CHAPTER 2

OBSERVED PRECIPITATION DATA

Data Sources

A dense network of surface observations from stations in the vicinity of Salt Lake City contributed to the success of the IPEX field experiment. Many of these stations are a part of the MesoWest cooperative network, a collaborative effort between the Department of Meteorology at the University of Utah and the SLC NWSFO to retrieve, archive, and display observations from automated weather stations in the western United States for operational and research purposes (Stiff 1997; Horel et al. 2000). Besides the National Weather Service (NWS), many government and private organizations contribute real-time data from their stations to MesoWest. In addition to the operational MesoWest stations, eight portable stations were deployed specifically for the experiment. Meteorological observations are also regularly reported by manual observers from the National Climatic Data Center (NCDC) cooperative observing network (COOP).

Within the IPEX domain, reports from 90 precipitation sensors were used to create the observed precipitation data set. Data are collected from a variety of independent sources that use different sensors and measurement techniques. Figure 2.1 shows the locations of these sensors, classified by type or network. With the exception of the extreme western part of the domain, most of the region is represented with precipitation sensors, with gauges located along the mountain ranges and over the Great Salt Lake as well as in

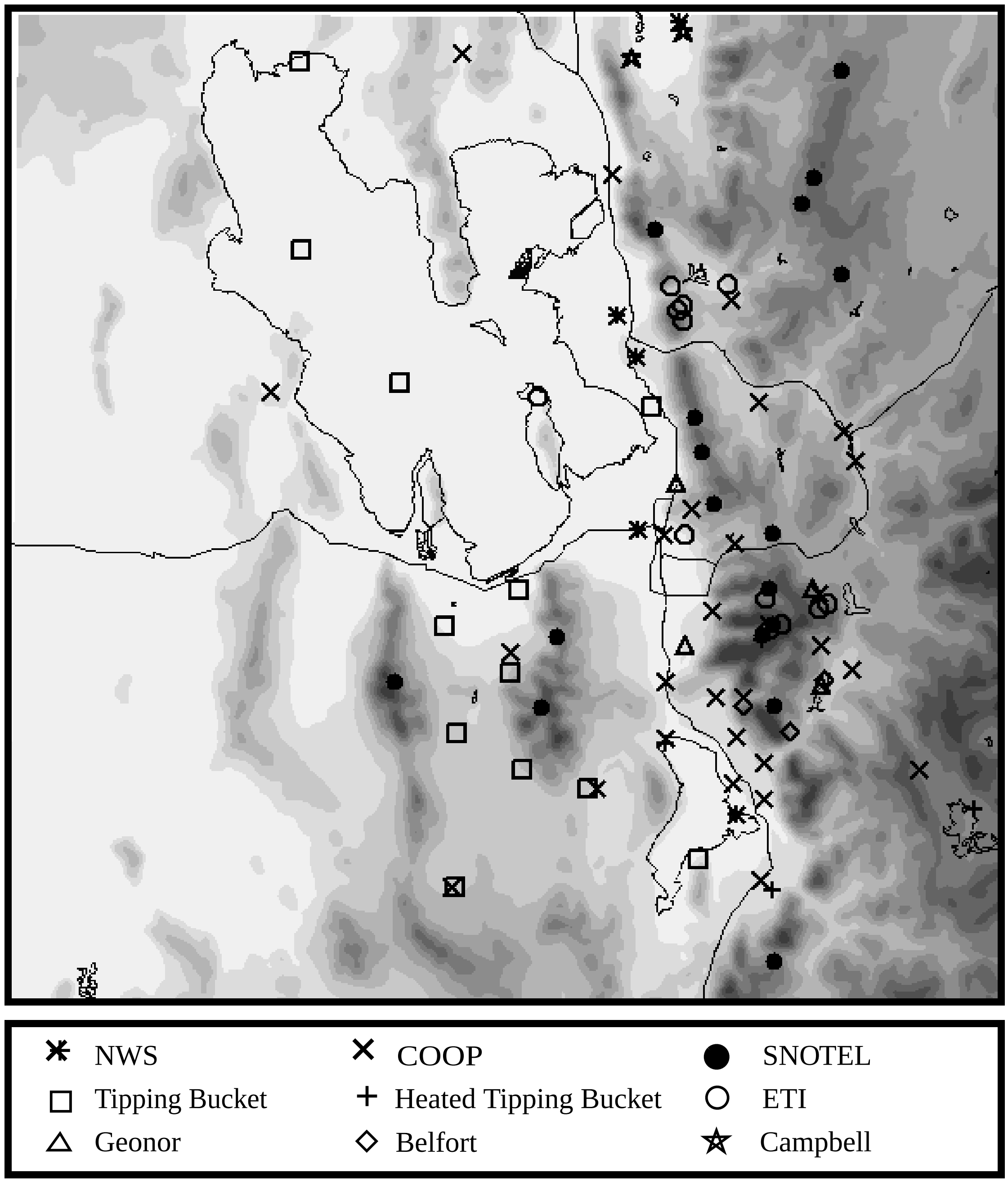

Figure 2.1. Locations of precipitation gauges used in the IPEX data set. Symbols represent different gauge types or networks according to the legend.

the valleys. The highest concentration of sensors is located along the Wasatch Front and the Wasatch Mountains, particularly the part of the mountains southeast of Salt Lake City.

Stations in the COOP and NWS networks are used primarily for operational or climatic purposes. Observations from COOP stations are typically read manually from a recording or nonrecording precipitation gauge. Because these sites are usually staffed by volunteers, observations are reported only once per day. Most NWS gauges are heated tipping buckets and are a part of the Automated Surface Observing System (ASOS). These sites are usually located at airports, and observations are reported hourly. However, at some NWS sites, three- and six-hourly accumulations may occasionally be augmented by manual observations, especially during snowstorms.

The United States Army Deseret Chemical Depot and Tooele County have a dense network of meteorological stations installed in the Tooele Valley. Besides aiding in weather observation and forecasting, these stations are intended for use in public safety and emergency response in the event of a chemical release. Sites that measure precipitation are equipped with unheated tipping bucket gauges that report hourly.

Stations in the Natural Resources Conservation Service (NRCS) Snow Telemetry (SNOTEL) network and those operated by the Central Utah Water Conservancy District (CUWCD) are used for water resources management. The SNOTEL network uses large weighing gauges, and the stations are usually located at high elevations and are equipped with wind shields. SNOTEL gauges can store several months’ worth of precipitation and are used mainly for seasonal measurements, although observations are made every hour. These gauges only have a resolution of 2.54 mm (0.10 in), as opposed to most of the other gauges in the area, which have a resolution of at least 0.25 mm (0.01 in). The CUWCD has several heated tipping bucket gauges that report hourly.

A local network, called Snownet, consists of several participating organizations including the University of Utah, the NWS, and the Utah Department of Natural Resources. Their objective is to monitor the weather for operational and research purposes. Some of the Snownet sites were installed for use in preparation for the 2002 Winter Olympics. Gauges used at Snownet stations vary. They include ETI, Belfort, and Geonor weighing gauges as well as unheated tipping buckets, which are used mainly over the Great Salt Lake. The frequency of reports from Snownet sites ranges from 5 min to 1 h. The two portable mesonet stations that measure precipitation are equipped with ETI gauges and report every 5 min.

Other gauges are provided by the United States Forest Service and Campbell Scientific, Inc. Stations operated by the Forest Service are important for avalanche forecasting. Hourly reports are made from ETI and Belfort weighing gauges and tipping bucket gauges. Two types of gauges designed by Campbell Scientific, Inc. are used near their headquarters in Logan.

The main concern with using data from so many different types of gauges to quantify areal distributions of precipitation is the lack of consistency in the data set. The observed spatial and temporal distribution could be influenced by differences in sampling frequency or measurement technique as well as by the actual variability of precipitation. Sites that sample at longer intervals, such as the COOP sites or manual NWS gauges, could suffer evaporative losses and report less precipitation than sites that sample more frequently. On the other hand, some types of gauges suffer increased wetting losses with more frequent sampling (Groisman et al. 1991). Heated tipping buckets are also prone to evaporative losses, as the heat source intended for melting frozen precipitation can cause evaporation or sublimation (Groisman and Legates 1994). Different gauge types also have different catch efficiencies and systematic errors. Furthermore, the presence and type of wind shielding mechanism surrounding a gauge also has an effect on catch efficiency. Despite these concerns, it is presently impossible to establish or find such a dense regional network of observational stations in complex terrain that uses standardized equipment. Thus, the data set benefits from the quantity of observations, but suffers from inhomogeneities due to variations in the type and frequency of the observations.

Quality Control Methods

As with all observational data, precipitation observations should be checked for quality before being used. Observational data are subject to all sorts of systematic and random errors. Precipitation data tend to be especially susceptible to measurement errors because several different factors influence the catch efficiency of a gauge, and many high resolution automated gauges are extremely sensitive to environmental conditions (Groisman and Legates 1994; DeFelice 1998). In addition, many automated gauges are located in remote areas such that they receive infrequent maintenance and are therefore not always reliable. While errors cannot completely be eliminated, they can be minimized if possible problems with the data can be identified.

The first step in the quality control process of precipitation data during IPEX was to determine the general reliability of each gauge. By comparing a station's data with radar reflectivity over the station and data from surrounding gauges, it was possible to determine if a gauge was in good working order. If a station consistently reported significant precipitation on clear days when surrounding stations were reporting no precipitation, data from that gauge were discarded. Several gauges failed to report precipitation during the entire IPEX period, and data from those gauges were discarded as well. Data from a few other gauges seemed rather erratic and inconsistent with the overall synoptic and mesoscale conditions based on subjective analyses during the IPEX period, and those gauges were also removed the data set.

After removing the problematic gauges, the next step was to quality control the individual precipitation values reported by the remaining gauges. Because of the variety of sensors used, no one quality control method was applied to all of the stations. Different stations have different errors, but certain types of errors appear to be specific to different sensor types. Therefore, specific quality control methods were applied to individual groups of sensors that appeared to have similar and consistent problems.

Observations from the Tooele Valley network and Snownet gauges located over the lake require significant quality control for periods of frozen precipitation. Because the sensors are unheated tipping buckets, frozen precipitation can accumulate in the orifice of the gauge instead of falling in, and the tipping mechanism tends to freeze when temperatures are below freezing. Since temperatures were generally warm at valley locations and precipitation fell as rain during most of the IPEX period, the unheated tipping buckets exhibited problems only during IOP 5 and IOP 7. The freezing problem is evident when comparing radar reflectivity and observations from surrounding sites with temperature and precipitation data from the station. Typically, when precipitation is occurring, these gauges report precipitation when temperatures are above freezing. Then, as temperatures drop below freezing, they fail to report precipitation even though other sources report precipitation in the area. As warm air returns and the ice in the gauges melt, significant amounts of precipitation are reported by these stations within two or three hours after the temperatures rise above freezing, regardless of whether or not precipitation is actually occurring at the time of the report. For the stations considered for this study, freezing usually occurred during the night (around 0700 UTC) and melting during the morning or afternoon (around 1700 UTC).

The freezing problem can be corrected in the data set in some cases, depending on the timing of the freezing and melting of the gauge relative to the precipitation event. Since 24-h precipitation totals in this research were determined only at 0000 UTC, if one complete cycle of freezing and melting occurred within one 24-h period ending at 0000 UTC, then it was likely that the reported precipitation occurred in that 24-h period. However, for extended periods of freezing or when a cold front caused the gauge to freeze prior to 0000 UTC and melting did not occur until the following afternoon, it was difficult to determine during which 24-h period the precipitation actually occurred. It was only possible if there was enough confidence that actual precipitation ended on the same day that the gauge froze, in which case the reported precipitation was added to that day’s total. Because both the freezing/melting cycle and the precipitation events are usually relatively long, this technique is nearly impossible to apply to 6-h totals.

SNOTEL sites are the most difficult to quality control because the raw data from many of these stations exhibit a significant amount of noise at high temporal resolution. Even though they report hourly, these sensors are more suited for measuring precipitation on the seasonal scale. Precipitation is reported as total accumulated depth, and due to temperature effects on the gauge, precipitation totals increase and decrease with time (Cooley et al. 1987). The fluctuations occur on a diurnal scale, and the signal is evident on clear days, although it can be masked during frontal passage. However, the strength of the signal varies by site, and not all sites exhibit the same signal pattern. Some stations report an increase in precipitation during warming and a decrease during cooling, while at other stations, this pattern is reversed.

Several steps were taken to filter out the noise in the hourly SNOTEL data. Because of the strong diurnal tendency of the signal, 24-h totals were assumed to be more reliable than hourly totals if determined directly from the change in precipitation depth. Therefore, hourly values were determined from the change in 24-h totals every hour. For example, if the 24-h precipitation is zero for the period ending at 0000 UTC, 0.5 mm for the period ending at 0100 UTC, and 1.0 mm for the period ending at 0200 UTC, then the hourly totals would be 0.5 mm for both periods 0000-0100 UTC and 0100-0200 UTC. This technique is only possible to apply if the first 24-h value is zero. Because most sites reported very little, if any, precipitation on 1 February, a 24-h total of zero was assumed for all of the SNOTEL sites during that day. For many stations, this method removed most of the diurnal signal, but because the strength and timing of the 24-h signal was not exactly the same every day, there was still evidence of weak diurnal noise. In an attempt to filter out any remaining noise, three passes of a 15-point median filter was applied to the data for all of the stations. A few remaining stations still had a small residual signal, and in those cases, negative changes in precipitation were disregarded. The data were compared with radar data and observations from nearby stations, and precipitation reported during periods that should have had no precipitation was adjusted to zero.

Figure 2.2 shows the results of the quality control process for the SNOTEL site that exhibited the most noise, Payson (PYSU1). The running total of hourly precipitation

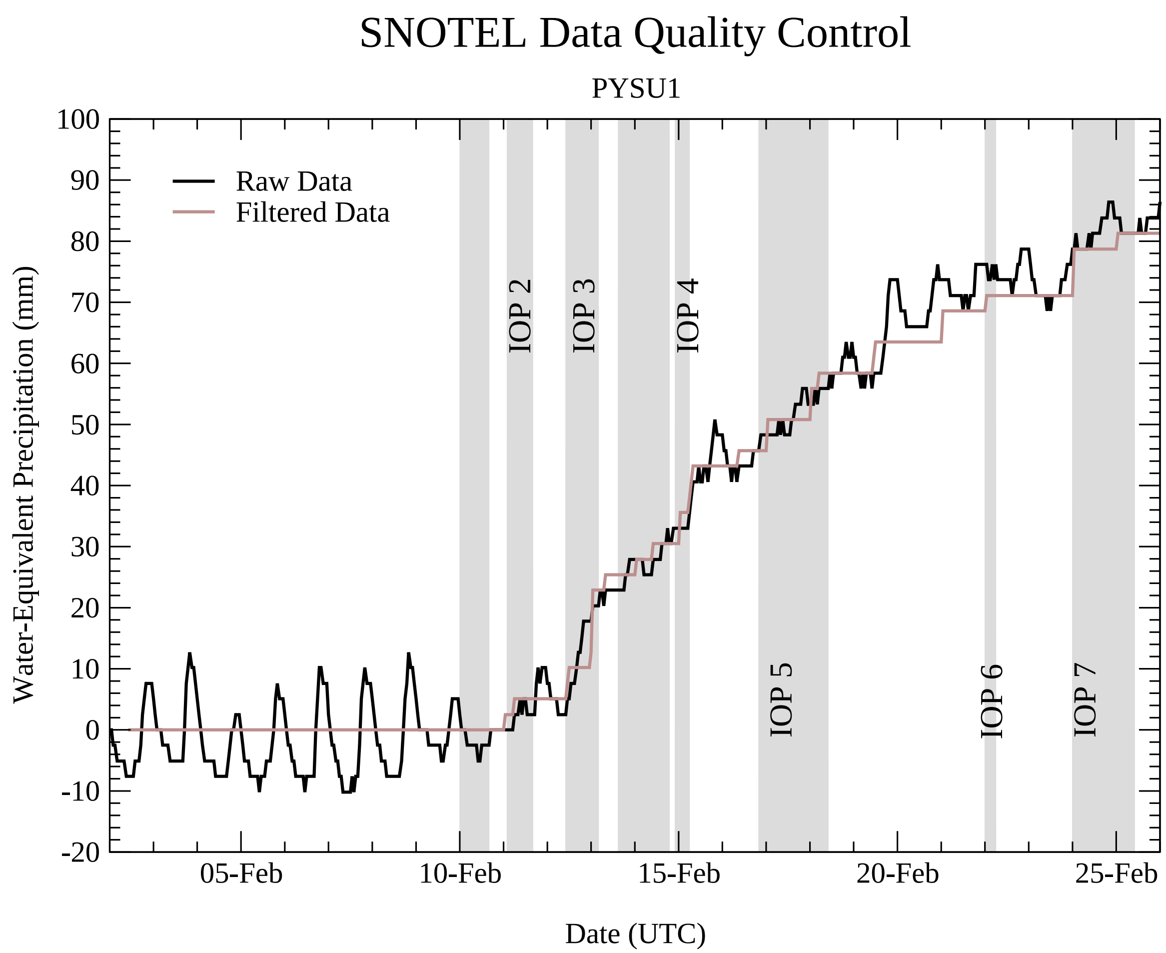

Figure 2.2. Total accumulated precipitation before and after quality control for the period 2-26 February 2000 at the Payson SNOTEL site. Shaded areas represent subjectively-determined periods of significant precipitation over the IPEX domain. Events associated with the IOPs are labeled.

values before and after quality control for the station is plotted. The shaded areas represent periods of widespread or significant precipitation as determined subjectively from radar reflectivity and data from all of the stations and is intended to help show when the heaviest precipitation is expected to be occurring. Precipitation events associated with the IOPs are labeled. A strong diurnal fluctuation is evident in the station’s raw data and is no longer apparent in the filtered data.

Several stations use Geonor gauges, which are extremely sensitive to environmental conditions such as wind. Slight disturbances of the vibrating string of the gauge may be registered as precipitation. Although the MesoWest real-time processing of data from these stations already includes a median filter, most of these gauges still report 0.3-1.0 mm (0.01-0.04 in) of precipitation on clear days, although some gauges report more. Presumably, this problem also introduces errors into the data set during precipitation events, but unlike during clear days, it is difficult to determine the extent of the error, since the signal would be masked by actual precipitation. Only the gauges with consistently small errors were kept in the data set. Any precipitation reported on obviously clear days by these gauges was adjusted to zero. No changes were made during actual precipitation events, but assuming the gauges over-report by similar amounts each day, the errors would be relatively small during significant precipitation events.

The COOP sites have perhaps the most reliable precipitation totals, since the measurements are made manually. Furthermore, they are checked for quality by the NCDC prior to being released to the public. However, not all of the COOP stations make observations for the same 24-h period. For the purposes of this research, only stations that report within one hour of 0000 UTC were used. Reports from these stations were all considered to be valid for the same 24-h period, even though there is a 2-h spread in reporting time. This may appear to introduce some error into the data set. It is important to realize, however, that the reporting times for each station are intended reporting times and do not reflect the time the observation was actually made. Nonrecording manual gauges require an observer to arrive and physically make measurements, and any number of factors can cause the actual observation time to vary.

Heated tipping buckets, Campbell Scientific, Belfort, and ETI gauges generally did not appear to have any noticeable widespread irregularities. Although heated tipping buckets can suffer evaporative losses, it is difficult to determine the amount lost without detailed experimentation. Therefore, no specific quality control methods were applied to these gauge types. Instead, data from these stations were checked individually for quality.

The quality control methods performed on the data set only serve to filter obviously erratic data. They do not attempt to correct for the gauge undercatch bias, which is a major concern when dealing with observed precipitation (Groisman and Legates, 1994). The undercatch ratio can vary, but at times it can be significant. A study by Golubev and Groisman (1992) of the standard 8-in diameter rain gauge used at many manual sites has determined that the undercatch for rain events is around 4% for an unshielded gauge with a mean wind of 2.8 m s^{-1} over the gauge orifice. Nešpor and Sevruk (1999) used wind tunnel simulations to study the airflow around three gauges and used the information to model their catch efficiencies. Their study showed that errors are largest for low rainfall rates and high wind speeds. Since lower rainfall rates tend to have a larger volumetric fraction of smaller raindrops, they are more affected by strong winds. The undercatch is even greater for frozen precipitation. Goodison (1978) determined that for a wind speed of 5 m

s^{-1}, the catch efficiencies of snow are 40% and 51% for two types of gauges tested with wind shields, and only 20% and 32% for two unshielded gauges. One particular wind-shield used in that study actually caused the gauge to overcatch slightly for low wind speeds.

While it is important to adjust for the undercatch bias, such a task is not possible for such a dense network of stations of varying sensor types. There are simply too many factors that have to be considered, including wind speed, precipitation type, precipitation rate, gauge type, and the presence and type of wind shield. Gauge undercatch has been studied extensively, but correction factors exist only for a limited number of conditions and gauge types. To determine undercatch in this data set would require that each gauge be studied individually for each precipitation event.