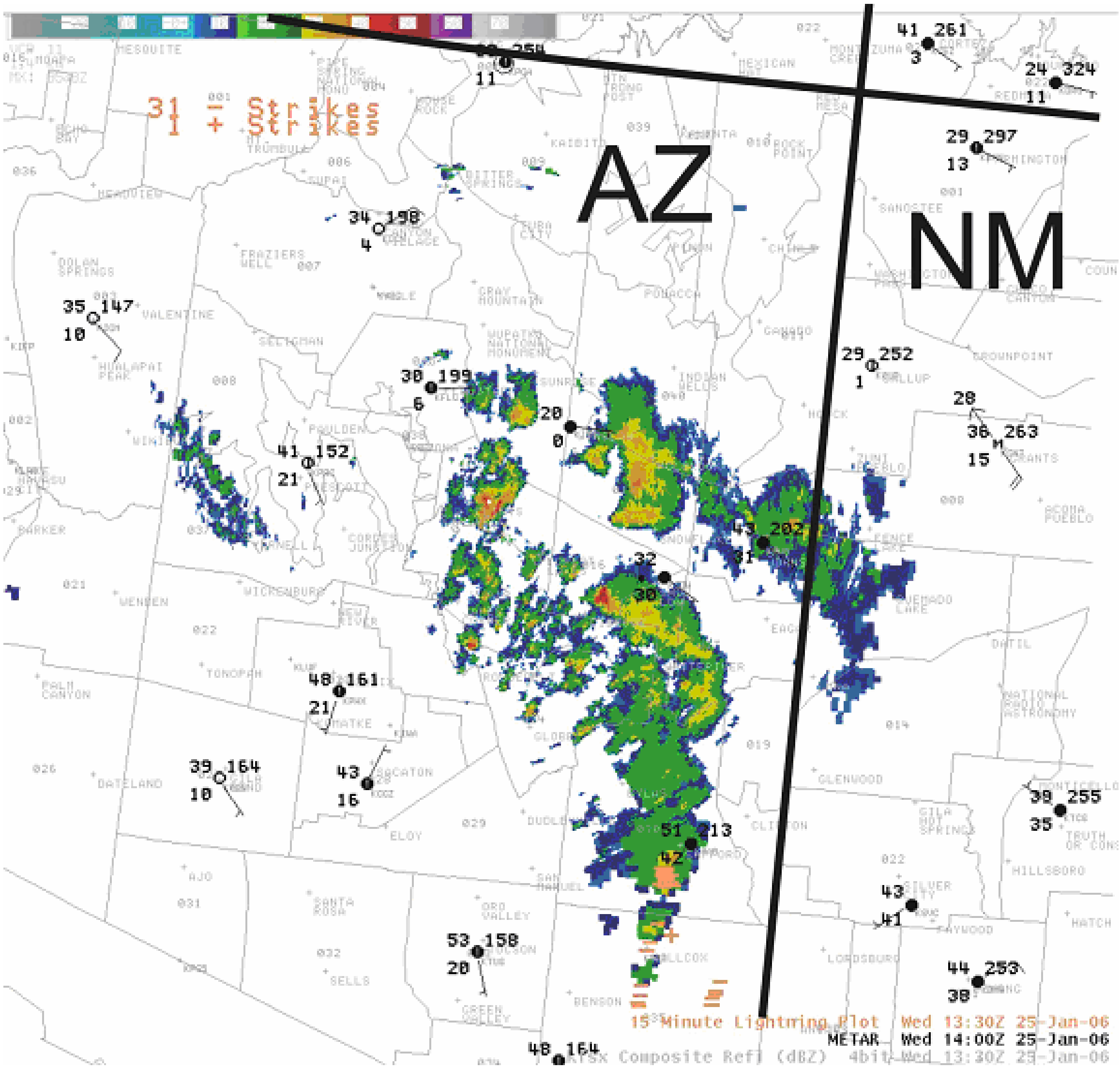

Figure 8. As in Fig. 6 but composite reflectivity and 15-minute lightning plot at 1330 UTC, with surface observation overlay at 1400 UTC.

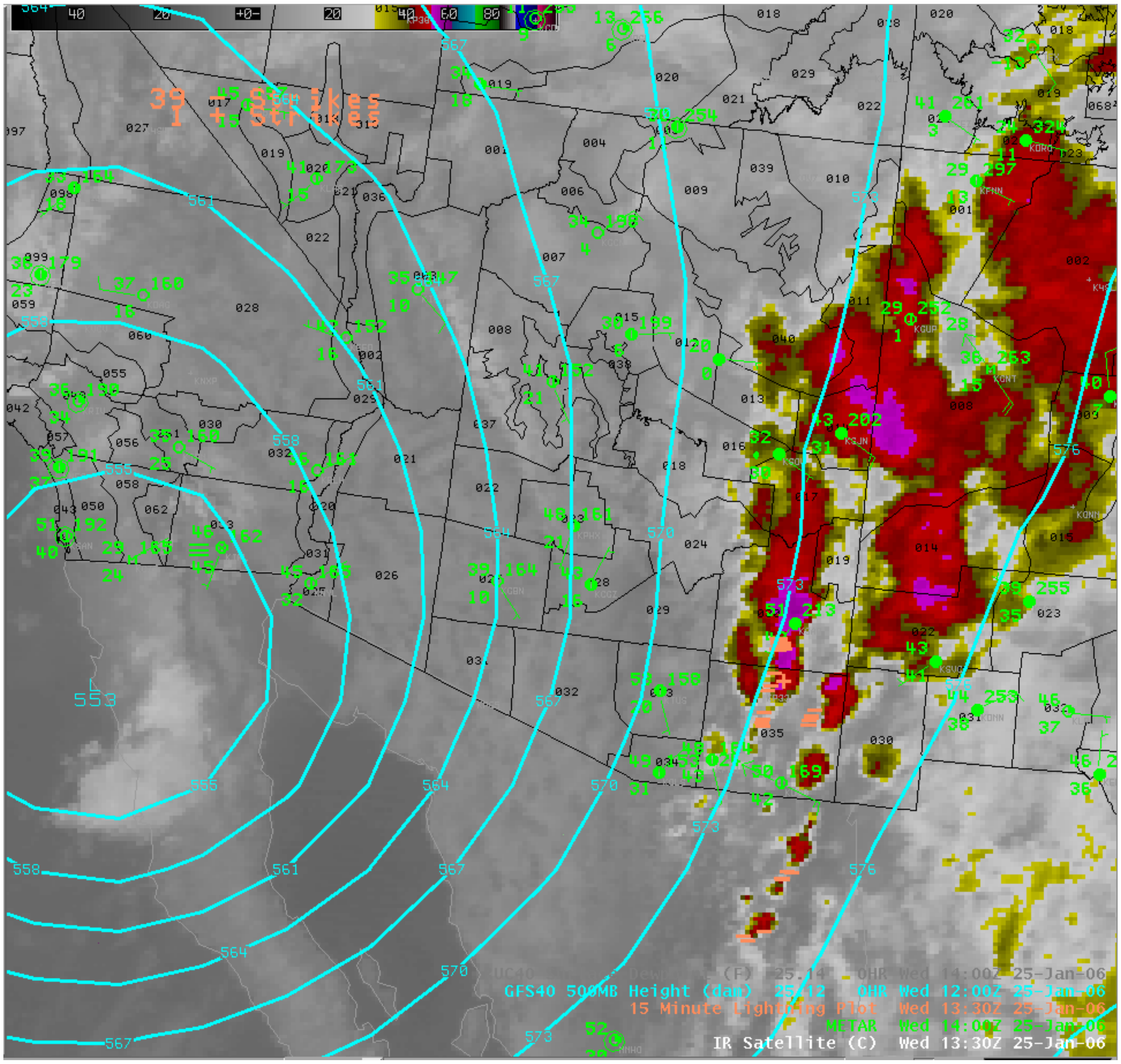

Figure 9. As in Fig. 1 but GFS 500 hPa heights at 1200 UTC, 15-minute lightning and infrared satellite at 1330 UTC, and surface observations at 1400 UTC.

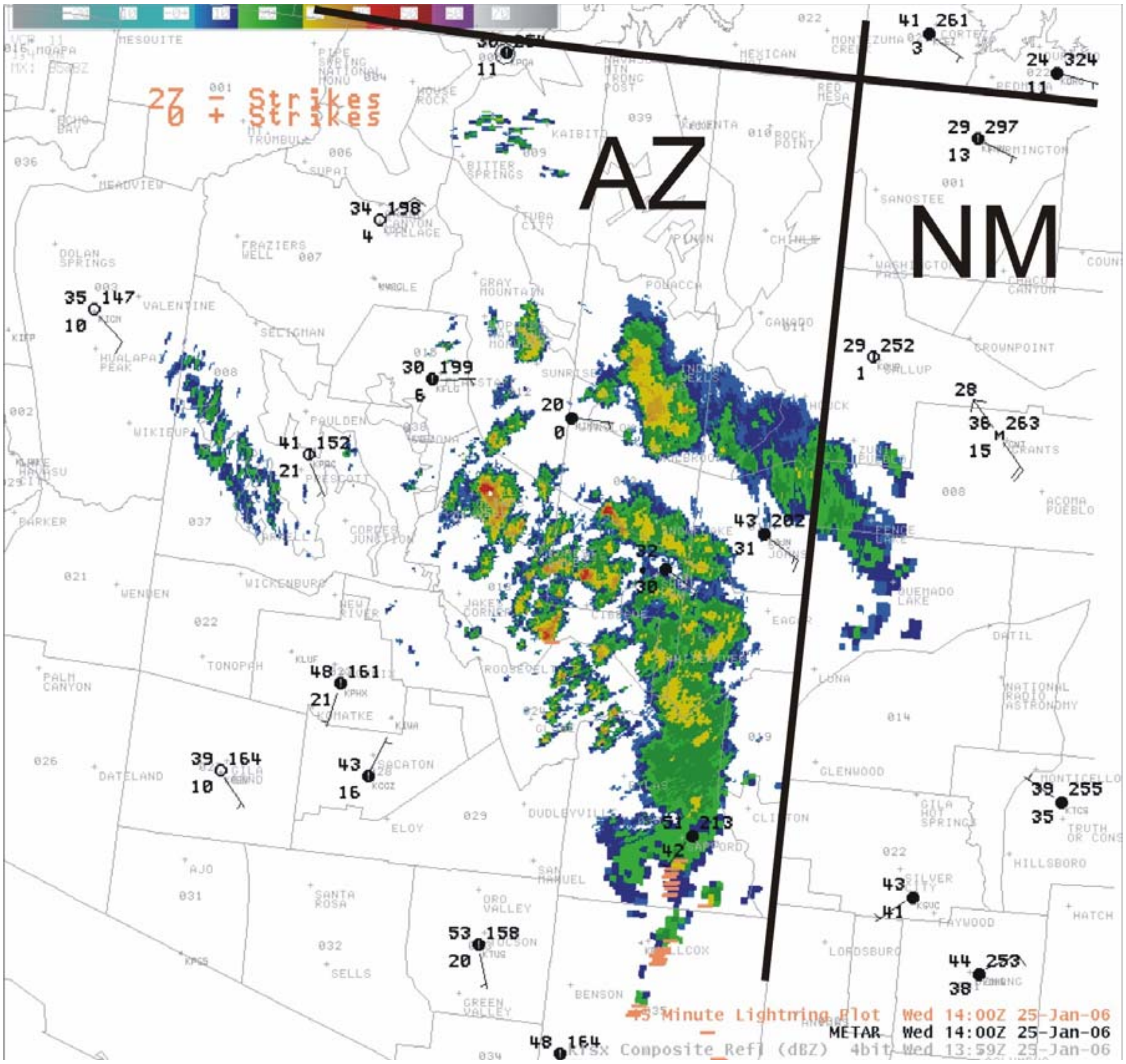

Figure 10. As in Fig. 6 but composite reflectivity at 1359 UTC, with 15-minute lightning plot and surface observation overlay at 1400 UTC.

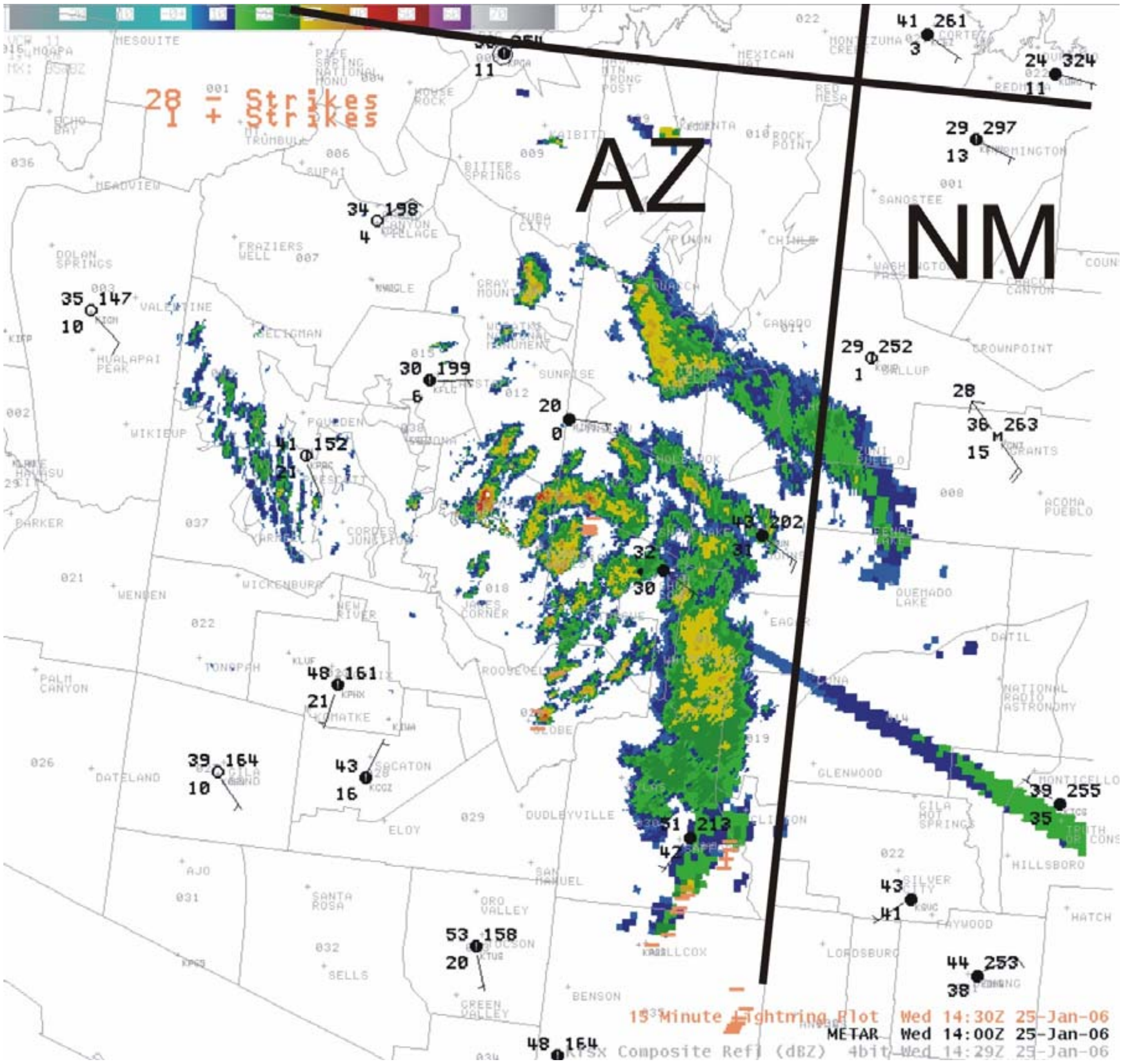

Figure 11. As in Fig. 6 but composite reflectivity at 1429 UTC, with 15-minute lightning plot at 1430 UTC and surface observation overlay at 1400 UTC.

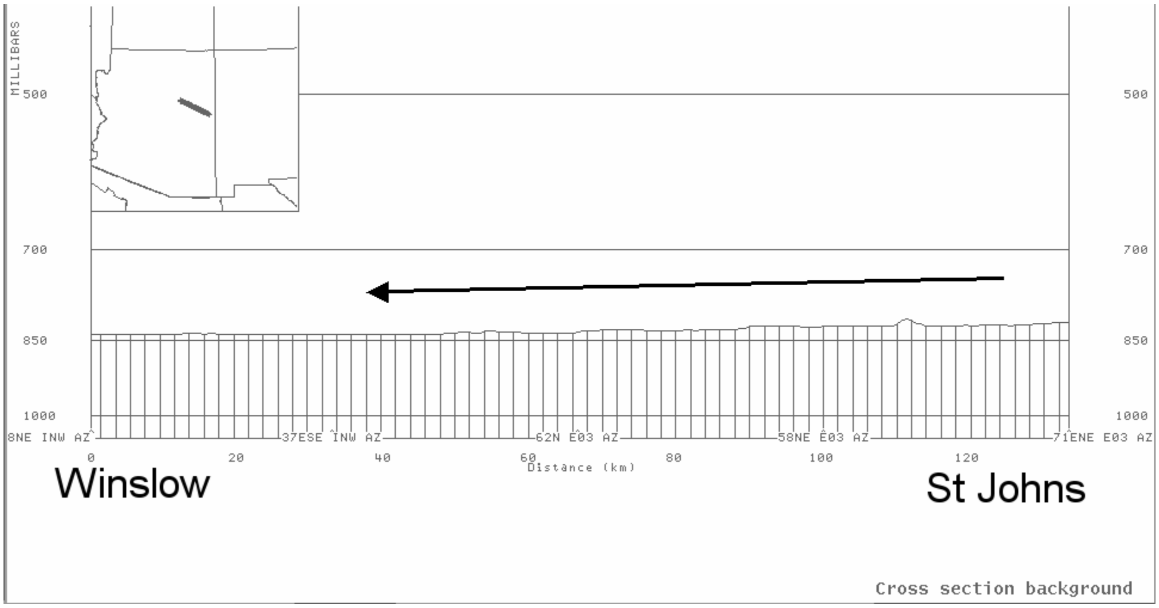

Figure 12. Cross-section from Winslow to St Johns, highlighting the southeast to northwest sloping nature of the LCRV.

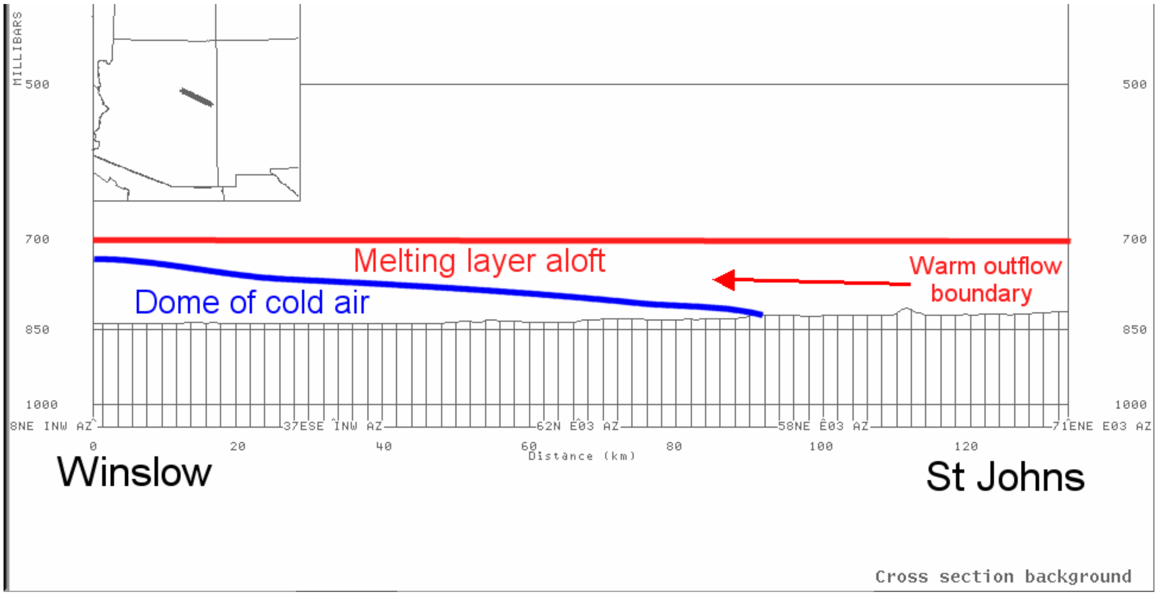

Figure 13. Cross-section showing warm air advecting into the LCRV from St Johns and over-riding the dome of cold air, resulting in the melting layer aloft (not to scale).

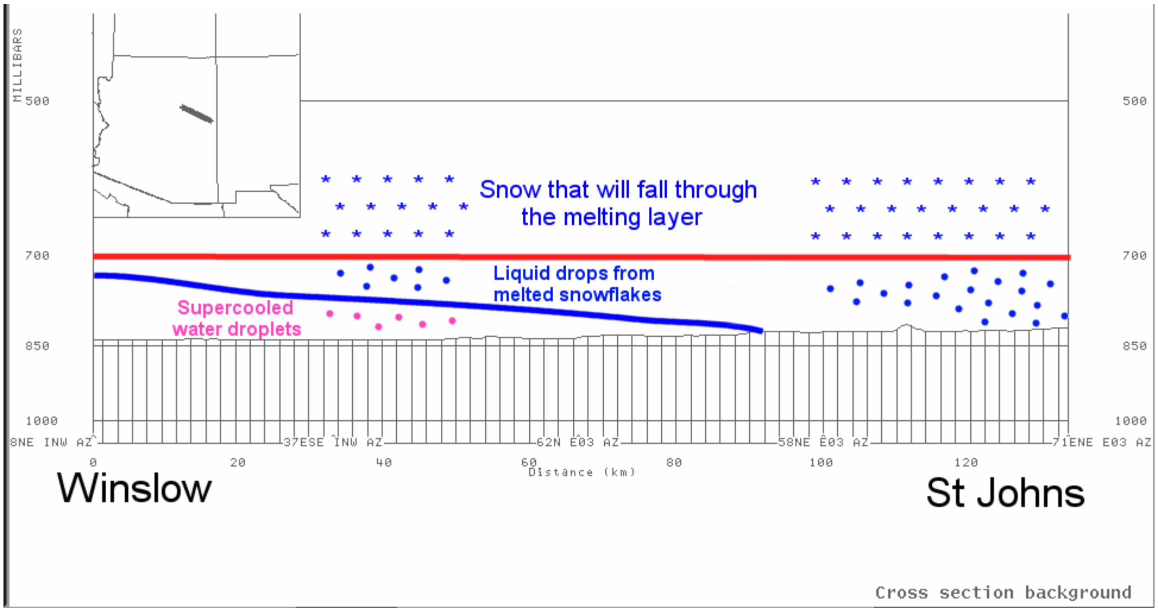

Figure 14. Conceptual diagram explaining the setup for the rare freezing rain event over the LCRV on 25 January 2006 (not to scale). Light snow falling over the St Johns area melted into liquid drops and remained in that state due to the warm layer extending down to the surface.