CHAPTER 4

OBSERVED PRECIPITATION DURING IPEX

During the field phase of IPEX, several storms with different characteristics occurred over northern Utah. These events ranged from a fast-moving squall line to slow-moving cold fronts and orographically-enhanced snowstorms. Because of the unusually warm winter, most of the storms during the experiment produced rain in the valleys instead of snow. Unfortunately, a lake-effect event (Carpenter 1993; Steenburgh et al. 2000) did not occur during February 2000.

The complex terrain of the Salt Lake City area had a strong impact on the distribution of precipitation during IPEX. To illustrate some aspects of the variability in quantitative precipitation, precipitation totals during the IPEX period at four different stations are compared. The locations of these stations are shown in Figure 4.1. The four stations represent mountain and valley climatological regimes and automated and manual measuring techniques. Ben Lomond Peak (BLPU1) is an automated SNOTEL site located in the northern Wasatch Range at an elevation of 2438 m (7999 ft). Alta Guard House (ATAU1), a manual site, is located in the southern part of the Wasatch at 2661 m (8731 ft). The other two sites are located in the Salt Lake Valley. The manually-augmented ASOS site at the Salt Lake International Airport (SLC) is at an elevation of 1288 m (4226 ft), and the automated Geonor site at Sandy (SNH) is located at an elevation of 1450 m (4757 ft).

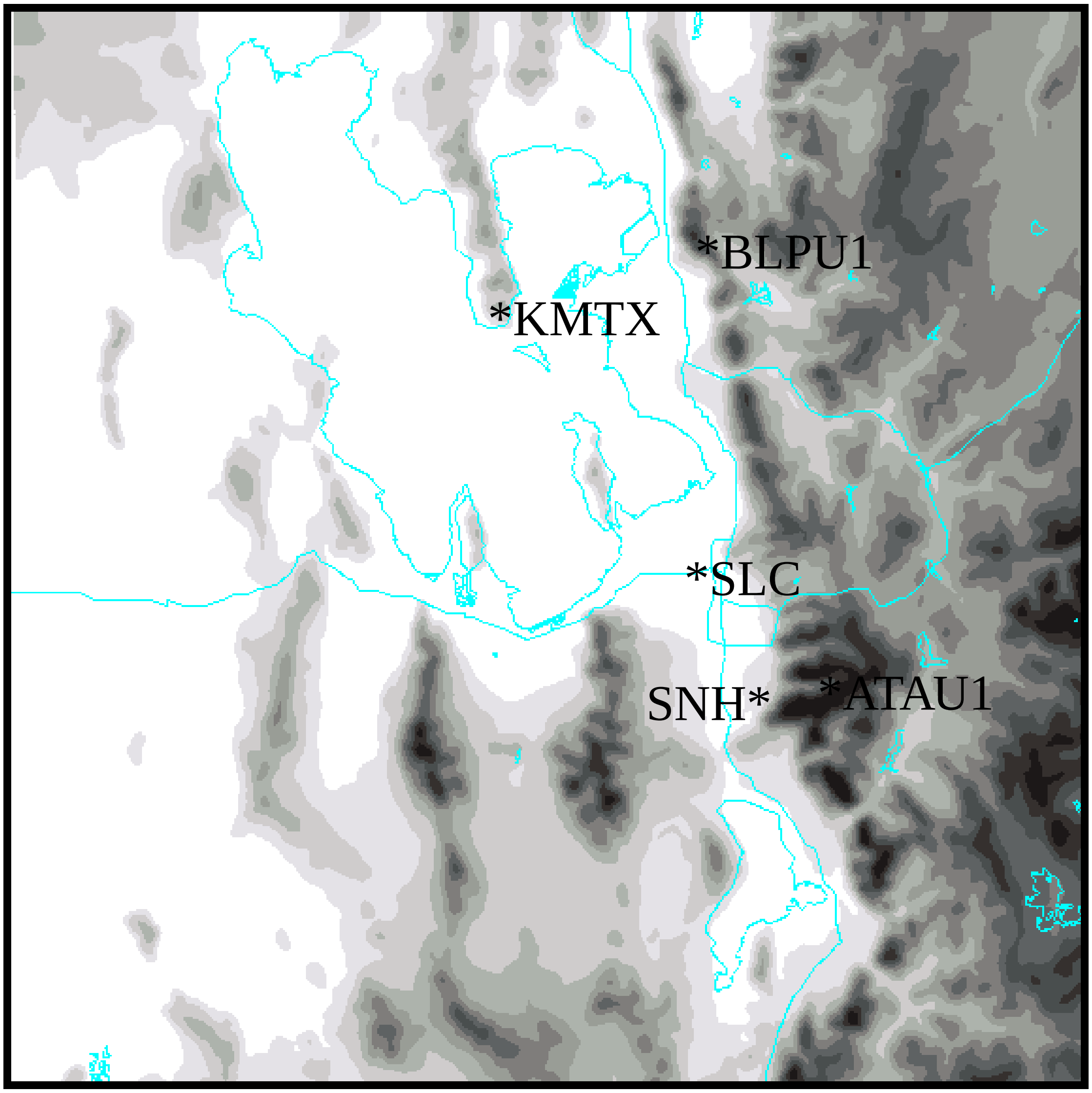

Figure 4.1. Locations of the four stations at which point precipitation data are compared. The location of the KMTX Doppler radar is also included.

Figure 4.2 shows the time series of cumulative precipitation at the four stations for the period 2-26 February 2000. The shaded areas represent subjectively-defined periods of widespread or significant precipitation based upon radar reflectivity and all available precipitation observations. The events that correspond to the IOPs are labeled. Note that each of the stations are plotted at different temporal resolutions corresponding to the station's reporting frequency. The frequency is 5 min for Sandy (SNH), 1 h for Ben Lomond Peak (BLPU1), 6 h for the airport (SLC), and 12 h for Alta (ATAU1).

The most obvious feature in the figure is the disparity in total precipitation between the mountain and valley sites, with the two mountain sites receiving cumulative totals five times greater than the totals at the valley sites during the period. However, while the difference between the two valley locations is less than 20 mm, the difference between the two mountain sites is more than 80 mm. Note, though, that most of this difference is due to the precipitation event that occurred around 14 February, between IOPs 3 and 4, during which Ben Lomond Peak (BLPU1) reported more than four times as much precipitation as Alta (ATAU1). Other features that can be discerned from Fig. 4.2 are the varying levels of orographic influence during the different events. For example, during IOP 3 and the 14 February event, the two high-elevation sites received much more precipitation than the two valley sites, which is evidence of strong orographic effects. Precipitation appears to be more evenly distributed during IOP 6, indicative of significantly less orographic enhancement. Descriptions of the synoptic and mesoscale conditions and the spatial variability of precipitation during each of the IOPs will be presented in the following sections.

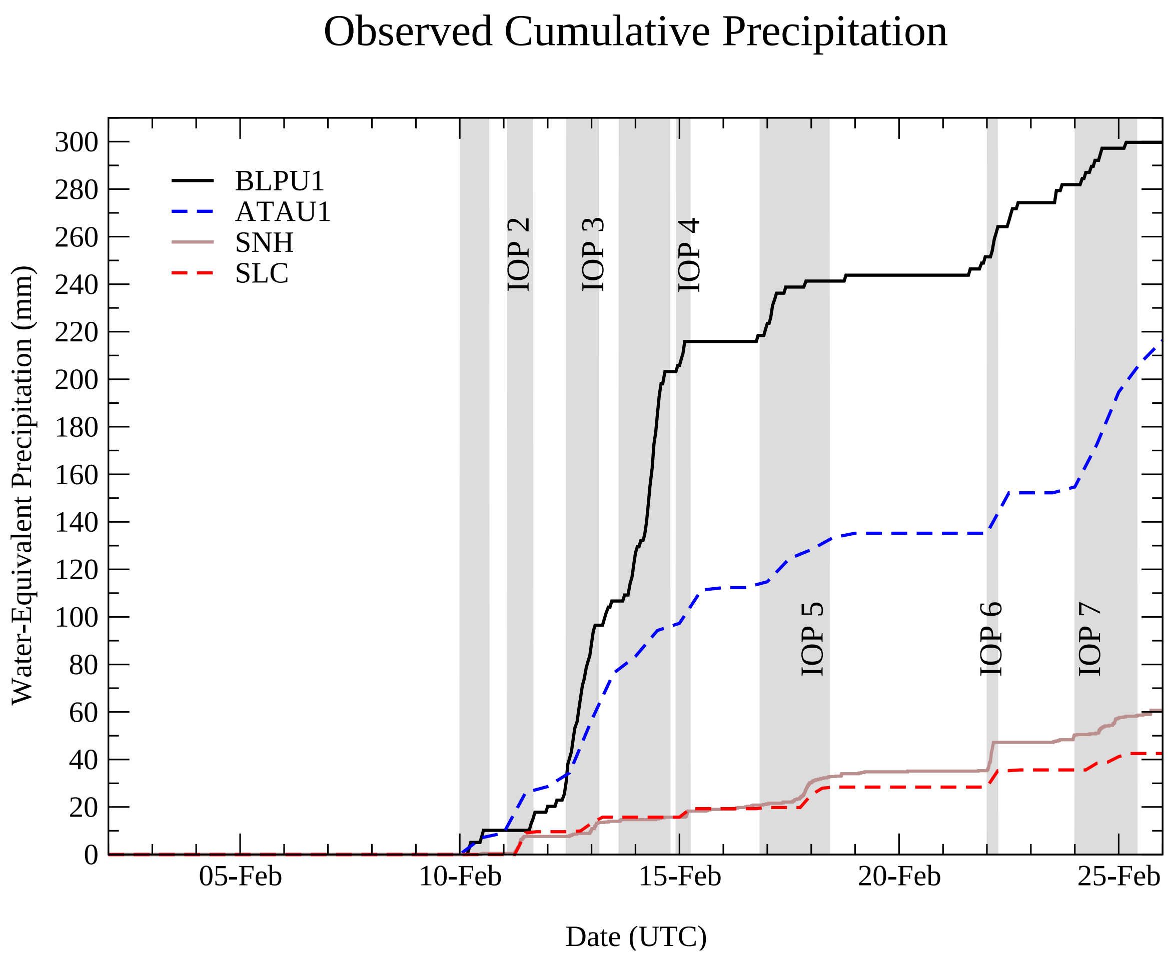

Figure 4.2. Observed cumulative precipitation at four stations during IPEX. Shaded areas represent subjectively-determined periods of significant precipitation over the IPEX domain. Events corresponding to the IOPs are labeled.

IOP 2

The first IOP in the Salt Lake City area, IOP 2, took place 1500 UTC 10 February-1500 UTC 11 February. It was held because several upper-level disturbances were expected to bring a significant amount of moisture and some instability to the region. However, precipitation in the region was mostly scattered until early in the day on 11 February, when the system brought snow to the mountains and rain in the valleys.

The synoptic conditions during this event are shown by the 0600 UTC 11 February analysis from the Rapid Update Cycle (RUC2) (Fig. 4.3). At this time, the 500-hPa trough was located over the southwestern United States, with an area of strong cyclonic vorticity extending northward into central Utah. An area of strong rising motion was analyzed over eastern Utah ahead of the trough. A region of at least 80% relative humidity at 700 hPa existed over much of Utah. The winds at 700 hPa were southwesterly ahead of the trough axis, but later shifted to the northwest.

While most stations reported precipitation during IOP 2, the largest amounts were limited to the southern part of the region due to a tight mesoscale mid-tropospheric vortex traveling through south of Salt Lake City. Radar loops (not shown) indicate that a northwest-southeast oriented band of precipitation moved northeast into the area around 0000 UTC 11 February. As it reached the southern part of the Great Salt Lake, the band moved eastward in association with the mid-tropospheric vortex.

The spatial distribution of cumulative precipitation in the Salt Lake City area for the 24-h period ending 1800 UTC 11 February is shown in Fig. 4.4. The start and end times of the period do not correspond exactly with those of the IOP due to the 6-h resolution of the quality-controlled observed precipitation data set. The markers identify

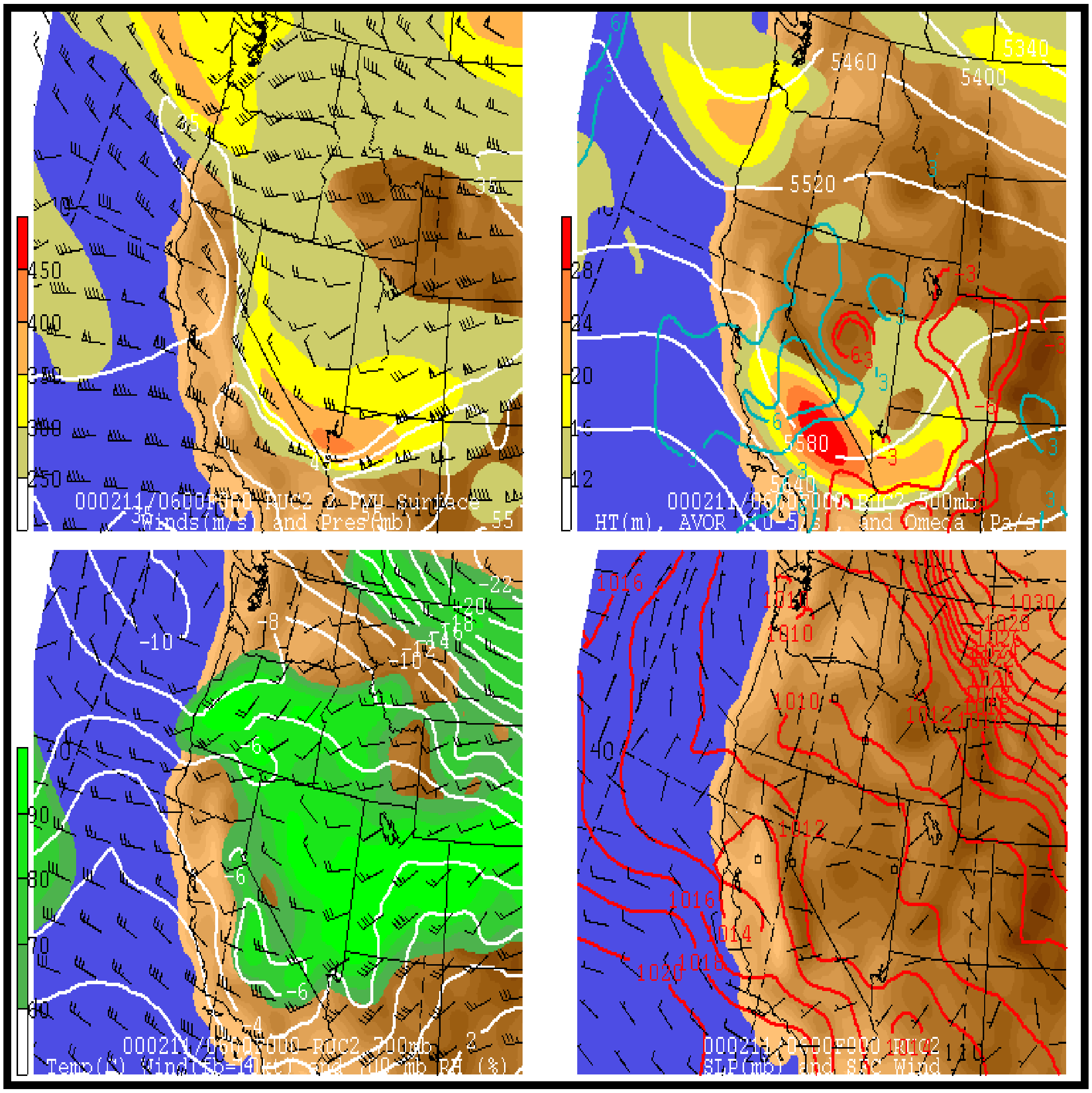

Figure 4.3. Four-panel RUC2 analysis from 0600 UTC 11 February. Upper left panel shows the pressure of the 2-PVU surface (hPa, shaded according to scale bar), wind speed (m s^{-1}), and wind (full barb=5.1 m s^{-1} (10 kt)). Upper right panel shows the 500-hPa height (m), absolute vorticity (10^{-5} s^{-1}, shaded according to scale bar), and vertical velocity (Pa s^{-1}). Lower left panel shows 700-hPa temperature (^{o}C), relative humidity (%, shaded according to scale bar), and wind (full barb=5.1 m s^{-1} (10 kt)). Lower right panel shows sea level pressure (hPa) and surface wind (full barb=5.1 m s^{-1} (10 kt)).

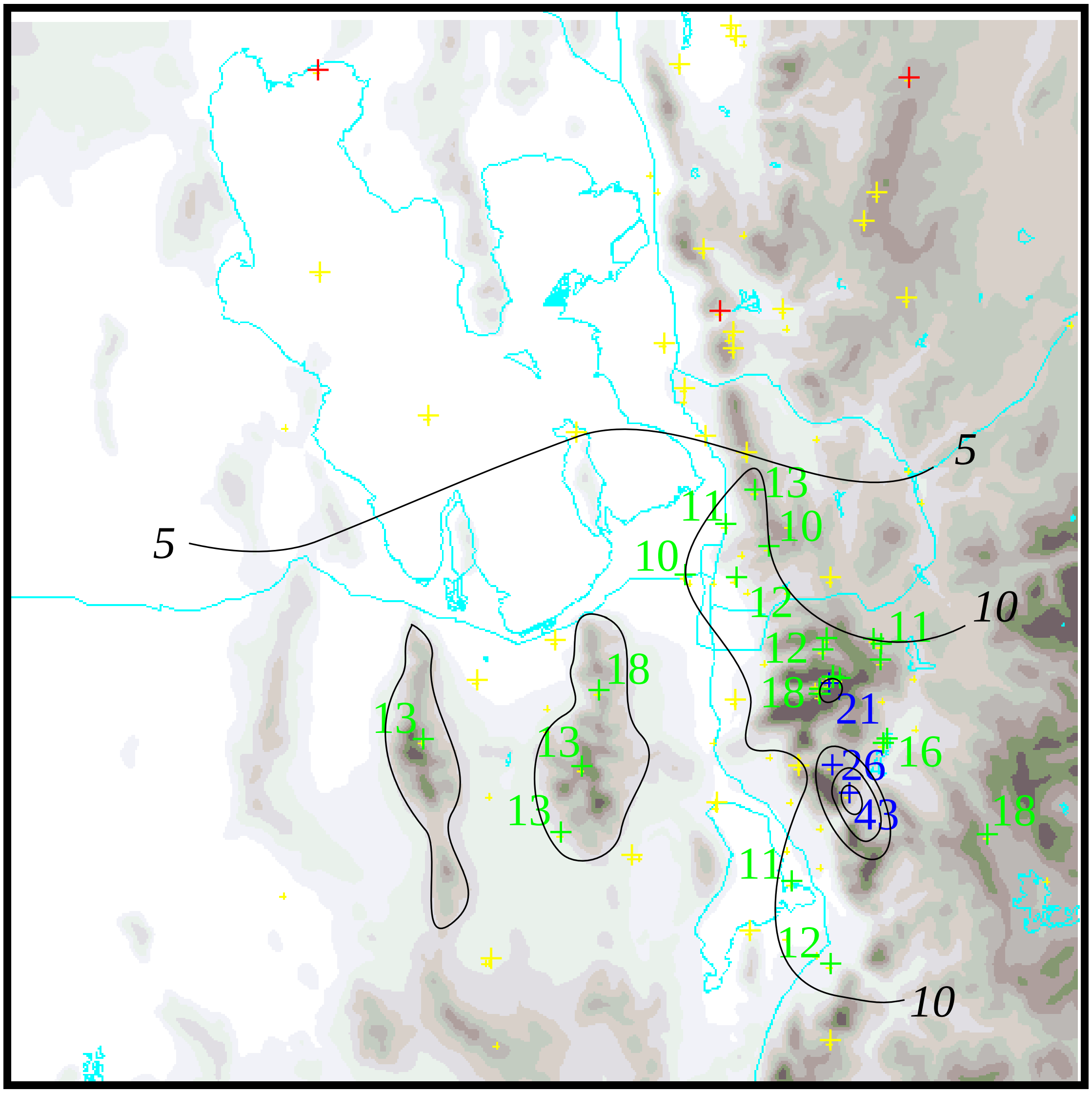

Figure 4.4. Observed spatial distribution of precipitation for the period 1800 UTC 10 February-1800 UTC 11 February during IOP 2. Markers identify stations reporting precipitation during the period. Red markers denote stations reporting zero or trace amounts of precipitation, yellow markers denote stations reporting measurable precipitation but less than 10 mm, green markers denote stations reporting at least 10 mm but less than 20 mm, and blue markers denote stations reporting at least 20 mm of precipitation. Selected stations are labeled with the observed precipitation totals to the nearest mm. Contours were created subjectively based upon the available data. Contours are isohyets of 5, 10, 20, 30, and 40 mm.

stations reporting precipitation data during the period. Most of the area north of Salt Lake City and Interstate 80 (I-80, the east-west road on the map) received less than 10 mm of precipitation. Valley regions south of I-80 also received less than 10 mm, with the exception of those sites directly upstream of the mountains. The heaviest precipitation was reported along the southern part of the Wasatch Range, with a maximum of 43.0 mm at the Sundance Mid-Mountain site. Thus, orographic enhancement is evident during this IOP, with larger precipitation totals observed in the mountains and at those sites immediately upstream of the mountains.

Rain gauges can provide valuable insight into the spatial and quantitative aspects of precipitation, but they are not evenly distributed throughout the region and thus may not be fully representative of the precipitation distribution. To fill in some of the voids where gauge data are lacking, as well as to help corroborate the gauge data, median reflectivity from the KMTX WSR-88D is used. The radar is located at the south end of the Promontory Mountains on the north shore of the Great Salt Lake, as shown in Fig. 4.1. The method of computing median reflectivity is described by Slemmer (1998), and the technique was also applied by Steenburgh and Onton (2001) to characterize the structure and intensity of storms. Median reflectivity helps to define the typical intensity of reflectivity and precipitation during the time interval.

Precipitation totals along with median radar reflectivity for each of the 6-h periods from 1800 UTC 10 February-1800 UTC 11 February are shown in Fig. 4.5. During the first 6-h period (Fig. 4.5a), very little precipitation fell in the area. Only a few sites in the southern part of the region reported light amounts. The median reflectivity values were

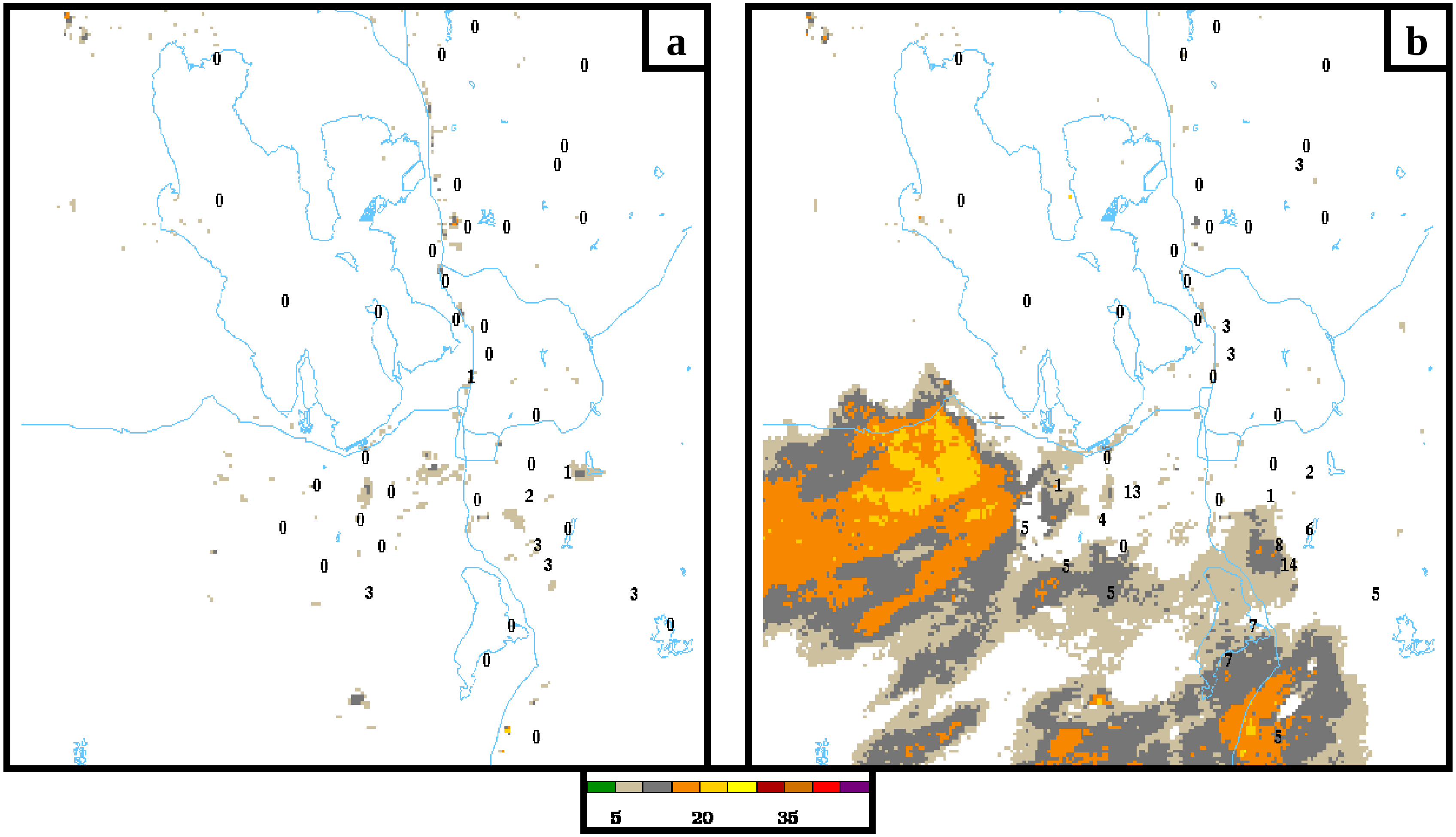

Figure 4.5. Precipitation (mm) and median reflectivity (dBZ) for the 6-h periods ending a) 0000 UTC, b) 0600 UTC, c) 1200 UTC, and d) 1800 UTC 11 February during IOP 2. The median reflectivity is shaded according to the scale at the bottom of the figure.

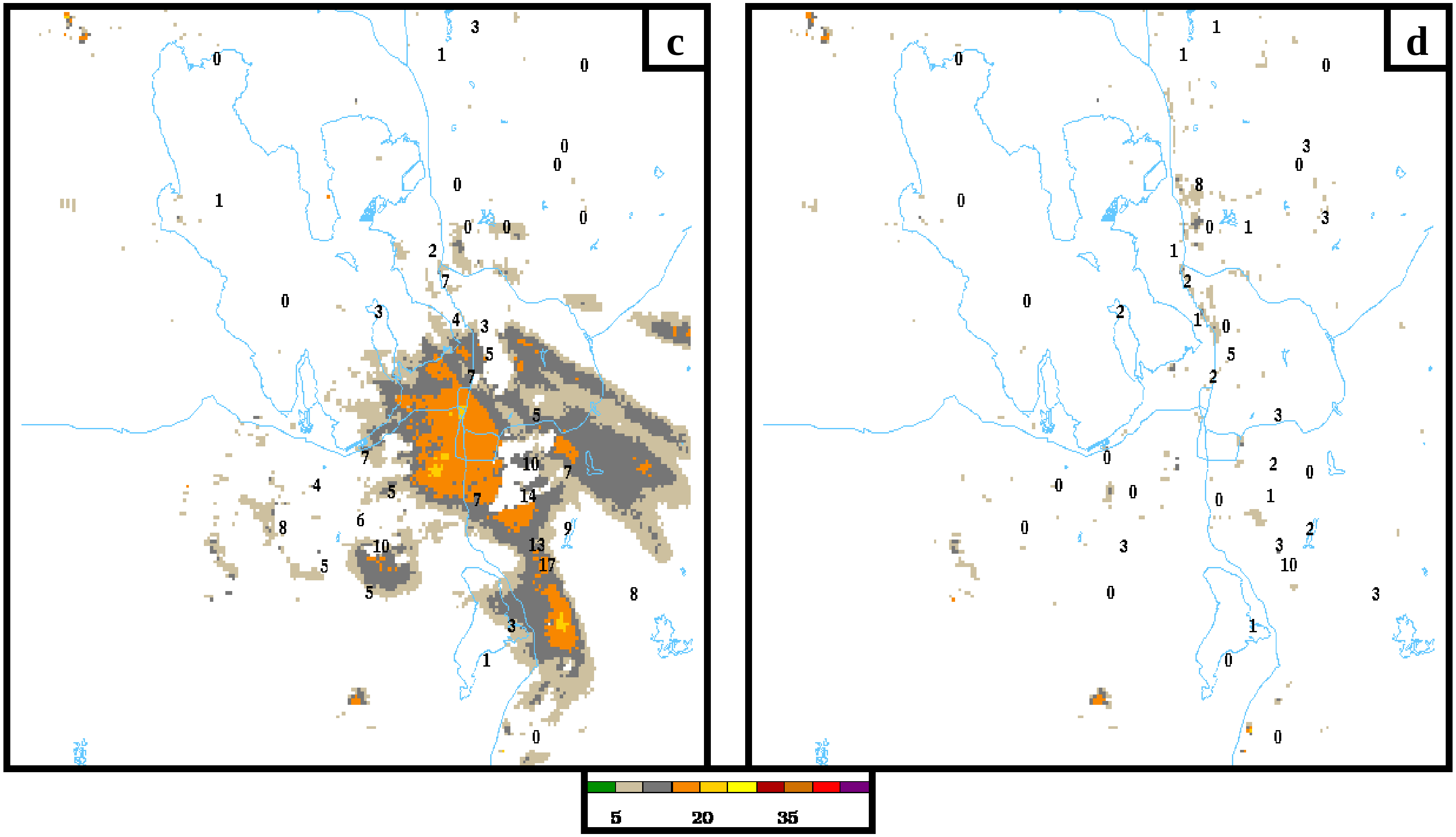

Figure 4.5. (Continued)

below 5 dBZ for almost the entire region, meaning heavy precipitation did not occur for a significant amount of time during this period.

During the next 6-h period, 0000-0600 UTC (Fig. 4.5b), the radar data show areas with median reflectivity values greater than 15 dBZ to the southwest of the Great Salt Lake. This suggests that precipitation was falling in that part of the region, even though no gauges are available in the west desert to confirm that precipitation was reaching the ground. Gauge data show that precipitation also occurred in the southern part of the Wasatch and the Oquirrh and Stansbury Mountains. However, beam blockage and ground clutter removal over the high terrain make it difficult to relate the median reflectivity and precipitation observations in this instance.

Data during the third period (Fig. 4.5c) show precipitation now occurring in the Salt Lake Valley and in the Wasatch Mountains south and east of Salt Lake City. Gauge data from this period verified well with the radar reflectivity, with the largest totals being reported in areas of high reflectivity. During the last period (Fig. 4.5d) precipitation occurred mainly in the Wasatch Mountains and along the Wasatch Front. The lack of significant median reflectivity during this period indicates that most of the precipitation had ended by 1500 UTC.

IOP 3

The third IOP of IPEX took place 0600 UTC 12 February-0600 UTC 13 February as an upper-level trough was forecast to move into the region. A deep moist layer was expected to bring significant precipitation into the area, with westerly flow favoring orographic enhancement. As the system moved through, significant orographic precipitation was observed. The storm brought the heaviest snowfall of the season to the northern Utah mountains, which resulted in several avalanches.

Figure 4.6 shows the synoptic conditions from the RUC2 analysis at 1500 UTC 12 February. At this time, an upper-level trough was situated over the western United States. Strong rising motion ahead of the trough was analyzed over most of central Utah. At 700 hPa, the winds over Utah were southwesterly, and a broad area of high relative humidity extended over the entire western United States. By 0000 UTC 13 February, the upper-level trough had already moved through the region, and northern Utah was under west-northwesterly 700-hPa flow (not shown).

Figure 4.7 shows the spatial distribution of precipitation during the IOP. Strong orographic forcing is evident during this event, with the heaviest precipitation reported along the Wasatch Range, especially to the north of I-80. The largest total was reported at Ben Lomond Peak, which received 73.7 mm. A strong gradient in precipitation totals is also evident, with most of the mountain sites receiving more than 40 mm and the adjacent valleys receiving less than 20 mm. Precipitation minima of less than 10 mm are evident in the northwestern part of the domain and in the southern part of the valleys.

The observed precipitation and median reflectivity for the four 6-h periods during IOP 3 are shown in Fig. 4.8. During the first 6-h period, 0600-1200 UTC 12 February (Fig. 4.8a), the median reflectivity shows precipitation occurring predominantly along the northern Wasatch and in the mountains east of Provo. Gauge reports indicate that the heaviest precipitation was occurring at high-elevation sites. The large-scale flow at 700 hPa during this period was southwesterly (not shown).

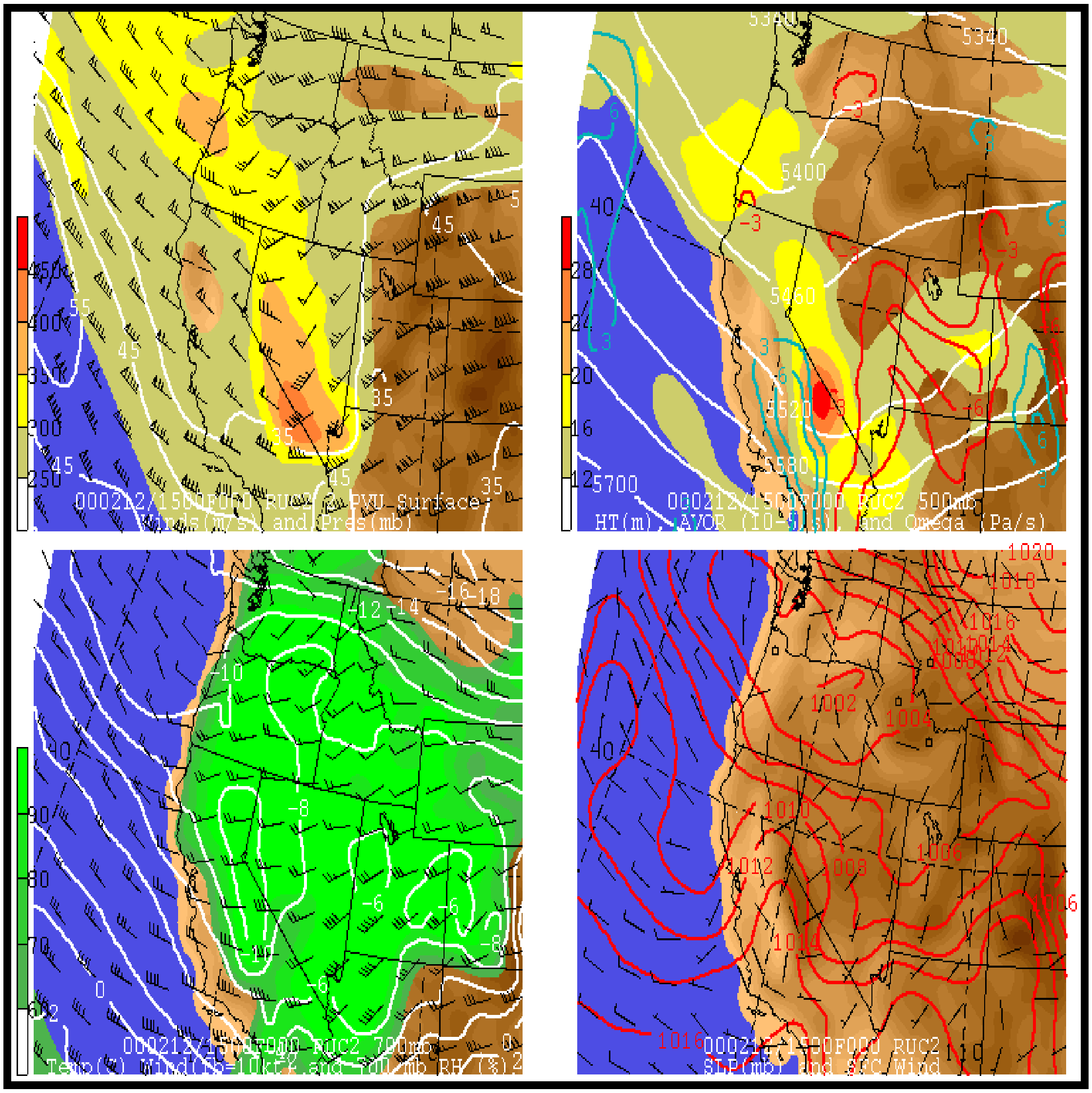

Figure 4.6. Four-panel RUC2 analysis from 1500 UTC 12 February. Upper left panel shows the pressure of the 2-PVU surface (hPa, shaded according to scale bar), wind speed (m s^{-1}), and wind (full barb=5.1 m s^{-1} (10 kt)). Upper right panel shows the 500-hPa height (m), absolute vorticity (10^{-5} s^{-1}, shaded according to scale bar), and vertical velocity (Pa s^{-1}). Lower left panel shows 700-hPa temperature (^{o}C), relative humidity (%, shaded according to scale bar), and wind (full barb=5.1 m s^{-1} (10 kt)). Lower right panel shows sea level pressure (hPa) and surface wind (full barb=5.1 m s^{-1} (10 kt)).

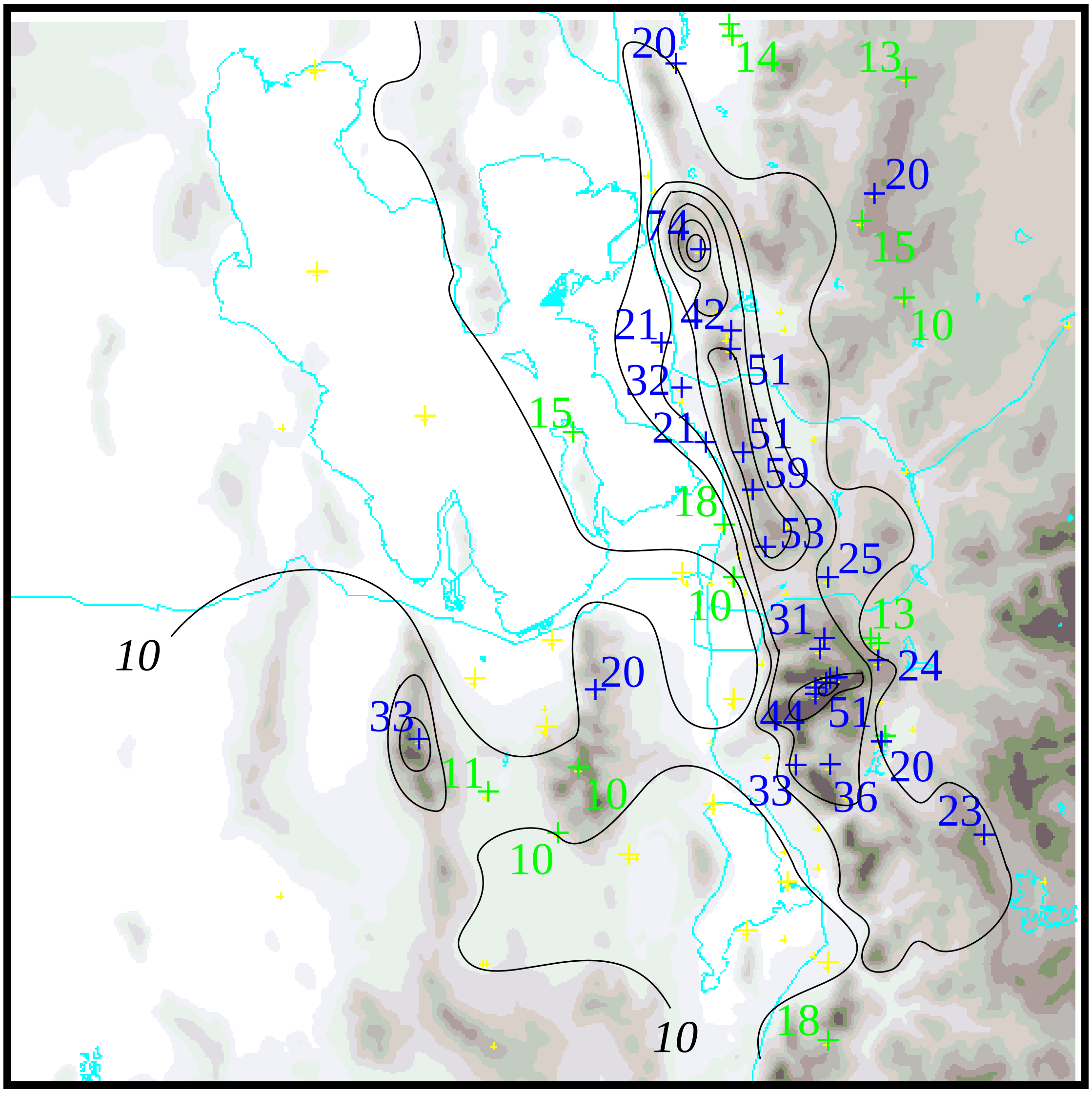

Figure 4.7. Observed spatial distribution of precipitation for the period 0600 UTC 12 February-0600 UTC 13 February during IOP 3. Markers identify stations reporting precipitation during the period. Red markers denote stations reporting zero or trace amounts of precipitation, yellow markers denote stations reporting measurable precipitation but less than 10 mm, green markers denote stations reporting at least 10 mm but less than 20 mm, and blue markers denote stations reporting at least 20 mm of precipitation. Selected stations are labeled with the observed precipitation totals to the nearest mm. Contours were created subjectively based upon the available data. Contours are isohyets of 10, 20, 30, 40, 50, 60, and 70 mm.

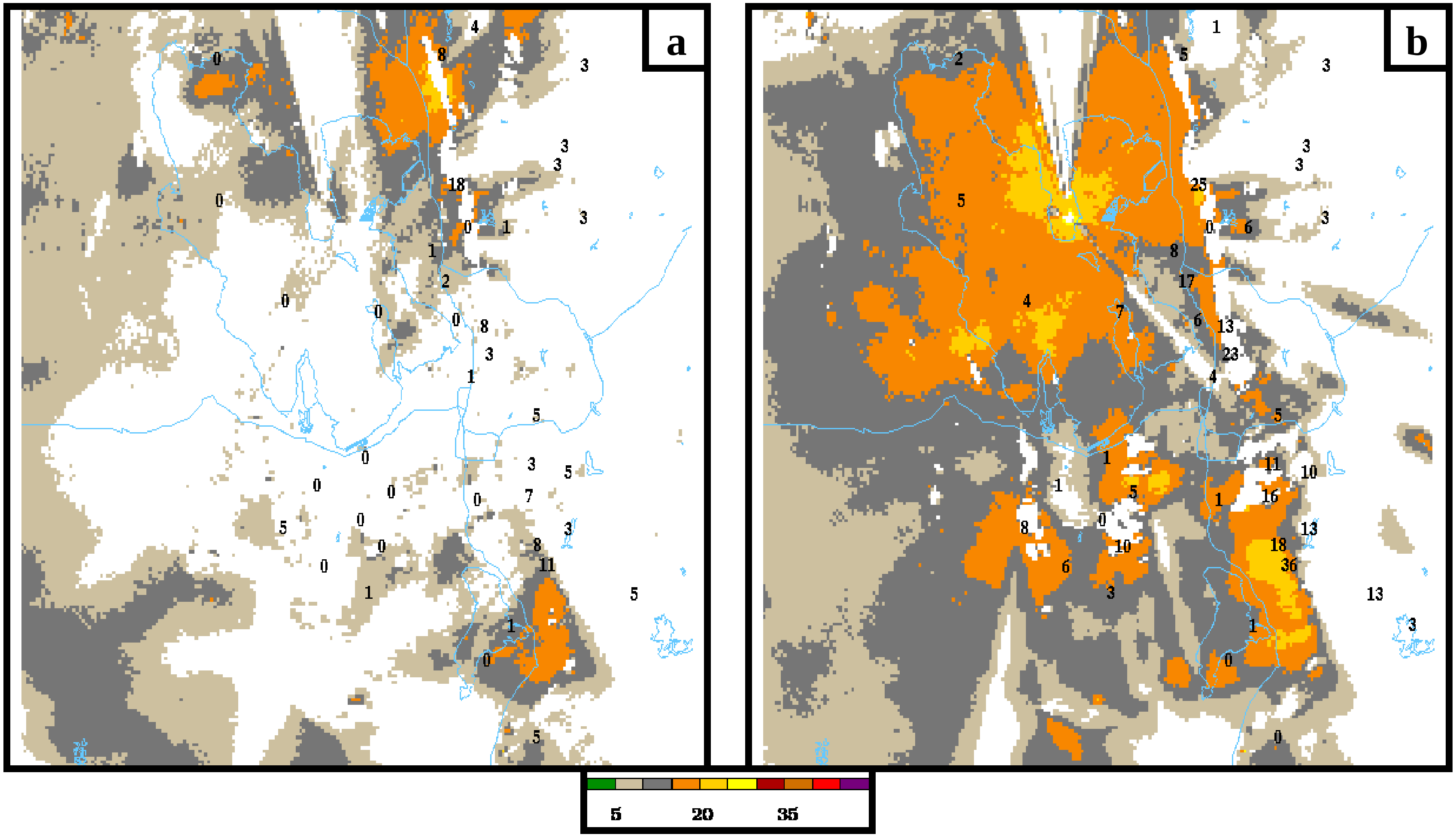

Figure 4.8. Precipitation (mm) and median reflectivity (dBZ) for the 6-h periods ending a) 1200 UTC and b) 1800 UTC 12 February and c) 0000 UTC and d) 0600 UTC 13 February during IOP 3. The median reflectivity is shaded according to the scale at the bottom of the figure.

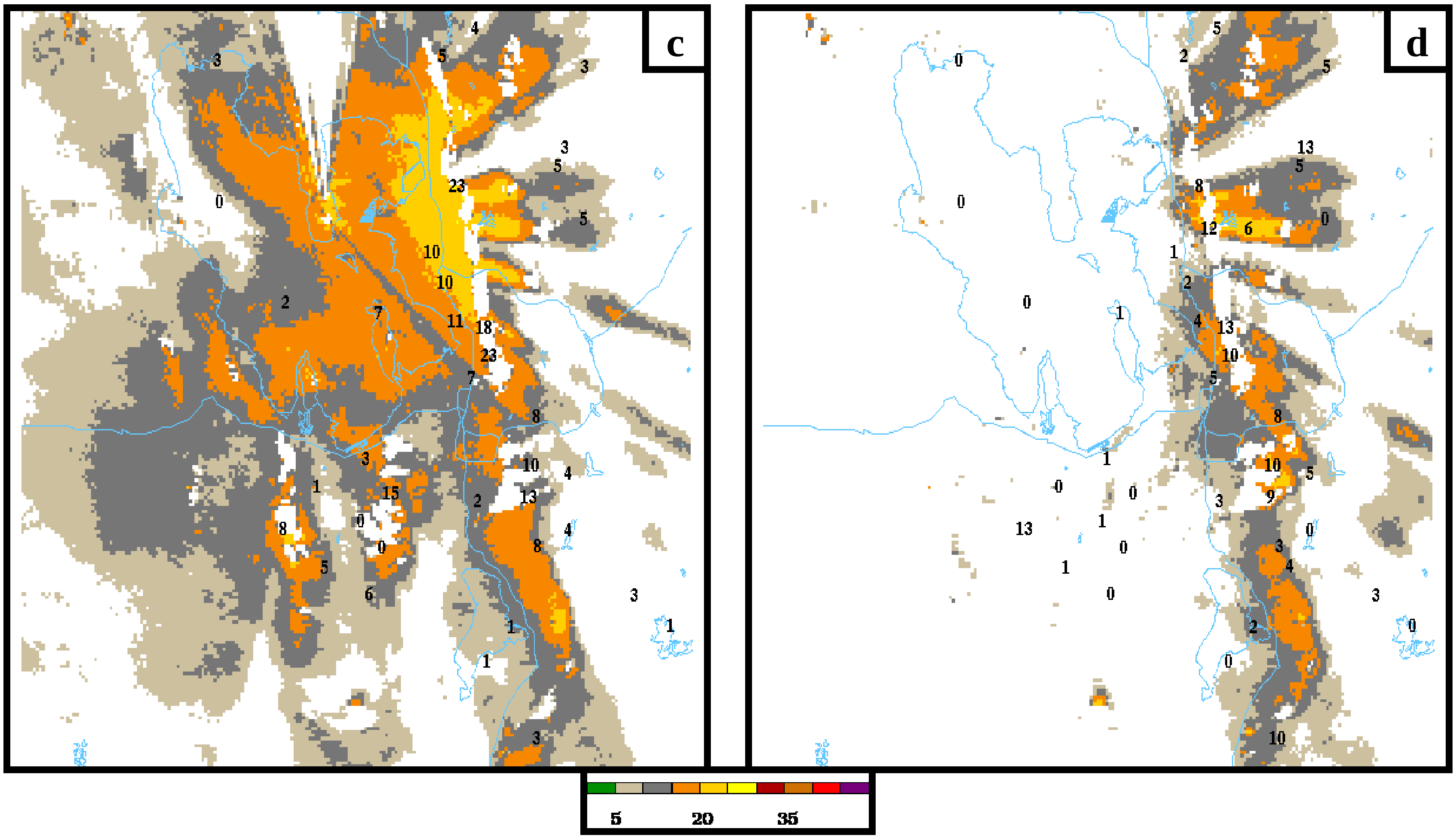

Figure 4.8. (Continued)

During the next 6-h period, the flow was still southwesterly, and SLC soundings show a deep layer of moisture from near the surface up to around 500 hPa (not shown). Precipitation in the area during this period became more widespread (Fig. 4.8b), as evident from both the radar and gauge data, with enhancement along the mountain ranges. Areas of radar beam blockage and ground clutter removal are evident in the reflectivity field, with blockage along the Wasatch, Oquirrh, and Stansbury mountains. A large area of blockage is also evident along the Promontory Mountains immediately to the north of the radar.

The 700-hPa flow shifted to westerly during the next 6-h period, with significant moisture still present in the middle troposphere. Precipitation was still widespread (Fig. 4.8c), but the heaviest was concentrated in the mountains, particularly the northern Wasatch Range. Median reflectivity values for most of the northern Wasatch during this period were greater than 20 dBZ. Finally, during the last period, the flow became west-northwesterly, and precipitation was mainly limited to the mountains (Fig. 4.8d). Median reflectivity values exceeding 20 dBZ are evident along parts of the Wasatch Range.

IOP 4

A strong cold front with an associated line of thunderstorms was forecast to move through northern Utah around 0000 UTC 15 February. An IOP took place 1800 UTC 14 February-0900 UTC 15 February to study this event. Strong winds were associated with this cold front, and a bow echo formed over the Snake River Plain in Idaho. Wind gusts in northern Utah reached 27 m s^{-1} (60 mph) for many areas, with a peak gust of 43 m s^{-1} (96 mph) reported at Hidden Peak in the Wasatch. Significant damage was reported, including broken windows and downed power lines and trees. One casualty caused by a falling tree was reported in Brigham City in northern Utah.

The squall line approached the Great Salt Lake from the northwest around 2300 UTC 14 February. Reflectivity values associated with the squall line were greater than 45 dBZ in several places. An analysis from the RUC2 at 0000 UTC 15 February (Fig. 4.9) shows a 500-hPa trough situated over parts of Oregon, Idaho, and Nevada. Large-scale ascent over southern Idaho and northern Utah was analyzed ahead of the trough. A baroclinic zone at 700 hPa is evident along southern Idaho, northwest Utah, and Nevada. Winds at 700 hPa were analyzed to be more than 25 m s^{-1} (50 kts) over portions of Idaho, Utah, and Nevada. The surface pressure trough can be seen extending from the Idaho/ Wyoming border through northwest Utah and into Nevada.

A sounding taken from SLC at 0000 UTC 15 February (Fig. 4.10a) shows a relatively dry atmosphere just prior to the passage of the squall line. Three conditionally unstable layers capped by shallow inversions or stable layers are evident. Winds were strong from the surface up to 400 hPa. The winds were southerly at the surface and southwesterly at 700 hPa. The surface temperature at this time was around 12 ^{o}C. By the time the next sounding was taken, at 0300 UTC (Fig. 4.10b), the cold front had already passed through. The atmosphere had moistened significantly, the surface temperature had dropped to 5 ^{o}C, and winds at the surface had shifted to northwesterly, but the winds were still strong throughout the troposphere.

Figure 4.11 shows the observed precipitation for the period 1800 UTC 14 February-1200 UTC 15 February. Precipitation totals were relatively small throughout most of the region compared to the previous two IOPs due to the fast-moving nature and

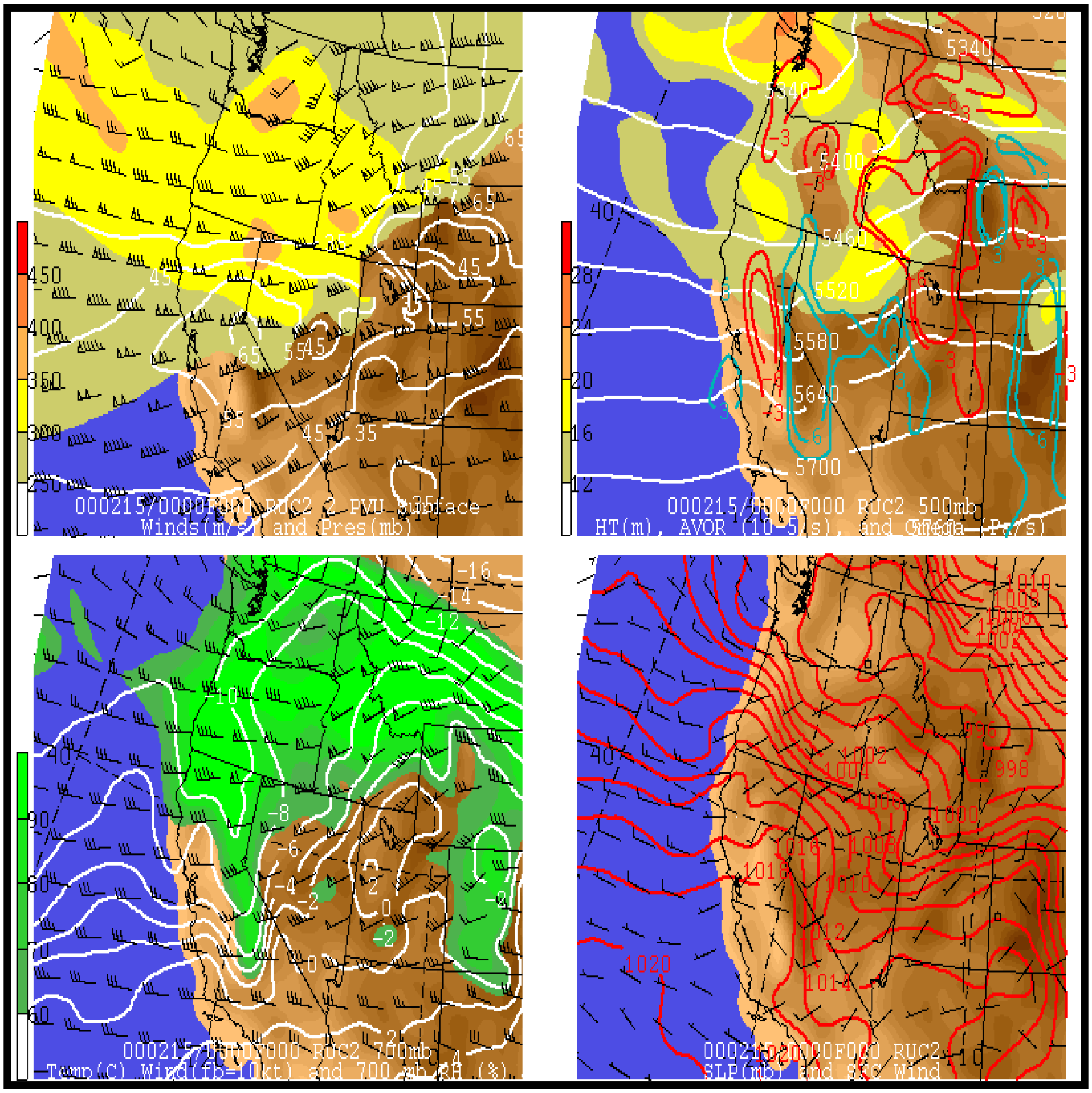

Figure 4.9. Four-panel RUC2 analysis from 0000 UTC 15 February. Upper left panel shows the pressure of the 2-PVU surface (hPa, shaded according to scale bar), wind speed (m s^{-1}), and wind (full barb=5.1 m s^{-1} (10 kt)). Upper right panel shows the 500-hPa height (m), absolute vorticity (10^{-5} s^{-1}, shaded according to scale bar), and vertical velocity (Pa s^{-1}). Lower left panel shows 700-hPa temperature (^{o}C), relative humidity (%, shaded according to scale bar), and wind (full barb=5.1 m s^{-1} (10 kt)). Lower right panel shows sea level pressure (hPa) and surface wind (full barb=5.1 m s^{-1} (10 kt)).

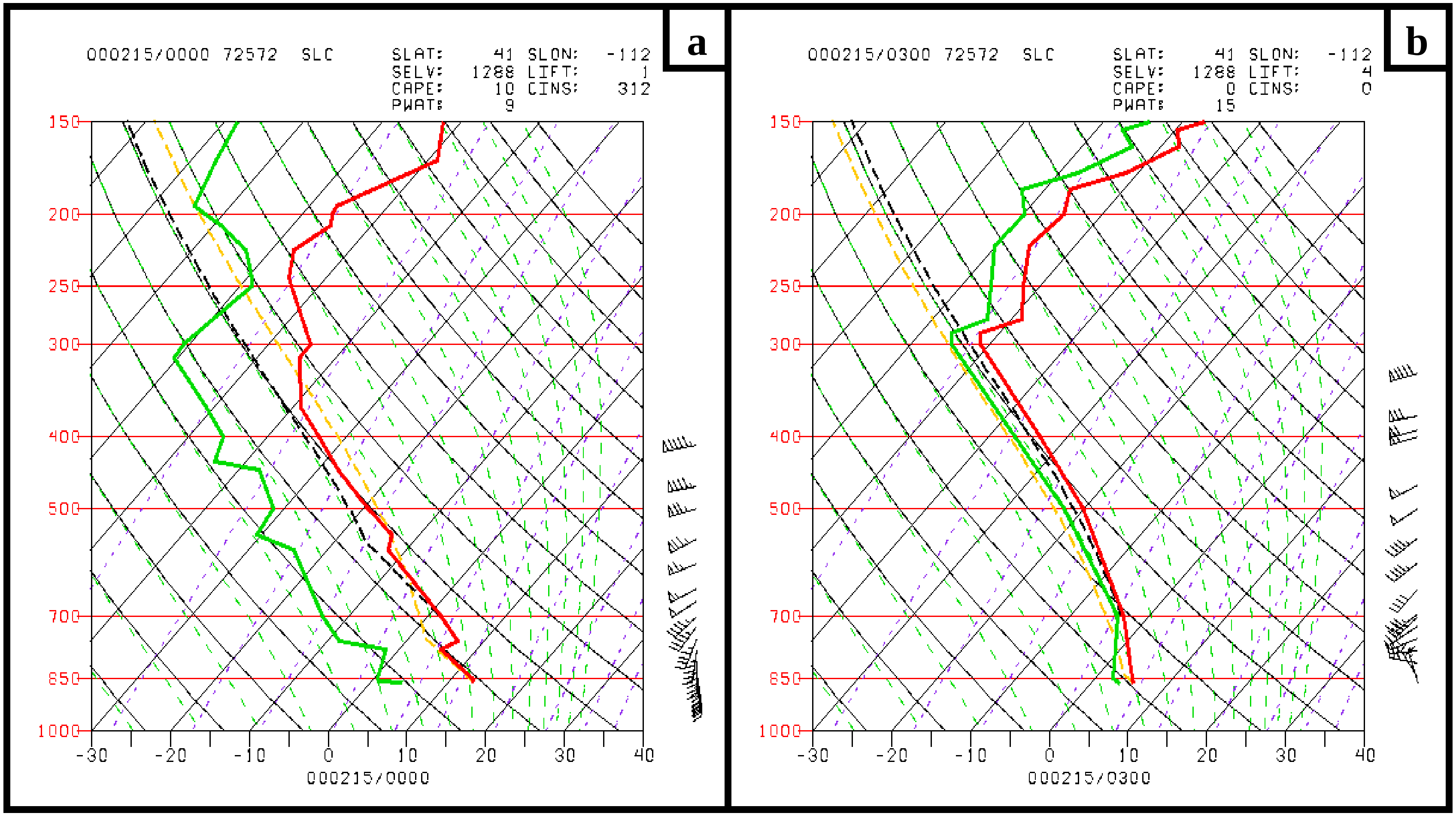

Figure 4.10. Soundings taken from SLC at a) 0000 UTC and b) 0300 UTC 15 February.

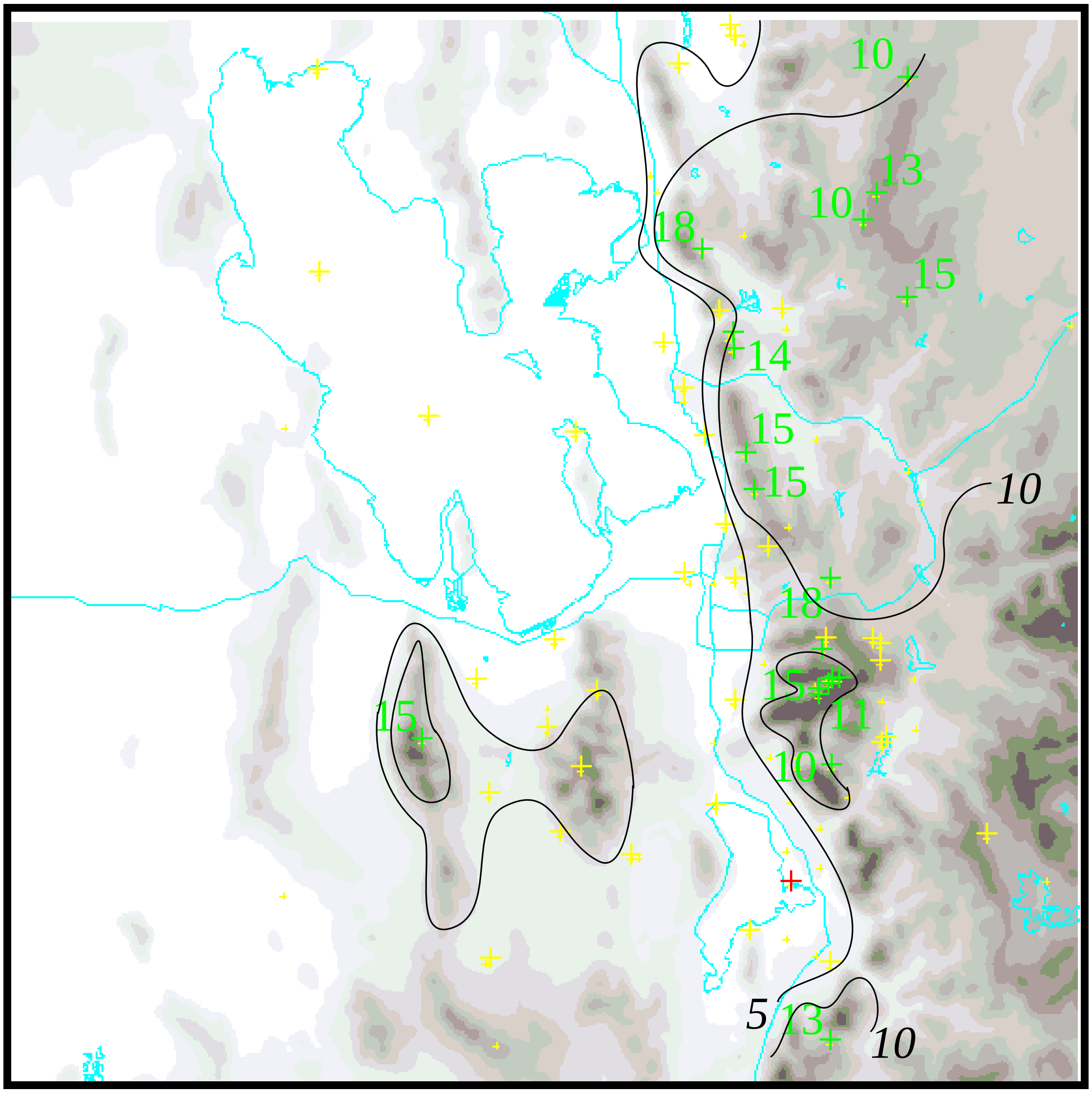

Figure 4.11. Observed spatial distribution of precipitation for the period 1800 UTC 14 February-1200 UTC 15 February during IOP 4. Markers identify stations reporting precipitation during the period. Red markers denote stations reporting zero or trace amounts of precipitation, yellow markers denote stations reporting measurable precipitation but less than 10 mm, green markers denote stations reporting at least 10 mm but less than 20 mm, and blue markers denote stations reporting at least 20 mm of precipitation. Selected stations are labeled with the observed precipitation totals to the nearest mm. Contours were created subjectively based upon the available data. Contours are isohyets of 5 and 10 mm.

narrow structure of the precipitation band. Precipitation totals were less than 20 mm at all of the stations, with the largest amounts reported at higher-elevation sites, especially along the northern part of the Wasatch. Orographic enhancement of precipitation is evident during this IOP, but the contrast between the mountains and valleys is much smaller than during IOP 3.

Median radar reflectivity and observed precipitation for the three 6-h periods during the time range depicted in Fig. 4.11 are shown in Fig. 4.12. During the first 6-h period (Fig. 4.12a), surface reports show scattered light precipitation at high-elevation sites, particularly to the northeast. The precipitation in the northeast occurred near the beginning of the period in the warm advection ahead of the cold front, but ended shortly before the squall line moved through. During the next 6-h period (Fig. 4.12b), the median reflectivity shows a northeast-southwest oriented band. Radar loops (not shown) indicate that the band stalled at this position for several hours. Precipitation was predominantly located along and to the lee of the Wasatch and along the Stansbury Mountains. By the last 6-hr period (Fig. 4.12c), the precipitation band had moved out of the region and there were only a few scattered surface reports in the southeastern part of the domain.

IOP 5

The fifth IOP of IPEX was scheduled initially to study orographic enhancement of precipitation in moist northwesterly flow. The IOP took place 0900 UTC 17 February-1200 UTC 18 February as a low-level trough was expected to pass just north of the target area. However, as operations began to get under way, the large-scale circulation changed, and instead of passing to the north, the low-level center passed to the south of northern Utah, causing the flow to become northerly. The situation initially did not look too

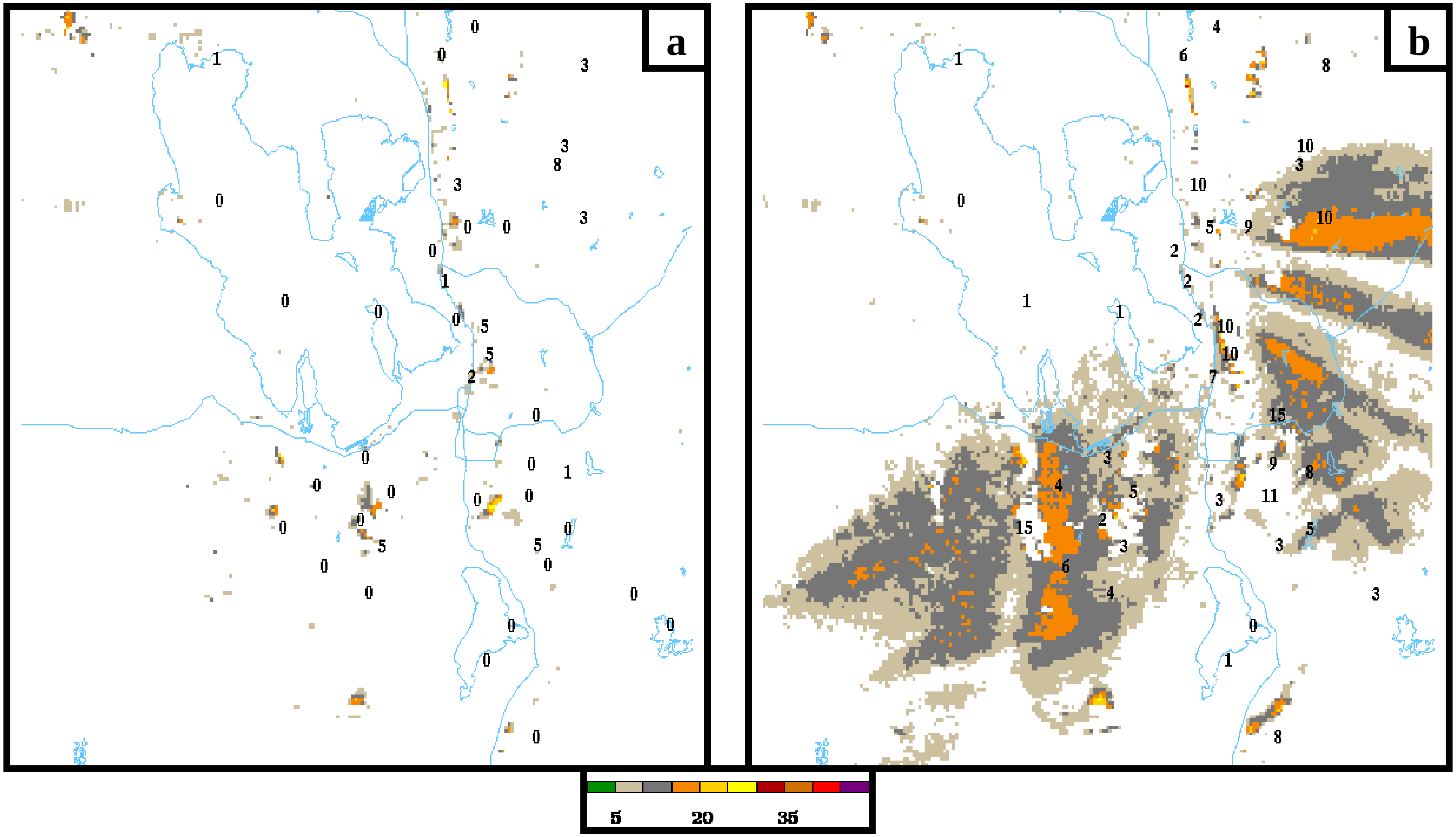

Figure 4.12. Precipitation (mm) and median reflectivity (dBZ) for the 6-h periods ending a) 0000 UTC, b) 0600 UTC, and c) 1200 UTC 15 February during IOP 4. The median reflectivity is shaded according to the scale at the bottom of the figure.

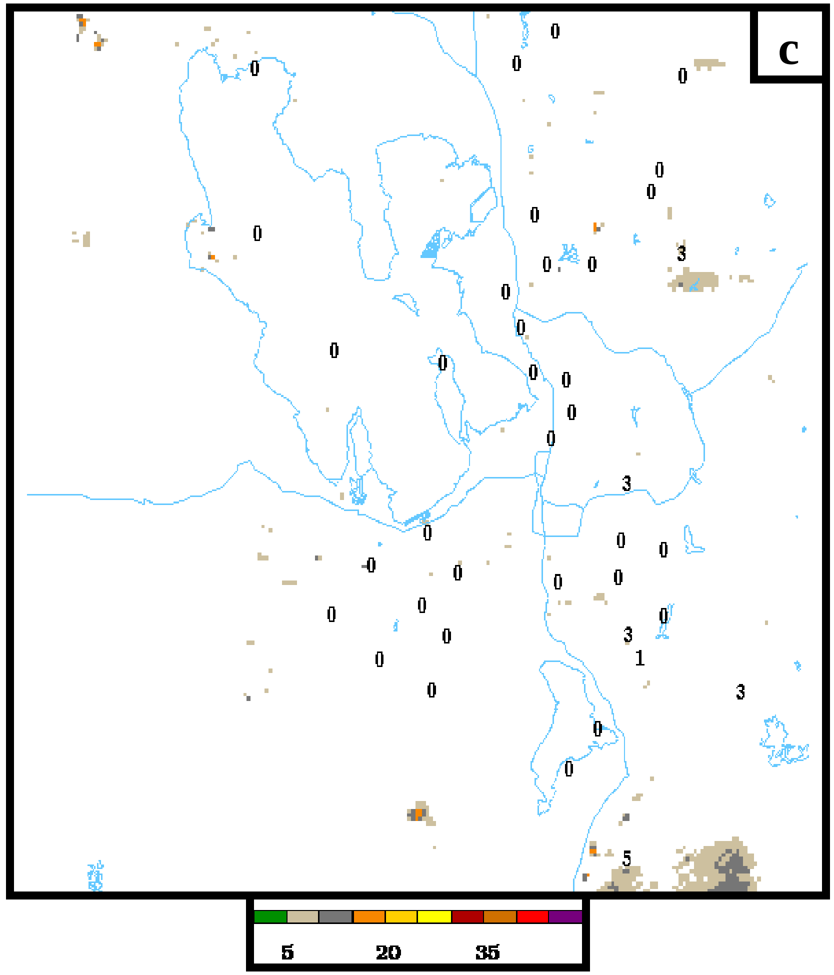

Figure 4.12. (Continued)

promising for an IOP. However, precipitation eventually developed in the area under a complex flow regime.

The synoptic situation at 1200 UTC 17 February, just after the start of the IOP, is depicted by the RUC2 analysis in Fig. 4.13. At this time, the upper-level trough was moving through northern Arizona, and the largest absolute vorticity values were located in southern Utah and further south. Winds at 700 hPa were northerly over northern Utah, and the relative humidity at that level was generally less than 80%. The surface low was located in central Utah just to the south of the target area. Soundings taken from SLC every 3 h during 17 February (not shown) indicate winds veering from southeasterly to northwesterly at the surface, and from southerly to easterly at 700 mb before settling at northwesterly by 18 February. Precipitation bands developed in northern Utah, with the storm eventually producing heavy localized precipitation in the Tooele Valley.

Figure 4.14 shows the observed precipitation during the 30-h period 0600 UTC 17 February-1200 UTC 18 February. The distribution of precipitation is rather complex, with maxima located in the Tooele Valley and parts of the Wasatch Front and Wasatch Range. Amounts were relatively light in most areas, with only one site reporting a total exceeding 20 mm. However, there was an outage in the data transmission system from the Tooele Valley sites for several hours during the snowstorm. Thus, it is impossible to determine the exact amounts from the automated stations there during the IOP, but the data that was retrieved for part of the IOP indicate that many of those sites received at least 10 mm. The heaviest precipitation during this IOP appears to be extremely localized, with evidence of only very weak orographic enhancement.

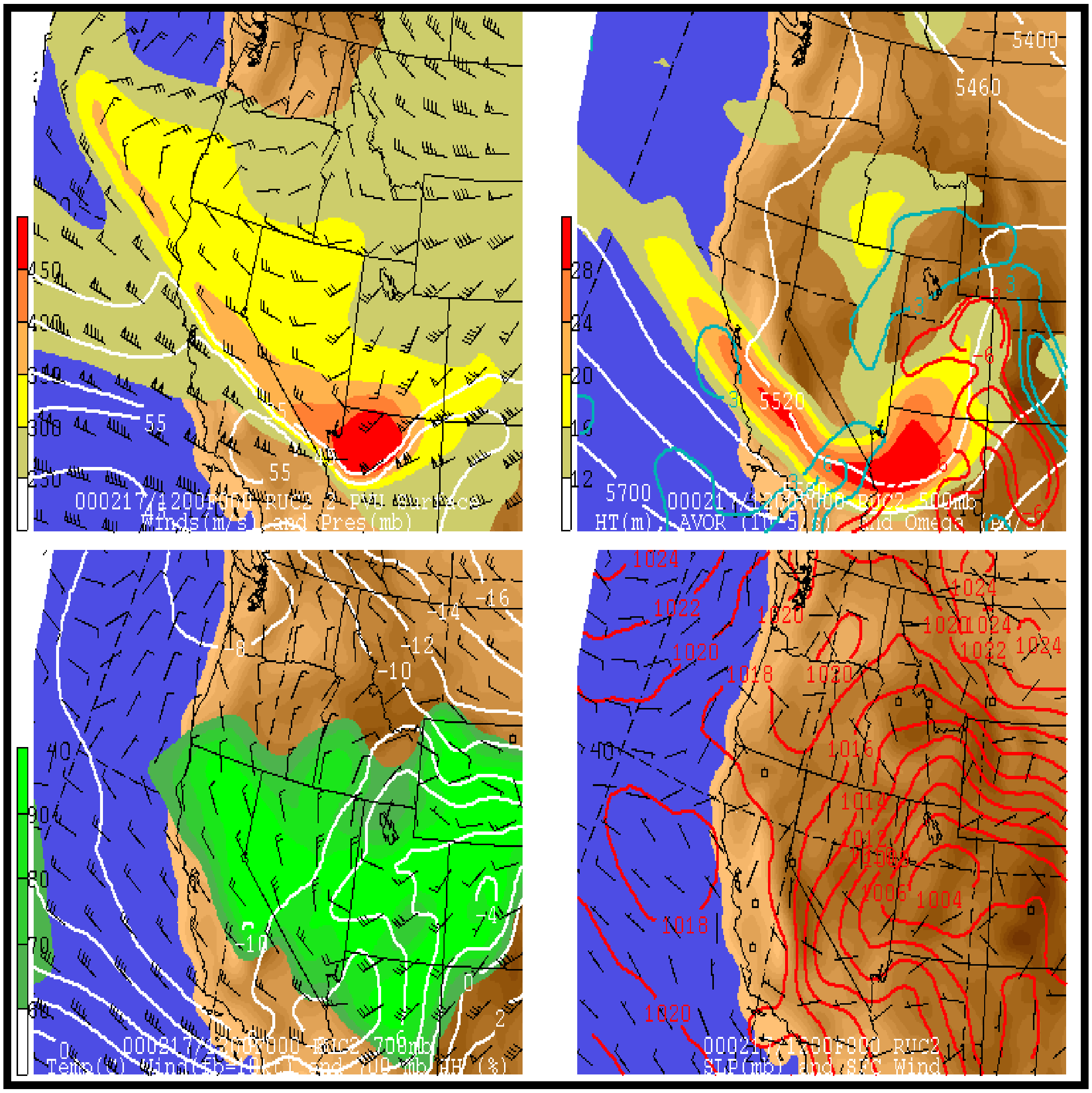

Figure 4.13. Four-panel RUC2 analysis from 1200 UTC 17 February. Upper left panel shows the pressure of the 2-PVU surface (hPa, shaded according to scale bar), wind speed (m s^{-1}), and wind (full barb=5.1 m s^{-1} (10 kt)). Upper right panel shows the 500-hPa height (m), absolute vorticity (10^{-5} s^{-1}, shaded according to scale bar), and vertical velocity (Pa s^{-1}). Lower left panel shows 700-hPa temperature (^{o}C), relative humidity (%, shaded according to scale bar), and wind (full barb=5.1 m s^{-1} (10 kt)). Lower right panel shows sea level pressure (hPa) and surface wind (full barb=5.1 m s^{-1} (10 kt)).

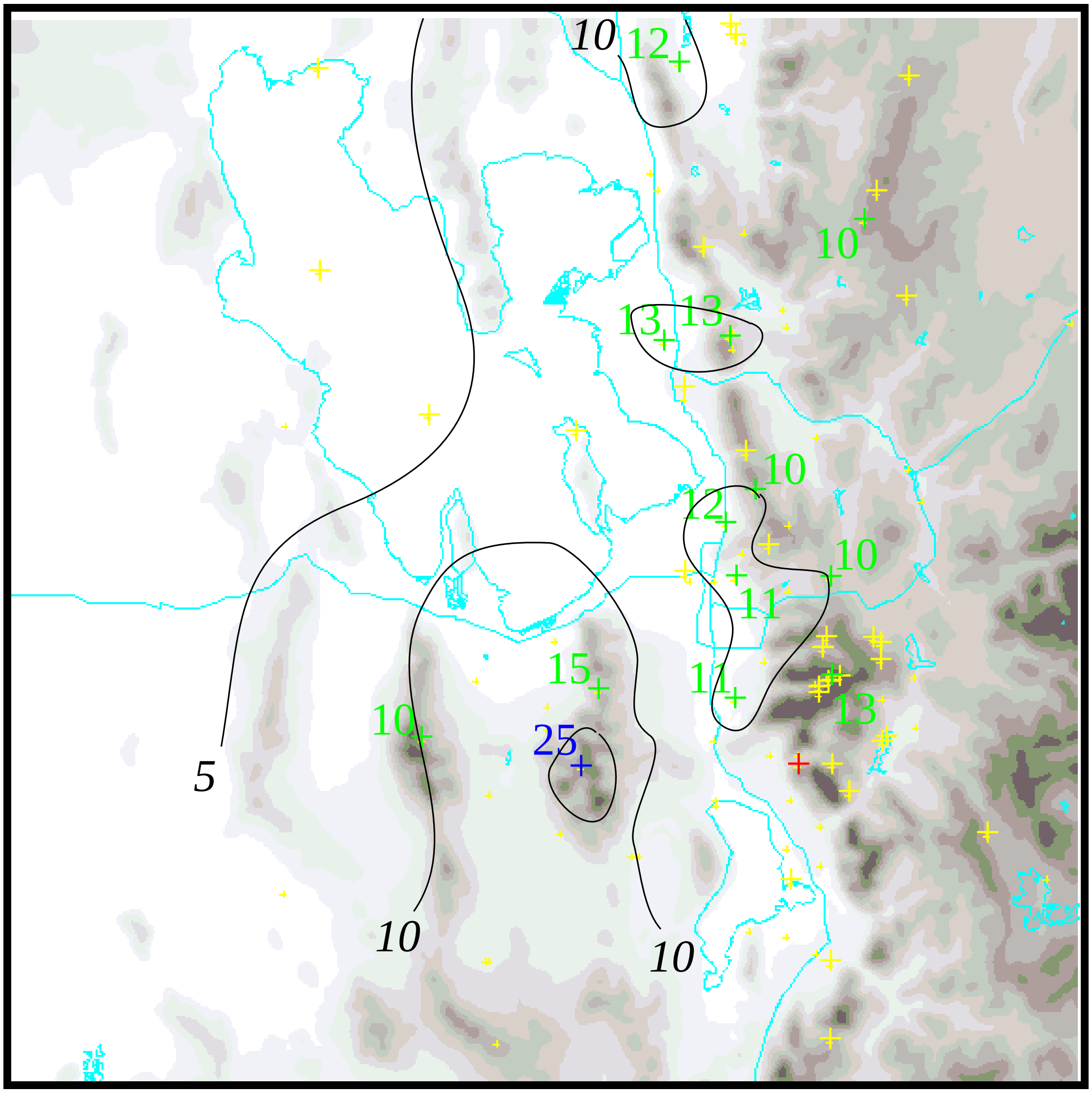

Figure 4.14. Observed spatial distribution of precipitation for the period 0600 UTC 17 February-1200 UTC 18 February during IOP 5. Markers identify stations reporting precipitation during the period. Red markers denote stations reporting zero or trace amounts of precipitation, yellow markers denote stations reporting measurable precipitation but less than 10 mm, green markers denote stations reporting at least 10 mm but less than 20 mm, and blue markers denote stations reporting at least 20 mm of precipitation. Selected stations are labeled with the observed precipitation totals to the nearest mm. Contours were created subjectively based upon the available data. Contours are isohyets of 5, 10, and 20 mm.

Figure 4.15 shows the median radar reflectivity along with surface reports for the five 6-h periods that make up the period shown in Fig. 4.14. During the first 6-h period (Fig. 4.15a), significant echoes are evident in a narrow northeast-southwest band that stretched across the northwestern part of the domain. A report of 2 mm at Gunnison Island in the northern part of the Great Salt Lake corresponds to the location of the band. Other surface reports show light amounts of precipitation in the Tooele Valley and scattered along the Wasatch Range. The flow at the beginning of this period was predominantly south-southwesterly from near the surface to 700 hPa, but veered around to northerly from the surface to just below 700 hPa by 1200 UTC (not shown).

During the next 6-h period, soundings (not shown) indicate an easterly 700 hPa flow, but the flow was northwesterly at the lower levels. The flow became northwesterly from the surface up to just below 700 hPa by the end of the period. A band of precipitation with a large area of at least 20-dBZ median reflectivity extended over the southern part of the Great Salt Lake and into the Tooele Valley (Fig. 4.15b) during this time. Gauge reports from the Stansbury and Oquirrh mountains confirm the occurrence of precipitation, but the data outage at the Tooele Valley sites occurred during this time. Scattered sites along the northern Wasatch Front and Wasatch Range as well as the southern Wasatch also reported precipitation. By the next 6-h period (Fig. 4.15c), the precipitation band extended from the southeastern part of the Great Salt Lake out into the valleys to the south and east. Data from the next 6-h period (Fig. 4.15d) show scattered light precipitation along the Wasatch Front and along the crest of the Wasatch as well as in the Tooele area. By the last period, very little precipitation was reported in the area (Fig. 4.15e).

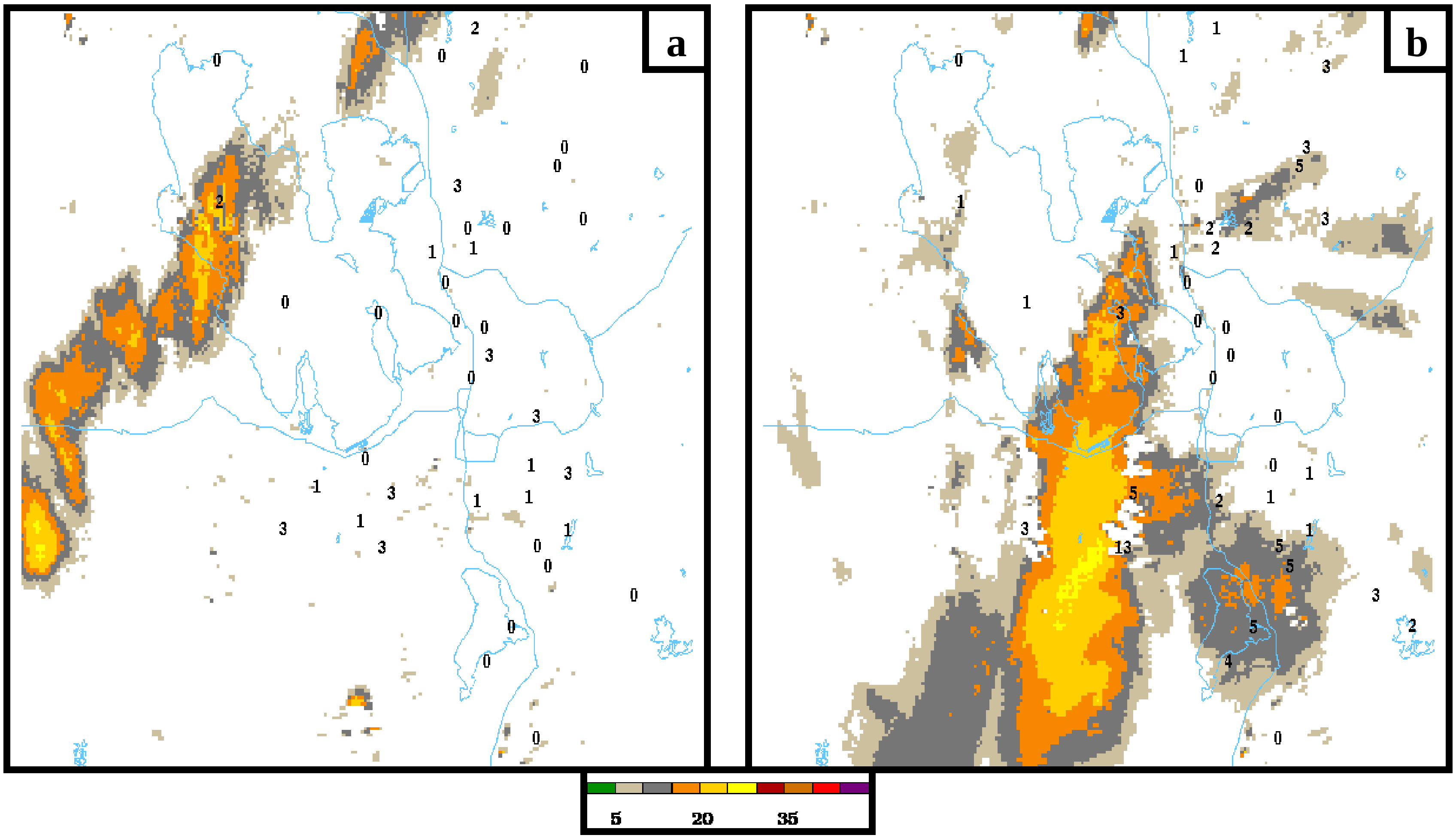

Figure 4.15. Precipitation (mm) and median reflectivity (dBZ) for the 6-h periods ending a) 1200 UTC and b) 1800 UTC 17 February and c) 0000 UTC, d) 0600 UTC, and e)1200 UTC 18 February during IOP 5. The median reflectivity is shaded according to the scale at the bottom of the figure.

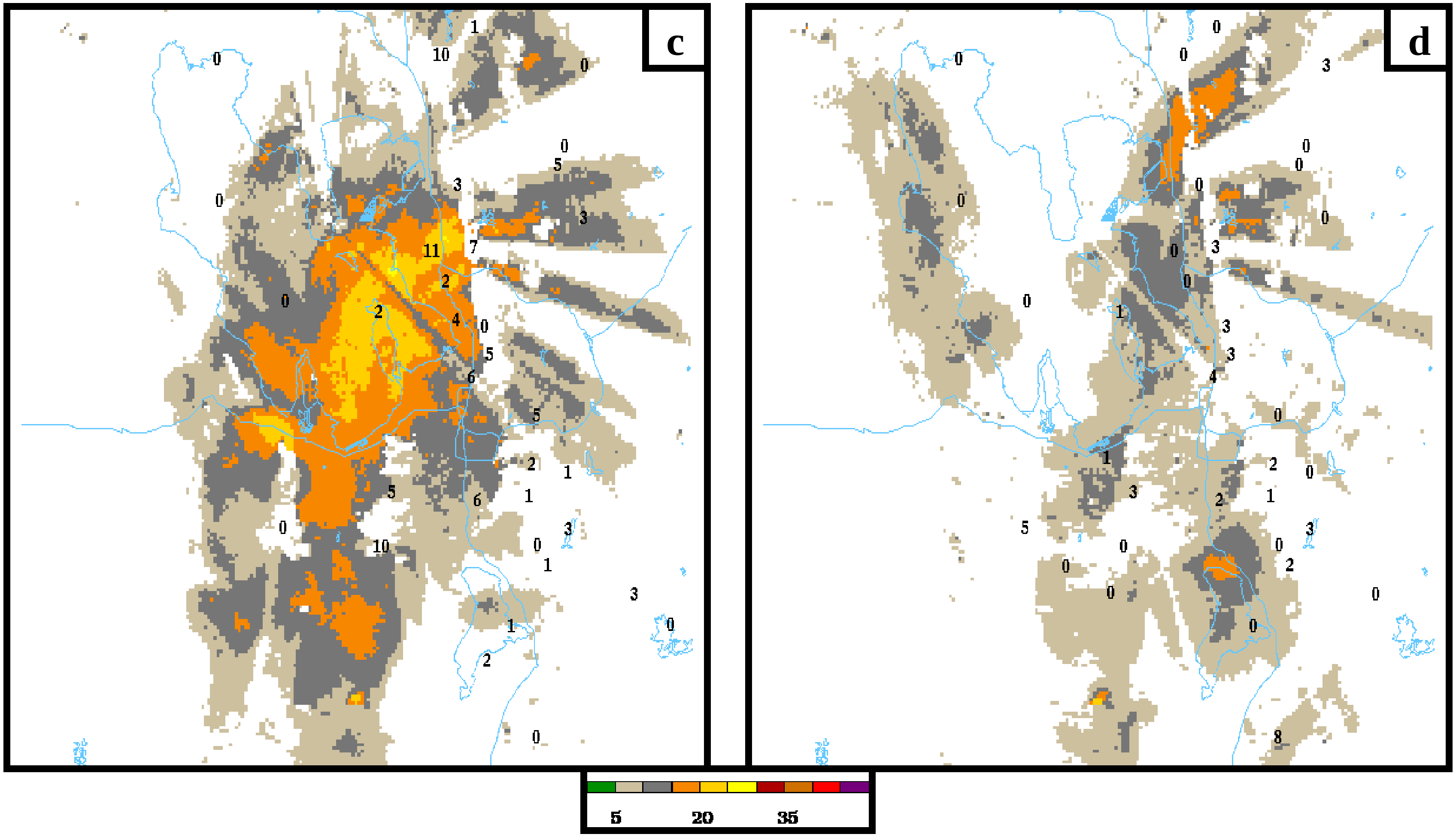

Figure 4.15. (Continued)

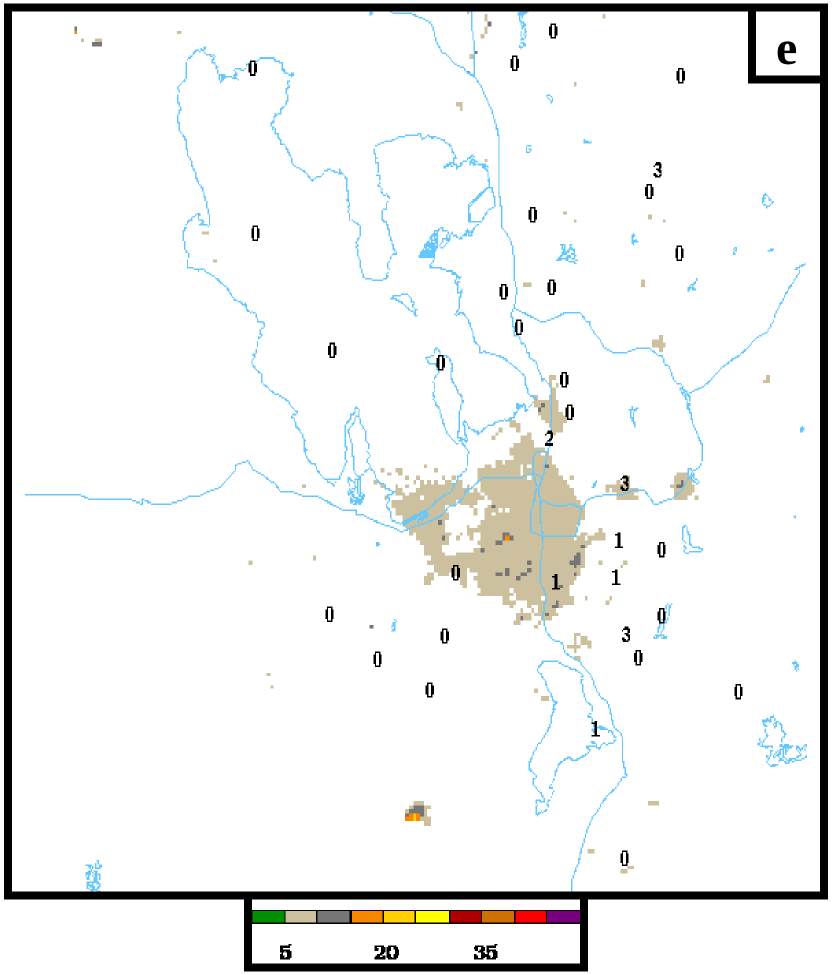

Figure 4.15. (Continued)

IOP 6

The sixth IOP of IPEX took place 2100 UTC 21 February-0600 UTC 22 February. The intent of this IOP was to study a large-scale convective event under southerly flow as a deep upper-level trough moved through the southwestern United States. This thunderstorm event brought hail to parts of southwest Utah and caused a rockslide in the Wasatch.

Figure 4.16 shows the synoptic conditions at 0000 UTC 22 February, shortly after the IOP began. A deep upper-level trough was located in the vicinity of southern California. The trough was preceded by a broad area of large-scale ascent over western Utah. A baroclinic zone with an associated area of 700-hPa relative humidity greater than 80% was moving into western Utah. The 700-hPa flow over Utah was southerly, and a surface low was located over northern Utah at this time. The SLC sounding taken at 0000 UTC (Fig. 4.17a), shortly before precipitation began, shows convective available potential energy (CAPE) greater than 145 J kg^{-1}, which is relatively high for the region during the winter. Winds veered from northerly to southeasterly between the surface and 700 hPa. The temperature at the surface at this time was 14 ^{o}C. By the time the 0300 UTC sounding (Fig. 4.17b) was taken, a deep moist layer was present with winds veering from southeasterly at the surface to southwesterly at 700 hPa, and the surface temperature had decreased to 8 ^{o}C.

Figure 4.18 shows the spatial map of precipitation during the period 1800 UTC 21 February-0600 UTC 22 February. The convective event brought precipitation to all of the observation stations. The distribution was fairly even, with just a slight increase along the

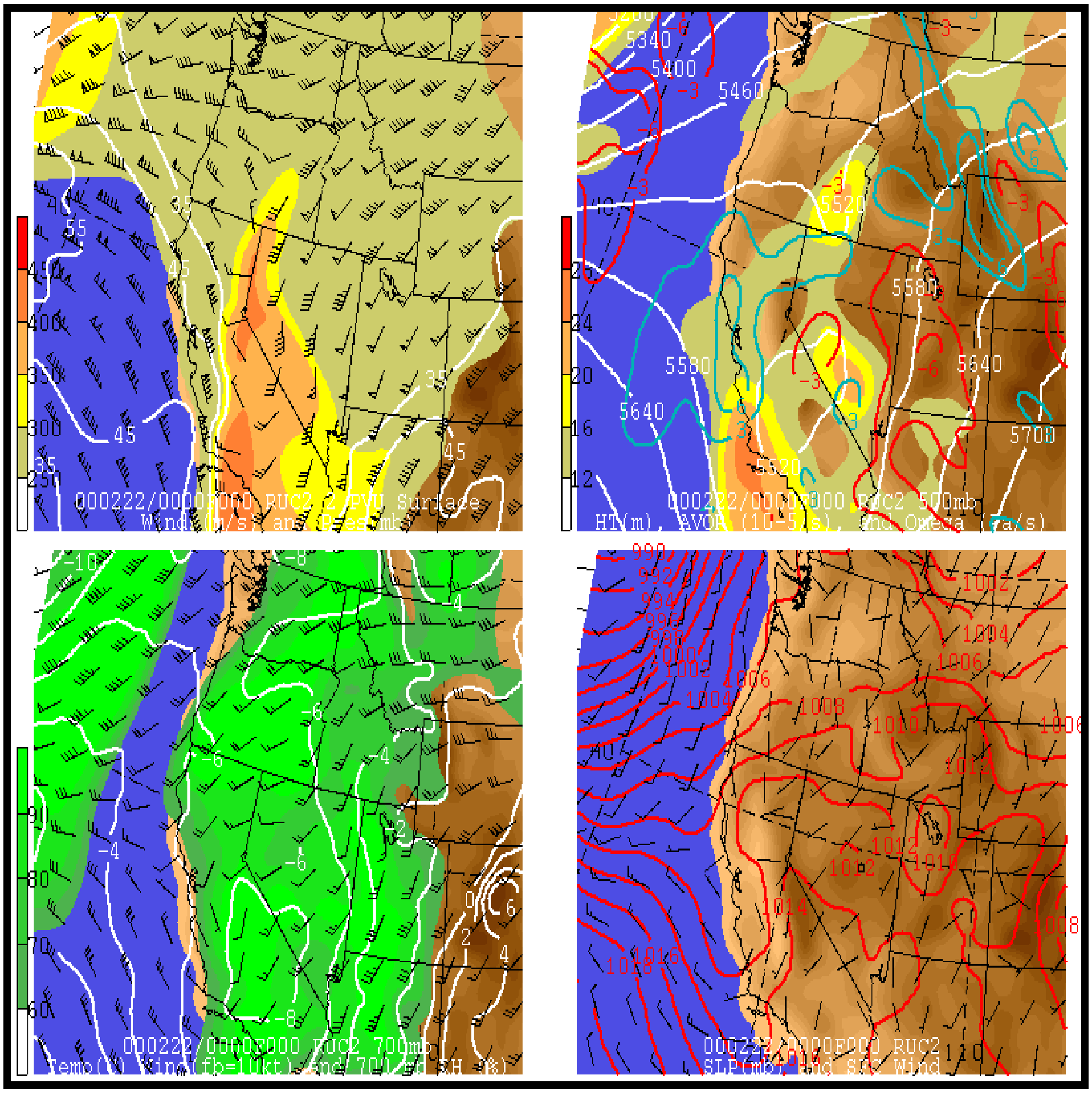

Figure 4.16. Four-panel RUC2 analysis from 0000 UTC 22 February. Upper left panel shows the pressure of the 2-PVU surface (hPa, shaded according to scale bar), wind speed (m s^{-1}), and wind (full barb=5.1 m s^{-1} (10 kt)). Upper right panel shows the 500-hPa height (m), absolute vorticity (10^{-5} s^{-1}, shaded according to scale bar), and vertical velocity (Pa s^{-1}). Lower left panel shows 700-hPa temperature (^{o}C), relative humidity (%, shaded according to scale bar), and wind (full barb=5.1 m s^{-1} (10 kt)). Lower right panel shows sea level pressure (hPa) and surface wind (full barb=5.1 m s^{-1} (10 kt)).

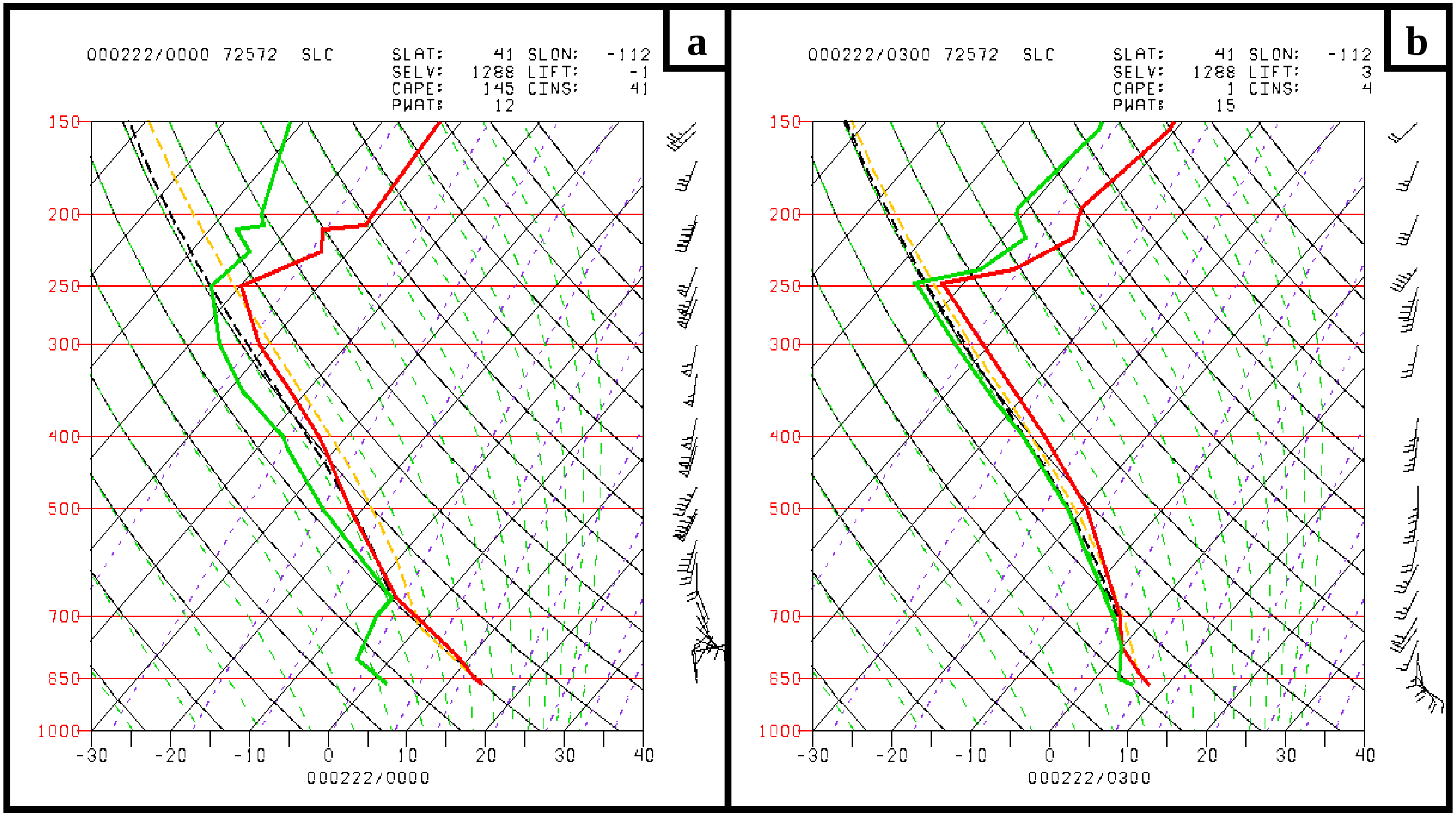

Figure 4.17. Soundings taken from SLC at a) 0000 UTC and b) 0300 UTC 22 February.

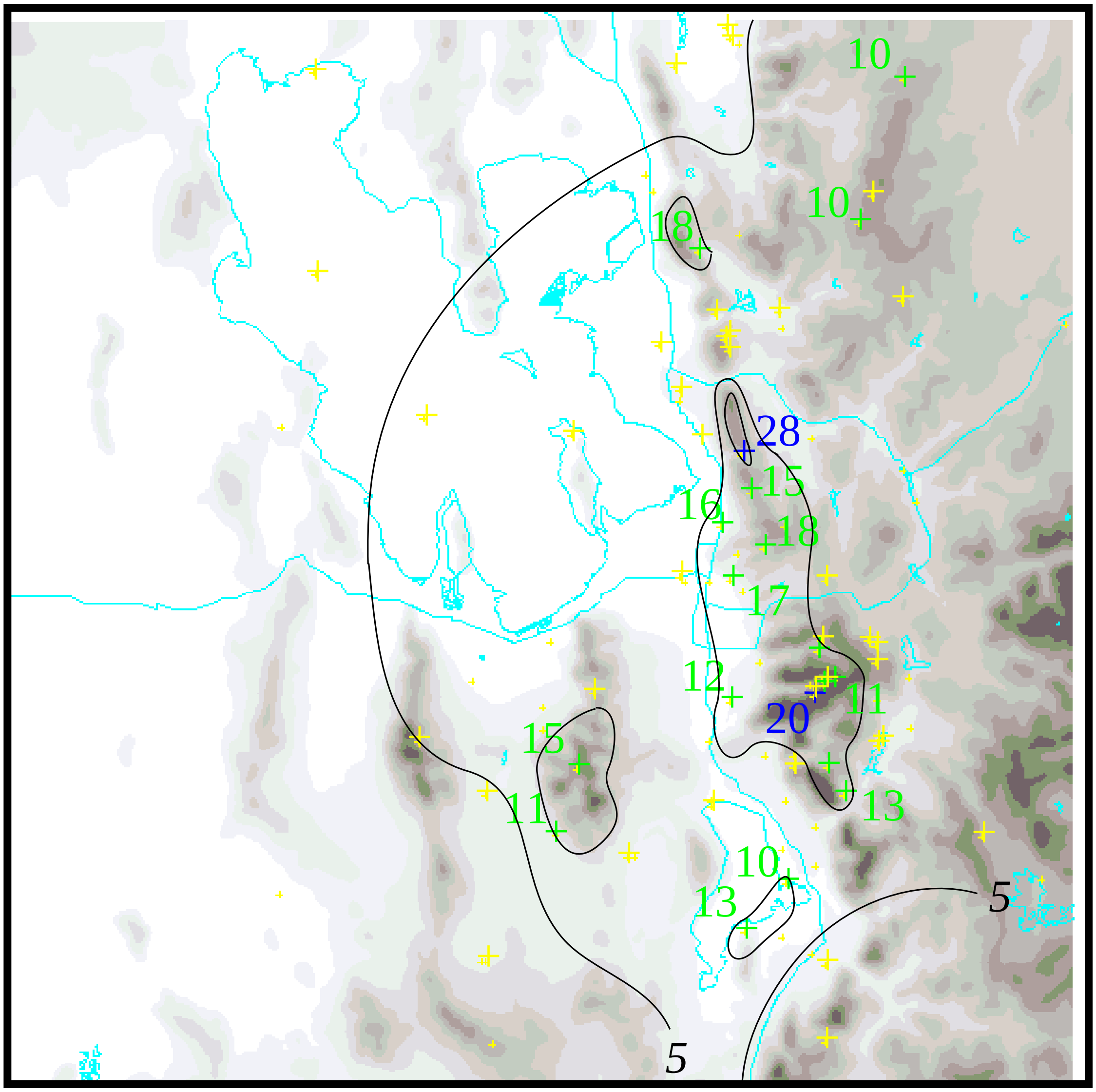

Figure 4.18. Observed spatial distribution of precipitation for the period 1800 UTC 21 February-0600 UTC 22 February during IOP 6. Markers identify stations reporting precipitation during the period. Red markers denote stations reporting zero or trace amounts of precipitation, yellow markers denote stations reporting measurable precipitation but less than 10 mm, green markers denote stations reporting at least 10 mm but less than 20 mm, and blue markers denote stations reporting at least 20 mm of precipitation. Selected stations are labeled with the observed precipitation totals to the nearest mm. Contours were created subjectively based upon the available data. Contours are isohyets of 5, 10, and 20 mm.

Wasatch Range and Wasatch Front. The maximum reported precipitation was 27.9 mm at Farmington. Other sites reported 20 mm of precipitation or less.

The 6-h precipitation totals and median radar reflectivity are shown in Fig. 4.19. Data from first 6-h period, ending at 0000 UTC 22 February (Fig. 4.19a), show precipitation reported in the Tooele Valley and Oquirrh mountains and at three sites along the Wasatch, with Farmington reporting 15 mm. Data from the next period (Fig. 4.19b) show a band of precipitation along the Wasatch Front and Wasatch Mountains, with median reflectivity values of at least 20 dBZ over several areas. The largest precipitation totals during this period were reported along the Wasatch crest. The large-scale flow during this period was predominantly southwesterly (not shown).

IOP 7

The final IOP of IPEX was called because an extended period of snow was likely as a cold front pushed through the western United States. The IOP took place 2100 UTC 23 February-0000 UTC 26 February. This event brought snow to the valley floor along the Wasatch Front. An avalanche was reported in the Snowbasin ski area near Ogden as a result of the heavy snow.

Figure 4.20 shows the synoptic conditions at 0900 UTC 24 February as the cold front was moving through northwest Utah. The upper-level trough axis and an associated vorticity maximum was located over the California/Nevada border at this time. Large-scale ascent was occurring over northwest Utah. The 700-hPa baroclinic zone was analyzed over the Utah/Nevada border, and the relative humidity was over 80%. Winds over Utah at 700 hPa were still southerly, but have shifted to northwesterly over Nevada. A

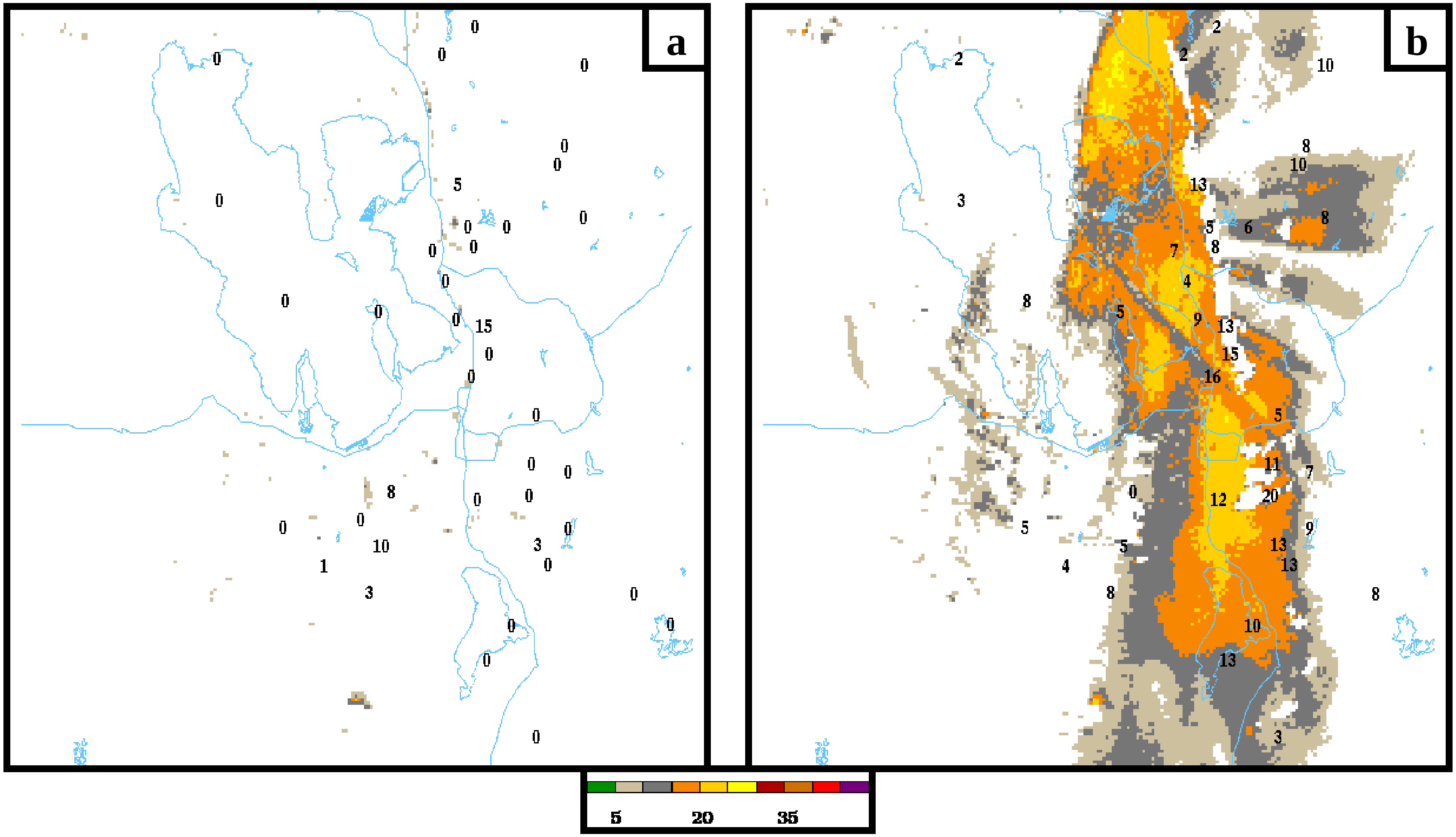

Figure 4.19. Precipitation (mm) and median reflectivity (dBZ) for the 6-h periods ending a) 0000 UTC and b) 0600 UTC 22 February during IOP 6. The median reflectivity is shaded according to the scale at the bottom of the figure.

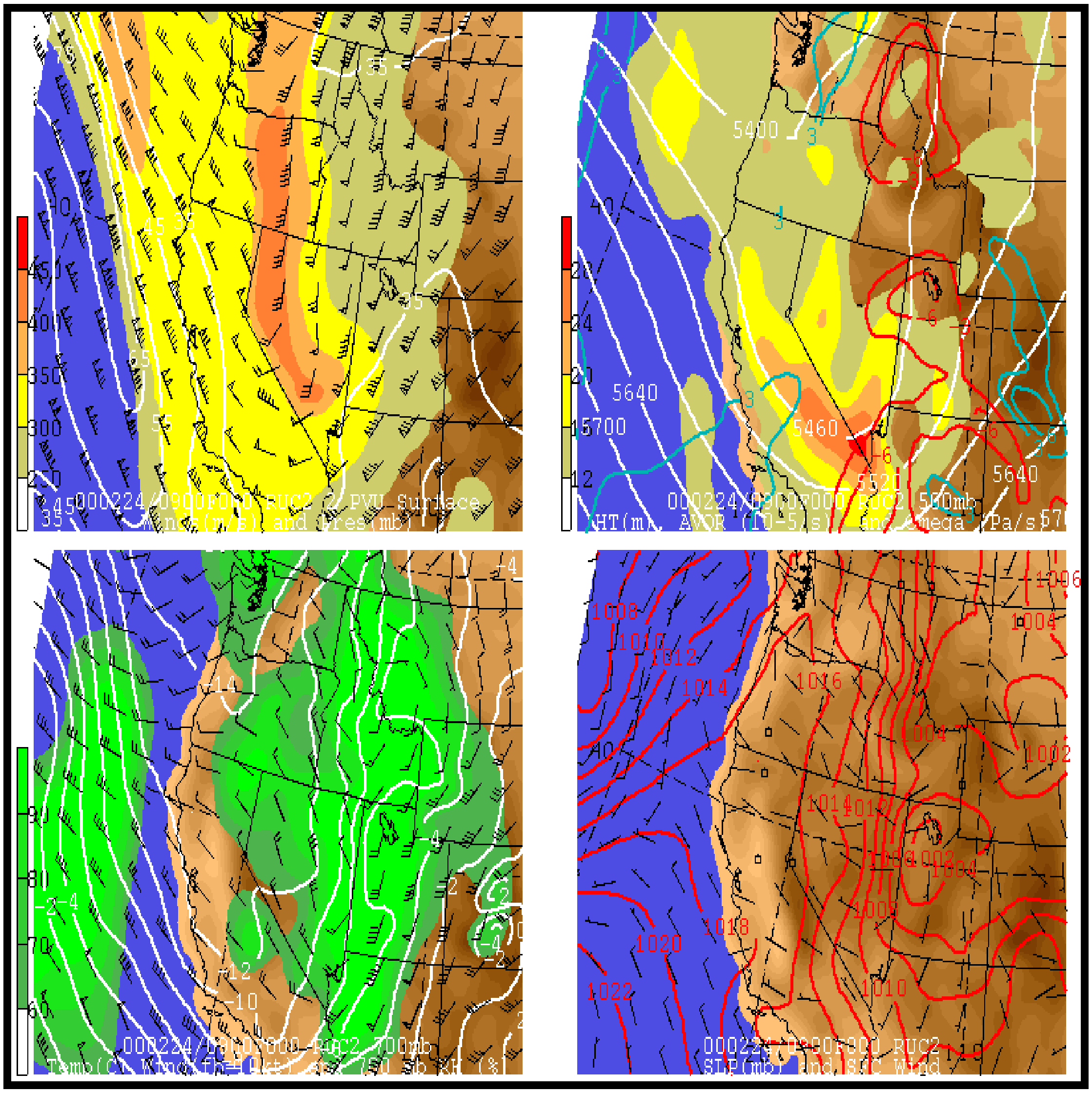

Figure 4.20. Four-panel RUC2 analysis from 0900 UTC 24 February. Upper left panel shows the pressure of the 2-PVU surface (hPa, shaded according to scale bar), wind speed (m s^{-1}), and wind (full barb=5.1 m s^{-1} (10 kt)). Upper right panel shows the 500-hPa height (m), absolute vorticity (10^{-5} s^{-1}, shaded according to scale bar), and vertical velocity (Pa s^{-1}). Lower left panel shows 700-hPa temperature (^{o}C), relative humidity (%, shaded according to scale bar), and wind (full barb=5.1 m s^{-1} (10 kt)). Lower right panel shows sea level pressure (hPa) and surface wind (full barb=5.1 m s^{-1} (10 kt)).

surface low pressure center was located over the Great Salt Lake with a strong pressure gradient just to the west.

Figure 4.21 shows the observed precipitation distribution for the period 0000 UTC 24 February-0000 UTC 25 February. The focus here is on the 24-h period when most of the precipitation fell, rather than on the entire IOP. Using the 0000-0000 UTC period takes advantage of the COOP observations, which are reported only once per day. Figure 4.21 shows that all sites reported measurable precipitation, with the heaviest totals located in the mountains. Several localized maxima are evident along different parts of the Wasatch and Oquirrhs. The maximum amount reported during this period was at the Collins lift at the Alta ski resort in the Cottonwood Canyons area, which had 43.4 mm of precipitation. Strong gradients of precipitation are evident in some areas of the Wasatch and Oquirrh Mountains. Relatively large totals were reported in climatologically arid areas such as over the Great Salt Lake and in the desert west of the lake. The spatial distribution of precipitation during this IOP is rather complex compared to the previous IOPs.

Figure 4.22 shows the surface observations and median reflectivity for the four 6-h periods during 24 February. During the first 6-h period (Fig. 4.22a), surface stations reported light precipitation throughout much of the area. Radar data show an east-west band of precipitation south of the Great Salt Lake. The main precipitation band was beginning to move into the area from the northwest. During the next 6-h period (Fig. 4.22b), precipitation was widespread, with reflectivity values greater than 20 dBZ in some areas. The heaviest precipitation during this period occurred around the mountains south of I-80. During this time, the flow was south-southeasterly, and orographic enhancement was evident on the eastern slopes of the mountains. The eastern slopes are the

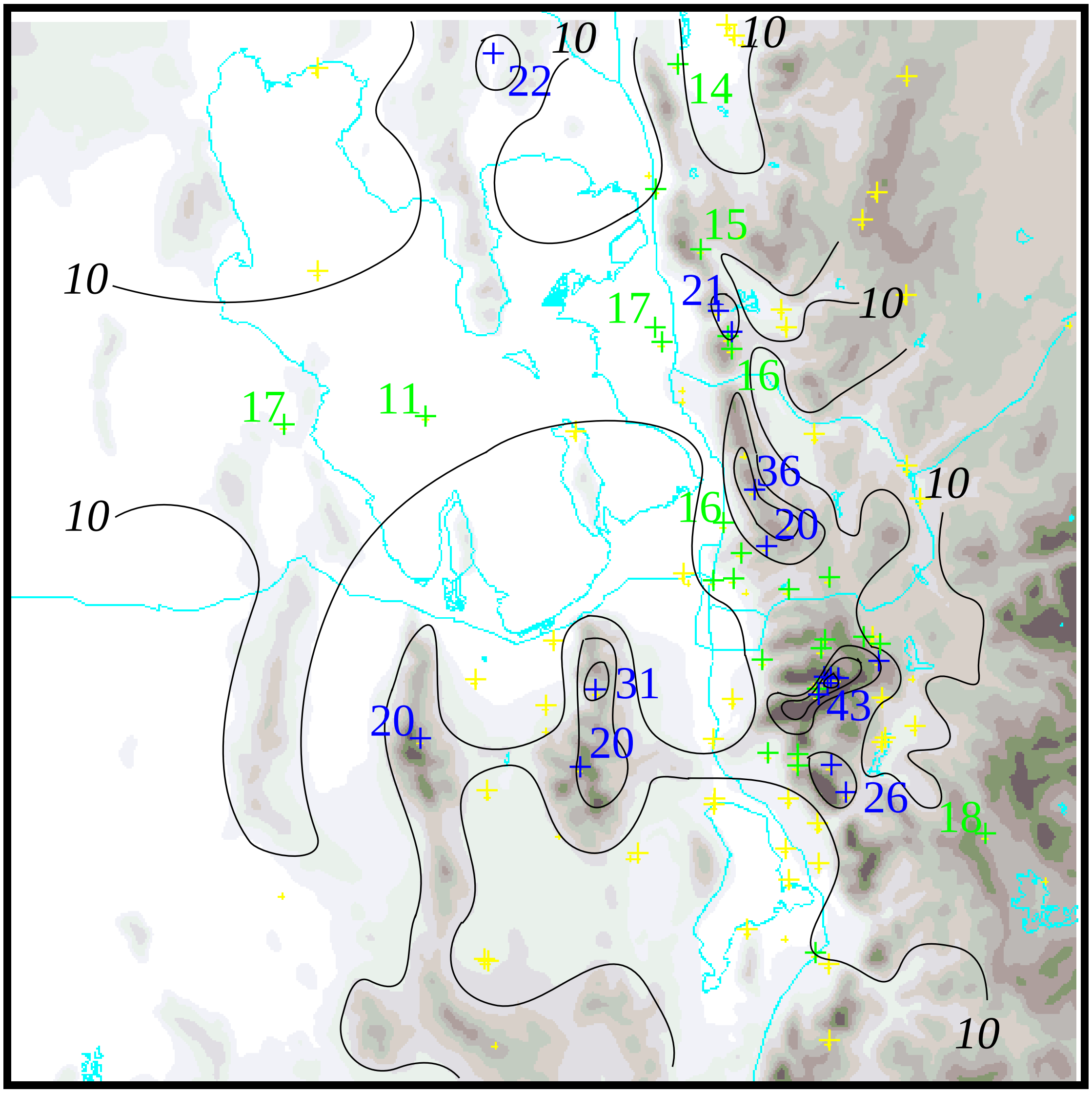

Figure 4.21. Observed spatial distribution of precipitation for the period 0000 UTC 24 February-0000 UTC 25 February during IOP 7. Markers identify stations reporting precipitation during the period. Red markers denote stations reporting zero or trace amounts of precipitation, yellow markers denote stations reporting measurable precipitation but less than 10 mm, green markers denote stations reporting at least 10 mm but less than 20 mm, and blue markers denote stations reporting at least 20 mm of precipitation. Selected stations are labeled with the observed precipitation totals to the nearest mm. Contours were created subjectively based upon the available data. Contours are isohyets of 10, 20, 30, and 40 mm.

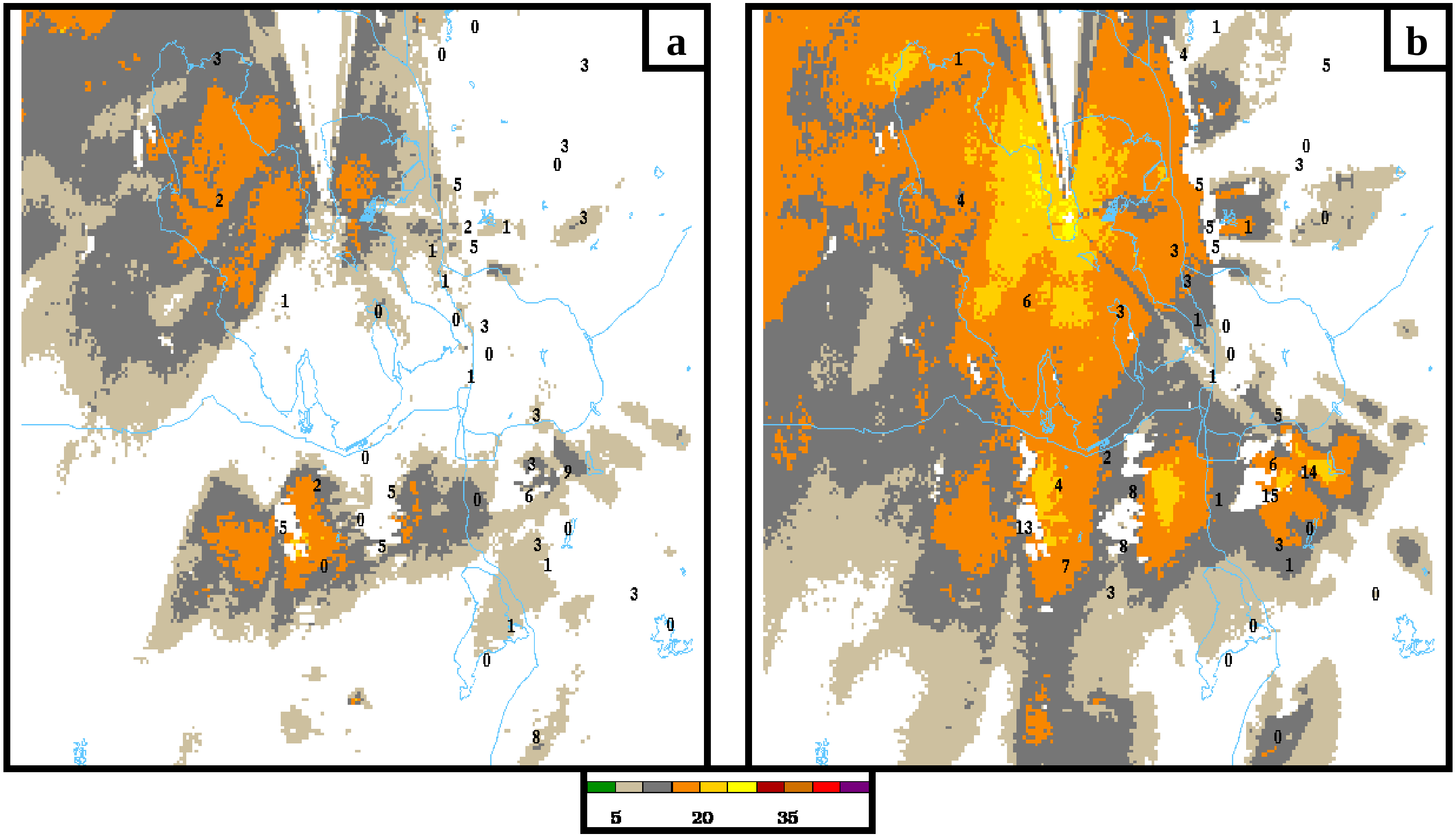

Figure 4.22. Precipitation (mm) and median reflectivity (dBZ) for the 6-h periods ending a) 0600 UTC, b) 1200 UTC, and c) 1800 UTC 24 February and d) 0000 UTC 25 February during IOP 7. The median reflectivity is shaded according to the scale at the bottom of the figure.

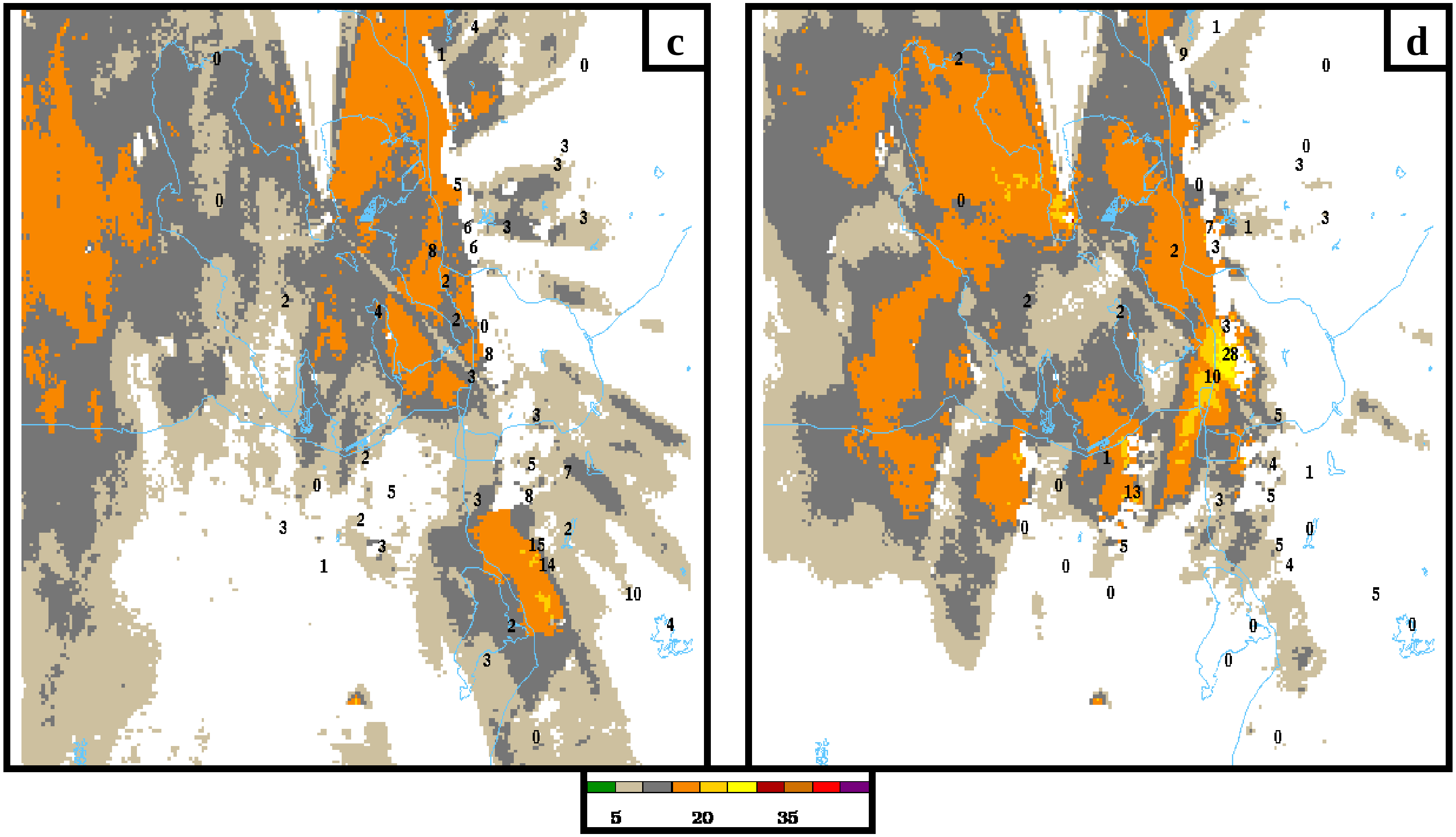

Figure 4.22. (Continued)

climatological lee slopes and usually receive less precipitation than the western slopes. However, the orographic enhancement on the eastern slopes in this case contributed to the relatively large totals reported at the stations immediately to the east of the Cottonwoods area of the southern Wasatch.

Precipitation decreased a little during the next 6-h period (Fig. 4.22c), with the largest totals reported along the southern Wasatch Mountains. During the final 6-h period (Fig. 4.22d), the surface front stalled against the mountains, and an area of enhanced median reflectivity was evident along the mountains southeast of the Great Salt Lake. By this time, the flow had veered around to northwesterly, and orographic enhancement was now evident on the western slopes of the mountain ranges.