Storm Precipitation Analysis System (SPAS) Description

Introduction

The Weather Bureau (currently the National Weather Service, or NWS) and the Corps of Engineers routinely performed detailed storm precipitation analyses until the 1950s. Since then, only a few selected storms have been analyzed. Using digital precipitation data now available, storm precipitation analysis procedures and software have been developed to provide detailed precipitation analyses using Geographical Information Systems (GIS). Hourly high spatial resolution precipitation analyses are used to compute depth-area precipitation relationships to quantify the spatial and temporal distribution of storm precipitation over watersheds.

Applied Weather Associates, LLC and Metstat, Inc. teamed to develop a precipitation analysis procedure for analyzing precipitation associated with extreme storms. The Storm Precipitation Analysis System (SPAS) applies the same basic approach used by the Weather Bureau and the Corps of Engineers, thereby achieving a level of consistency between the depth-area results from newly analyzed storms with historic storms previously analyzed. The SPAS algorithm is a suite of Linux-based programs that utilize the Geographic Resources Analysis Support System (GRASS) GIS engine to evaluate the spatial, temporal and depth-area characteristics of precipitation events. (GRASS 2009) SPAS uses a spatial approach for allocating precipitation from hourly reports and at the daily reporting stations into hourly precipitation values, thus creating high resolution precipitation maps for each hour of the precipitation event.

As of December 2008, SPAS has been used for 58 storm analyses. These include recent events as well as some old (pre-radar) storms (e.g. Westfield, MA, 1955 and Ritter, IA, 1953) previously analyzed by the Weather Bureau. The first "storm" analyzed by SPAS was a theoretical storm for which the results could be mathematically verified against truth, computed results. SPAS also endured other rigorous tests to ensure the utmost accuracy, reliability and reproducibility. The depth-area results via the re-analysis of storms previously conducted by the Weather Bureau and SPAS compared favorably. SPAS results have been used in a number of FERC, state and local approved site-specific and regional PMP studies (Tomlinson, et al. 2003 and 2008).

Background

The Weather Bureau and Corps of Engineers produced many storm studies for extreme precipitation events that occurred during the first half of the last century. The DADs from these studies were used to compare precipitation events and were used in Hydrometeorological Reports (HMRs) to determine PMP precipitation amounts. Objective procedures were used in these analyses augmented with subjective judgment by well qualified hydrometeorologists. The SPAS analysis procedures incorporate many of the earlier procedures while providing a plethora of updated techniques along with GIS to improve the quality and speed of the analyses.

With SPAS, storm analyses (including storm-centered DADs and mass curves) can be completed faster and with more detail than historic analyses. In the past, a detailed analysis of a storm's precipitation required a great deal of manual labor, hence making it time consuming and prone to human errors. SPAS is a largely automated system, yet it provides flexibility and several enhancements over the old storm analysis procedure. In the past, it was time and cost prohibitive to produce hourly precipitation maps, therefore assumptions had to be made in the computations of the DAD results. SPAS, however, does not have to make as many assumptions since it has the ability to mimic and resolve the storm's precipitation much better through the use of GIS algorithms. Table 1 compares some procedures used historically by the Weather Bureau and SPAS; details of these will follow.

Table 1. Comparison between the Weather Bureau storm analysis method and SPAS.

Topic	Weather Bureau	SPAS
Disaggregate daily precipitation data	Mimics the hourly distribution of the nearest hourly station	Uses several representative hourly stations in an inverse distance weighting scheme
Pseudo precipitation data	Did not use	Various options for use
Base map options	100-year 24-hour or nothing	Multiple base map options
DAD calculations based on six hour duration analyses	The total storm, hand-analyzed isohyetal map	Based on hourly GIS-created precipitation grids
Automation	None	Largely automated

The principle components of SPAS are: storm definition, data extraction, quality control (QC), disaggregate of daily precipitation data into estimated hourly data, hourly and total storm precipitation grids/maps and a complete storm-centered DAD analysis.

Storm Definition

A storm definition is the first step in a SPAS analysis. A total storm precipitation map is created with readily available precipitation data to determine the areal extent of the storm. Based on the initial storm map, a user-defined domain is established as the SPAS study area, typically a latitude-longitude box. The study area and initial storm dates are entered into software that extracts and formats all of the available hourly and daily precipitation data. Through evaluation of the hourly and daily precipitation data, as well as other ancillary information (radar loops, etc.) a final storm begin and end time are established. Once a final storm domain and time frame are established the data extraction software is re-run which results in the SPAS precipitation data input files.

Precipitation Data

SPAS has unique ability to utilize a variety of different types of precipitation data in order to achieve the highest spatial and temporal resolution possible. The majority of data is obtained from digital archives provided by the National Climatic Data Center (NCDC). These datasets represent official precipitation information and therefore provide the most critical precipitation input to SPAS. However, supplemental data (e.g. storm total amounts, precipitation with unknown observation times, partial storm amounts, etc.) from other sources are used to better resolve the storm's characteristics. However, the two main types of precipitation data used are hourly and daily precipitation observations.

Hourly data

Precipitation data that is reported every hour comes from a variety of sources. The base hourly data is from the NCDC dataset TD-3240, U.S. Control Cooperative Hourly Precipitation. However, other hourly precipitation gauge data from Automated Local Evaluation in Real Time (ALERT) networks, Remote Automated Weather Stations (RAWS) stations, NWS's Automated Surface Observing Systems (ASOS), municipal networks, SNOTEL sites, etc. are also used.

Quality control (QC) is an ongoing exercise in SPAS. The first QC takes place after the hourly data has been collected. The hourly station data is evaluated based on knowledge acquired from weather maps, nearby stations, known orographic effects, station history and other documentation on the storm. Any hourly data errors are resolved.

Since the hourly data governs the temporal characteristics of the storm, every attempt is made to restore incomplete or accumulated hourly data records. This is done using the same knowledge used to QC the data. Based on professional judgment and the level of restoration required, the restored hourly stations are flagged either as pseudo-hourly stations or as supplemental hourly stations. Supplemental hourly stations will be treated in SPAS just like a complete hourly station. Pseudo-hourly stations, on the other hand, are only utilized for timing considerations. Pseudo-hourly stations allow the SPAS meteorologist to add data to the analysis to better resolve physical and meteorological processes that would otherwise be ignored in a strict model. Creating pseudo hourly data is accomplished by manual distributing precipitation at a daily station into hourly estimates. This distribution is determined from nearby hourly stations and information from other sources such as radar or local storm reports.

Daily data

Daily precipitation data representing a 24-hour accumulation, are more abundant than hourly precipitation data, and thus provide valuable spatial detail. Daily data are available from a number of sources, but the primary source is the NCDC datasets TD-3200, U.S. Cooperative Summary of Day, and TD-3206 U.S., Cooperative Summary of the Day – pre 1948. Additional supporting daily data is often obtained from other sources such as Automated Local Evaluation in Real Time (ALERT) networks, Remote Automated Weather Stations (RAWS) stations, NWS's Automated Surface Observing Systems (ASOS), municipal networks, SNOTEL sites, etc..

An initial QC screening of the daily data is conducted at this point. The daily data are summed into storm totals and mapped to spatially identify gross errors. Also, the daily data are subjected to a threshold check that identifies all of the daily precipitation values that equal or exceed a threshold. The threshold is usually objectively based on the depth of precipitation for a 50- or 100-year reoccurrence interval available from the current precipitation frequency atlases.

Once an initial QC pass is completed on all of the available data, SPAS begins its analysis of the hourly data in order to disaggregate the daily and supplemental data into estimated hourly amounts.

Supplemental data

Supplemental precipitation data is precipitation data that isn't hourly or daily, but often a storm total. Often unofficial, supplemental data is critical in the evaluation of extreme events because it provides SPAS information that SPAS would otherwise have to estimate via spatial interpolations and extrapolations. Supplemental data can reflect any of the following:

- Storm total.
- A daily station, but with unknown observation time.
- An estimated total storm value from a preexisting isohyetal map
- A known short duration (e.g. 4" from 4 p.m. to 8 p.m.) precipitation amount, with nothing else known.

Methodology

SPAS has the ability to disaggregate daily or irregularly measured precipitation into hourly precipitation estimates as illustrated in figure 1. In the past (Weather Bureau), daily measured precipitation was disaggregated to hourly data by associating each daily station to a single nearby hourly station (WMO 1969). SPAS, however, uses several hourly stations to time each of the daily and supplemental data, thereby allowing the hourly precipitation distribution to be unique at each daily station.

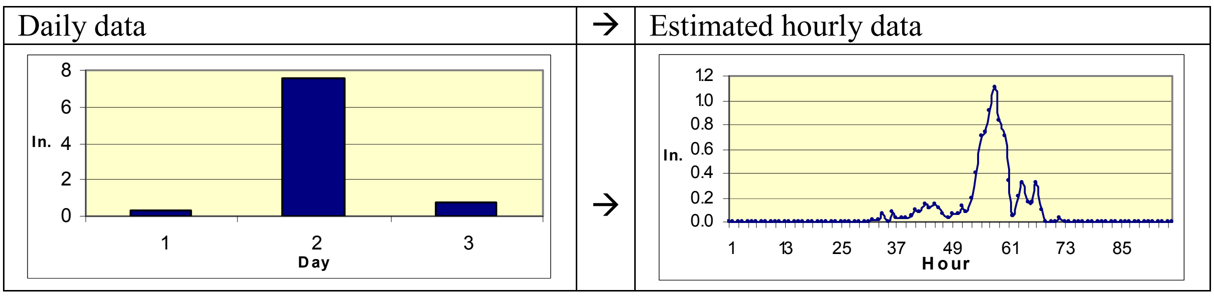


Figure 1. An illustration of how SPAS converts three days of daily precipitation into estimated hourly amounts.

After the daily and supplemental precipitation data has been disaggregate into hourly estimates, exhaustive and very effective QC measures are taken. Plots, like the one shown in figure 2, of the incrementally accumulated precipitation data (known as mass curves) are created for each station and then combined into a single plot with other nearby stations for evaluation. The most common QC issue detected at this stage are related to the observation time of the daily station.

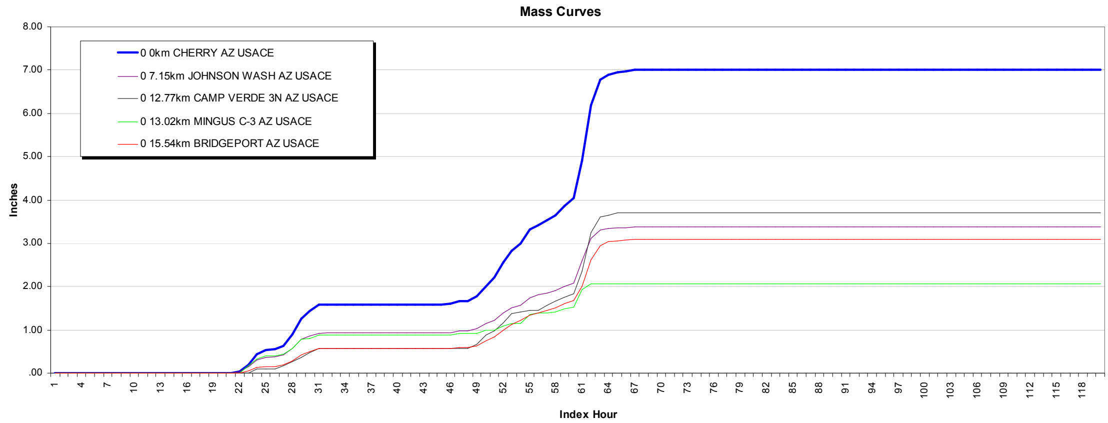


Figure 2. Sample 5-station mass curve.

All suspect observation times will cause a shift in the distribution of precipitation in comparison to the other nearby stations. All suspect observation times are corrected when possible. Otherwise, the station is converted to a supplemental station with the observational period set to the bounds of the storm period, hence making it not necessary to know the daily stations' observation time(s). Once any and all timing issues are resolved, SPAS is re-run.

Hourly Precipitation Grids

At this point the observed hourly and disaggregated daily/supplemental hourly precipitation data are spatially interpolated into hourly precipitation grids. SPAS has three main options for conducting this interpolation, which can be challenging in complex terrain or in convective (thunderstorm) situations, thereby allowing the model to be optimized for any particular type of storm or location.

Basic Approach

The most basic approach is to interpolate the hourly precipitation point values to a grid using an inverse distance weighting squared GIS algorithm. This is often the best choice for convective storms over flat terrain when radar data is not available.

Basemap-aided Approach

Another option includes the use of "base maps", also known as climatologically-aided interpolation. (Hunter, 2005) Base maps are independent grids of spatially distributed weather or climate variables. The spatial patterns of the base map aid in the interpolation between points of hourly precipitation estimates. Regardless of the base map, the hourly precipitation values are normalized by the grid cell value of the base map. The normalization allows information and knowledge from the base map to be transferred to the spatial distribution of the hourly precipitation. Using an inverse distance weighting squared algorithm, the normalized hourly precipitation values are interpolated to a grid. The resulting grid is then multiplied by the base map grid to produce the hourly precipitation grid.

Base map options could include:

- Precipitation Frequency grids - NOAA Atlas 14, TP-40, NOAA Atlas 2, etc.
- 30-year mean monthly precipitation - Parameter-elevation Regressions on Independent Slopes Model (PRISM)(Daly, 1997)
- 30-year mean annual precipitation – PRISM
- Total monthly precipitation (e.g. December 2004) – PRISM

Radar Approach

The most powerful approach, however, is SPAS's ability to use Next Generation Weather Radar (NEXRAD). The coupling of SPAS with NEXRAD provides perhaps the most accurate spatially and temporally distributed precipitation. For the coupling to be effective however, hourly precipitation observations must be obtained for calibrating the radar reflectivity to rain rate relationship (Z-R relationship) used in the NEXRAD algorithms to calculate precipitation amounts. The observations are often referred to as "ground truth". Although often scant, hourly precipitation data are identified, acquired, and quality controlled. Precipitation from daily or event reporting locations are more abundant and are also identified, acquired and quality controlled. In order to increase the number of observations used for calibrating the hourly Z-R relationship, the daily and event reporting observations are converted to estimated hourly values based on the temporal distribution of precipitation at nearby rain gauge locations that report hourly.

Weather radar data has been in use by meteorologists since the 1960's to estimate precipitation depth. In the late 1980's and early 1990's the new, highly efficient NEXRAD Doppler radar (designated the WSR 88D) was placed into service across the United States. Today NEXRAD coverage of the contiguous United States contains 158 operational stations; each radar covers an approximate 463 km (250 nautical miles) radial extent over which the radar can detect precipitation (Figure 4).

SPAS utilizes the Level II base reflectivity data from Weather Decision Technologies (WDT), which usually provides the data at a temporal resolution of 5 minutes, a spatial scale 1 degree x 1.0 kilometer (polar coordinates) and is reported at a precision of every 0.50 dBZ (dBZ (decibel) is the unit of radar reflectivity).

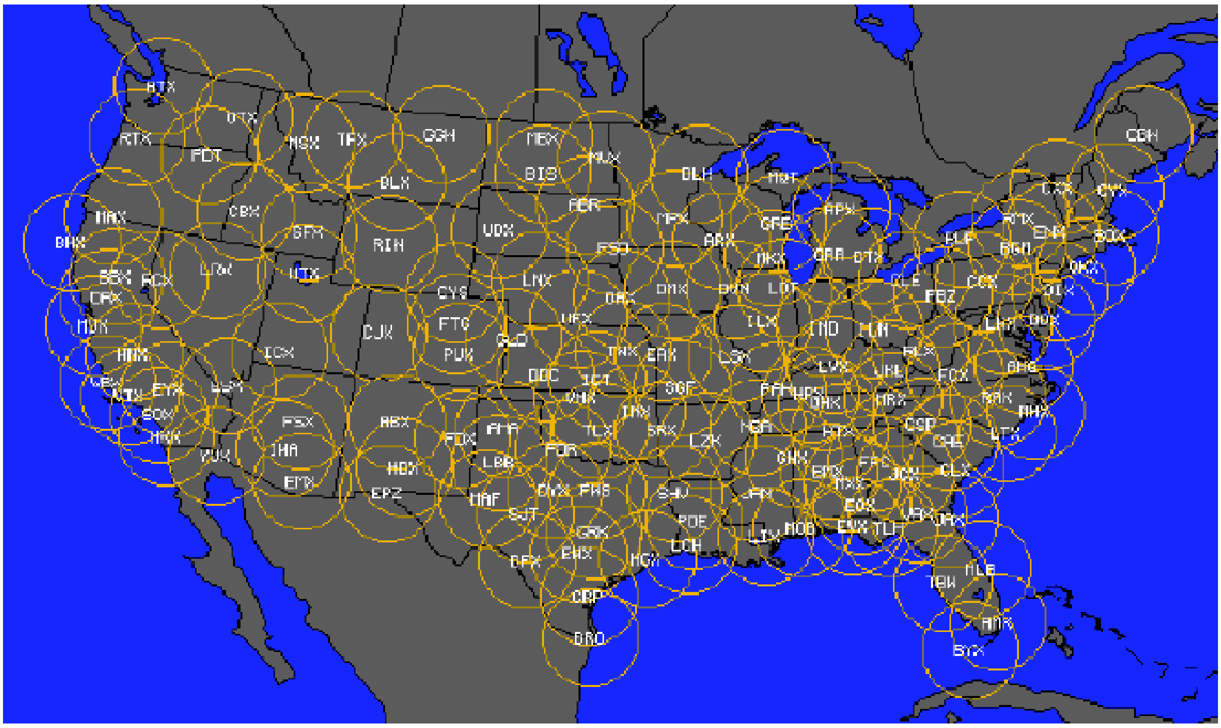


Figure 4. NEXRAD locations and 463 km (250 nautical miles) radar extent.

Radar can sometimes be contaminated by a significant amount of error. Radar clutter or "false echoes" in radar data can lead to considerable under or over estimation of precipitation. The WDT and NSSL have developed a Radar Data Quality Control Algorithm (RDQC) that removes non-precipitation artifacts from base Level–II radar data. These artifacts include ground clutter, sea clutter, anomalous propagation, sun strobes, clear air returns, chaff, biological targets, electronic interference and hardware test patterns. The RDQC algorithm uses sophisticated data processing and a Quality Control Neural Network (QCNN) to delineate the precipitation echoes from those echoes caused by radar artifacts (Lakshmanan and Valente, 2004). Beam blockages due to terrain are mitigated by using 30m DEM data to compute and then discard data from a radar beam that clears the ground by less than 50m and incurs more than 50% power blockage. A diurnal clear-air echo removal scheme is applied to radars in clear-air mode when there is no precipitation reported from observation stations within the vicinity of the radar and the observed surface temperature at all stations are above a dynamic threshold. In areas of radar coverage overlap, a distance weighting scheme is applied to assign reflectivity to each 1 km grid, for multiple vertical levels. This scheme is applied to data from the nearest radar that is unblocked by terrain.

Once the data from individual radars have passed through the RDQC, they are merged to create a seamless National Mosaic. A novel multi-sensor quality control is applied by post-processing the mosaic to remove any remaining "false echoes". This technique uses observations of infra-red cloud top temperatures by GOES satellite and surface temperature to create a precipitation/no-precipitation mask. Figure 5 shows the impact of WDT's quality control measures.

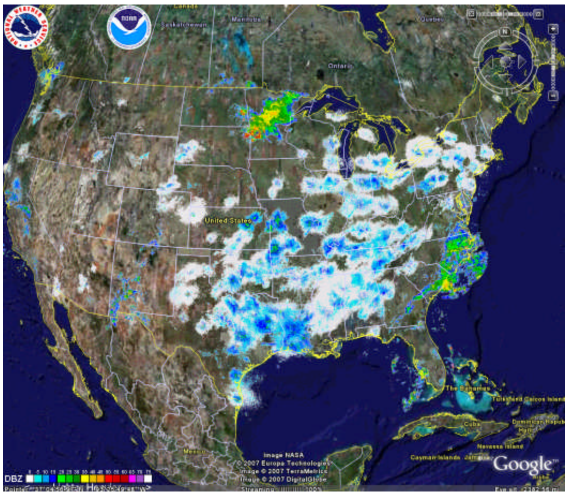


Figure 5a. Level-II radar mosaic of CONUS radars with no quality control

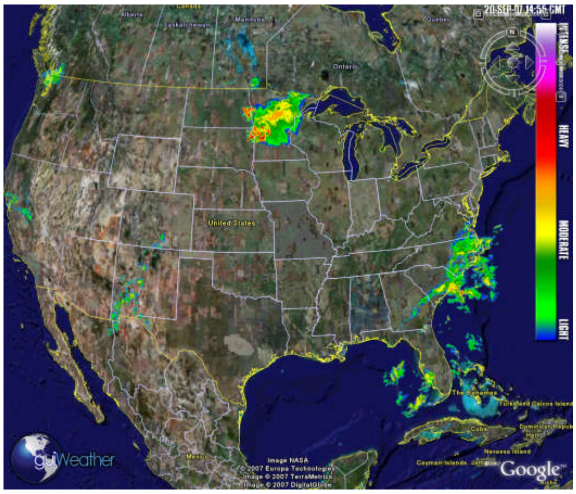


Figure 5b. WDT quality controlled Level-II radar mosaic of CONUS radars.

Reflectivity data from WDT are remapped from their native spherical coordinates to a Cartesian coordinate system, clipped to the storm analysis domain and ingested by SPAS. Level II base reflectivity information is provided at a temporal resolution of 5 or 6 minutes, a spatial scale of 1x1 km resolution (about 0.33 square miles) and reported at a precision of 0.50 dBZ (dBZ or decibel, is the unit of radar reflectivity).

SPAS conducts further QC measures to the radar mosaic utilizing a beam blockage mask, minimum/maximum allowable radar values and selection of a watershed. The clean radar mosaic across the watershed is the basis for accurate precipitation estimates over the course of the last hour.

Understanding and optimizing the relationships between NEXRAD reflectivity and rain gauge data are essential to confirm the accuracy and reliability of the radar derived precipitation. In general, most current radar-derived precipitation techniques rely on a relationship between radar reflectivity and precipitation rate. This non-linear relationship is described by the Z-R equation below:

$$Z = A\,R^{b}$$

where Z is the radar reflectivity, measured in units of dBZ, R is the precipitation rate (millimeters per hour), A is the "multiplicative coefficient" and b is the "power coefficient". Both A and b are directly related to the drop size distribution (DSD) and drop number distribution (DND) within a cloud (Martner et al 2005).

The National Weather Service (NWS) utilizes several different Z-R algorithms, depending on the precipitation characteristics, to estimate precipitation through the use of their network of NEXRAD radars located across the United States (Figure 4). A default Z-R relationship of $Z = 300R^{1.4}$ is the primary algorithm used throughout the country and has proven to produce highly variable results. The variability in the results of Z vs. R is a direct result of differing DSD, DND and air mass characteristics across the United States (Dickens 2003). The DSD and DND are determined by complex interactions of microphysical processes within a cloud. The DSD and DND fluctuate hourly, daily, seasonally, regionally, and even within the same cloud. For these reasons, SPAS has developed a method by which a Z-R relationship is computed and applied each hour.

SPAS utilizes an iterative procedure for optimizing the Z-R relationship for each hour of the analysis period. The process begins by determining if sufficient observed hourly precipitation data are available to compute a reliable Z-R. If insufficient observed precipitation data are available, then the Z-R relationship will either adopt the previous hours Z-R relationship (if available) or apply the default $Z = 300R^{1.4}$ algorithm. If sufficient precipitation data are available however, it is related to the hourly sum of NEXRAD reflectivity. A best fit power function through the data points is computed. The resulting multiplicative coefficient (A), power coefficient (b) and maximum predicted precipitation are subjected to several tests to determine if the Z-R relationship is acceptable.

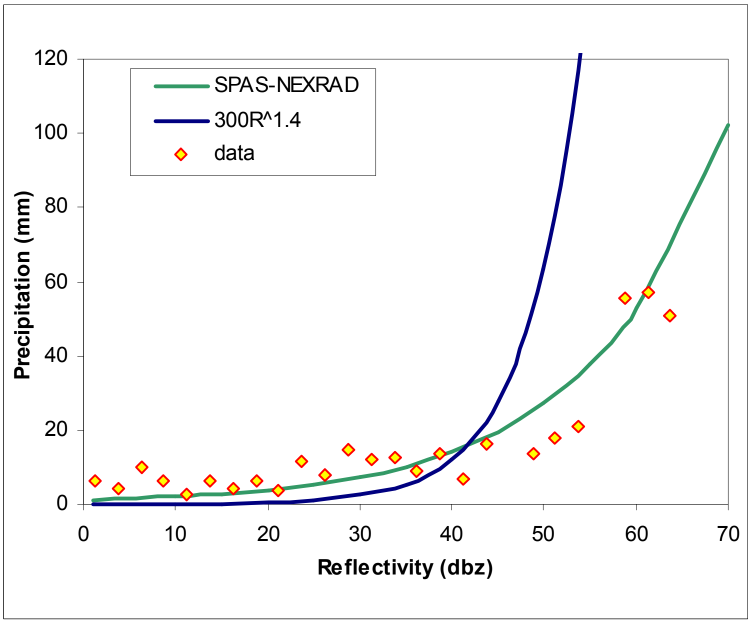


Figure 6. A comparative plot showing the optimized Z-R vs. the NWS default $300R^{1.4}$ algorithm.

Once a mathematically optimizated hourly Z-R relationship is determined (Figure 6), it is applied to the total hourly Z grid to compute an initial precipitation rate (millimeters per hour) at each gridcell within the extent of radar data (Figure 7).

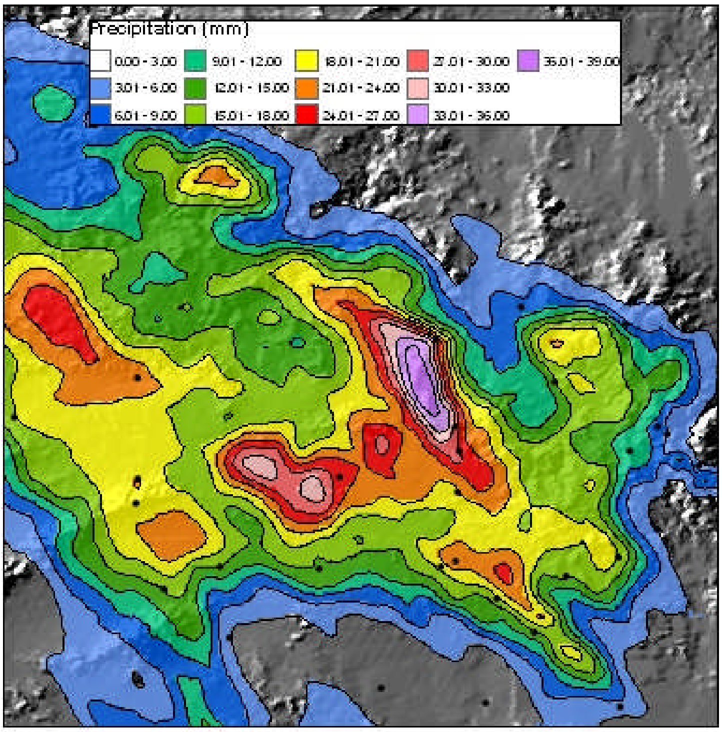


Figure 7. Initial hourly precipitation map.

Spatial differences in the Z-R relationship exists across the radar domain due to differences in DSD and DND. To account for these differences, SPAS computes residuals, the difference between the initial precipitation analysis (from the Z-R equation) and the actual observed precipitation (observed – initial analysis), for each gauging station. As figure 8 depicts, the residual field can be thought of as a local bias correction.

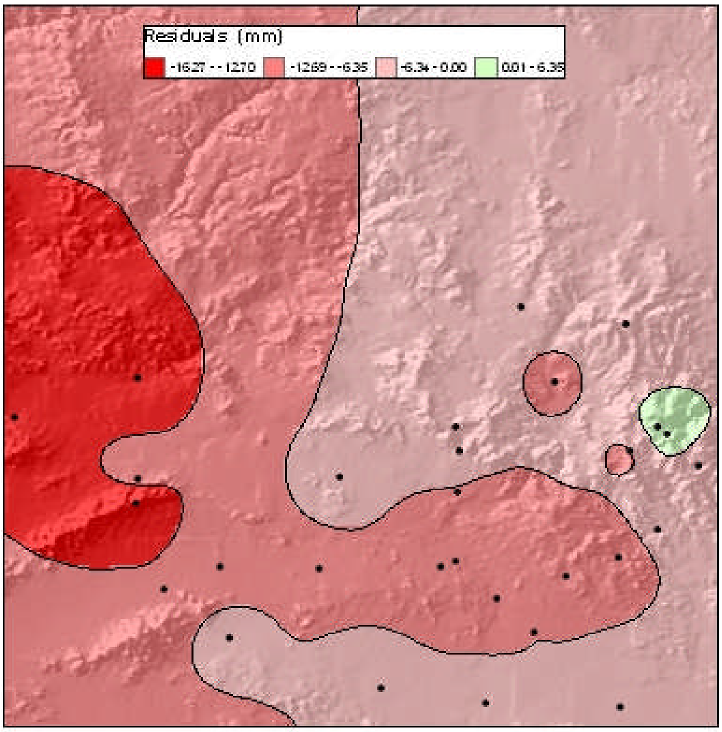


Figure 8. Hourly residual map.

A final hourly precipitation grid (Figure 9) is created by adding the smoothed residual grid to the initial grid.

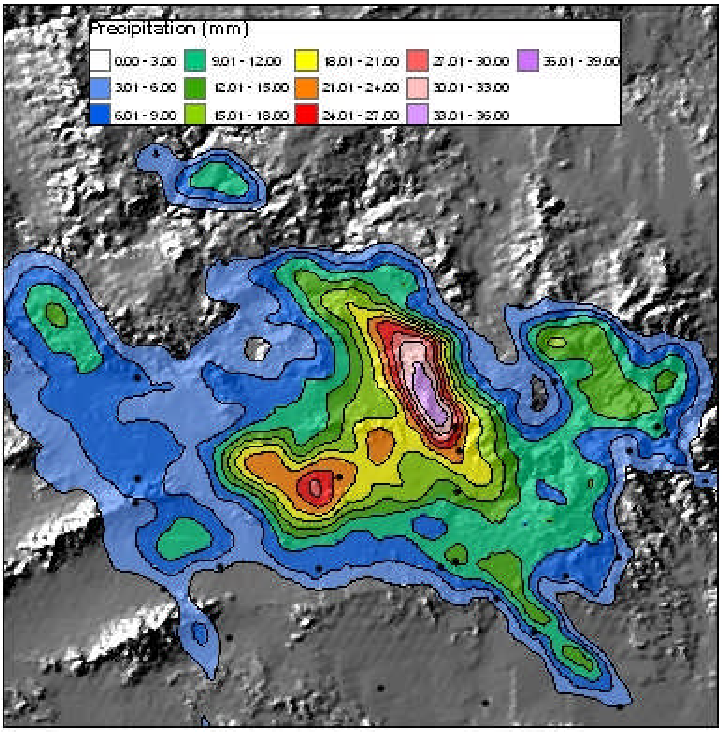


Figure 9. Final total hourly precipitation map.

Even with all the QC processes available, the radar data may still be unreliable in some mountainous areas of the Western U.S. due to poor radar coverage due to radar beam blockage. To overcome this issue, SPAS blends the climatologically-aided spatial interpolation technique with the radar data to accurately resolve precipitation patterns in complex terrain.

Hourly Precipitation Evaluation

The final hourly grids are then used to evaluate the performance of each SPAS hourly calculated precipitation amount. For each hour, a set of statistics are created; including the hourly Z-R coefficients, the observed hourly maximum precipitation, the calculated hourly maximum precipitation, the hourly bias, the hourly mean absolute error (MAE), root mean square error (RMSE), and the hourly coefficient of determination (r^2). In addition to the hourly precipitation data, total storm precipitation statistics are calculated.

The use of radar improves the reliability and is made possible by calibrating the NEXRAD data each hour with rain gauge observations. The computed precipitation amounts provide reliable hourly and sub-hourly precipitation amounts that fell over a region and/or individual watersheds with spatial scales down to approximately one third of a square mile and temporal scales as frequent as 5-minute. The high spatial and temporal resolution of the SPAS precipitation data allows for accurate determination of precipitation volumes over basins and sub-basins for calibration.

The increased accuracy of the precipitation analyses has eliminated the need for commonly made assumptions about precipitation characteristics (such as uniform precipitation over a watershed), thereby greatly improving the precision and reliability of hydrologic analyses.

Total Storm Grid

Once hourly precipitation grids are completed for a given storm, any subset of hours during the storm can be summed together and displayed. A summation of all hours provides a total storm grid, which is then converted into a cartographic map for evaluation (see figure 10a). The resulting isohyet pattern is then checked for accuracy by comparing the pattern to other existing storm maps or radar-estimated precipitation to gain some level of confidence in the final storm isohyetal pattern.

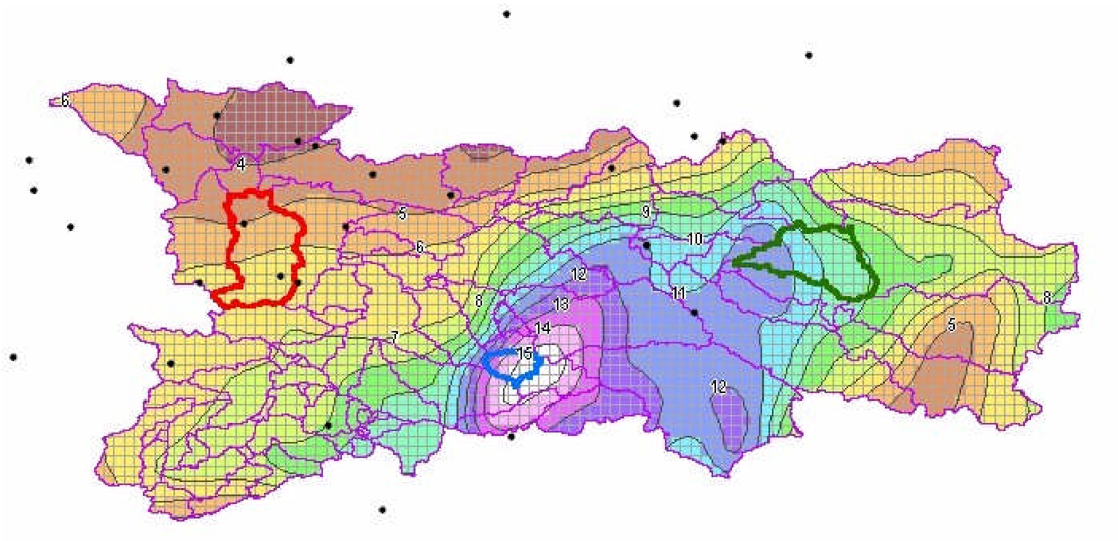
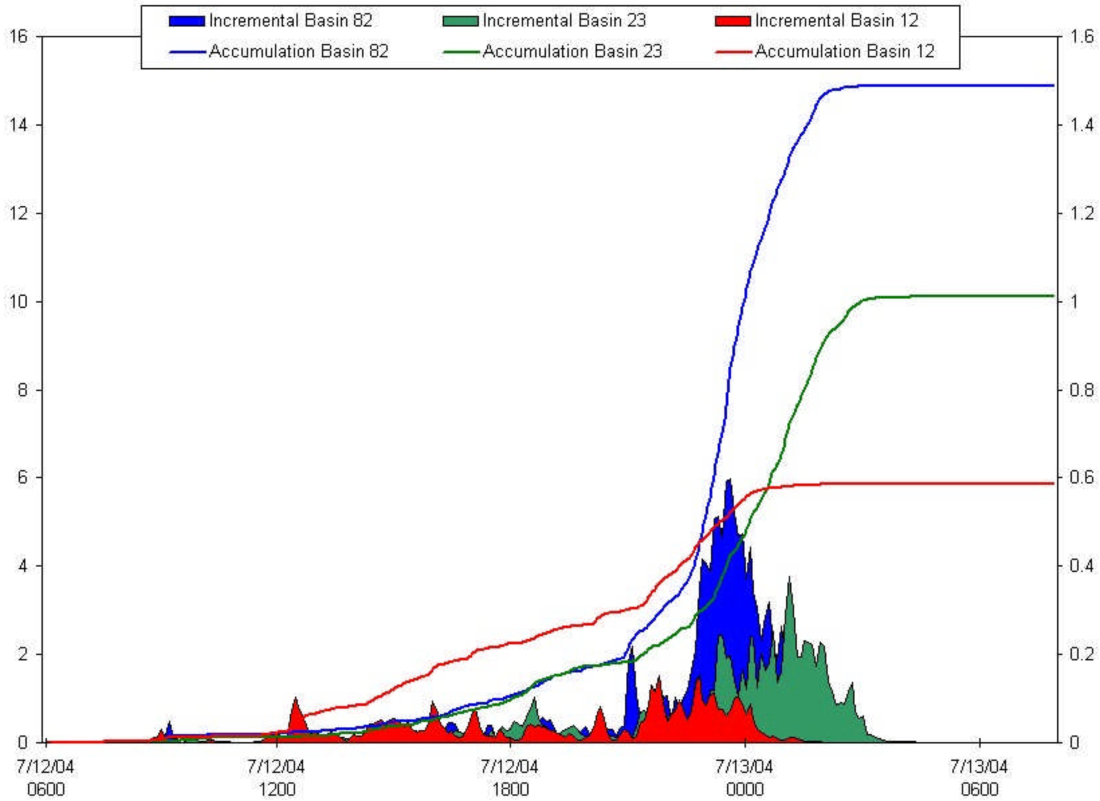


Figure 10a



b)

Figure 10b Gridded precipitation (a) and basin average accumulated and incremental precipitation (b). Black dots represent rain gauge locations.

Depth-Area-Duration

The hourly precipitation grids serve as the basis for the final phase of SPAS, the computation of DAD statistics. The SPAS DAD functionality has been rigorously tested both with a theoretical storm where the precipitation rates and spatial distributions are known exactly and with historic storms that have been previously analyzed by the Weather Bureau. The SPAS DAD analysis exactly evaluated the theoretical storm known as the "Pyramidville" storm. The Pyramidville storm dropped a tenth of an inch each hour over sequentially larger and larger areas for 24-hours, thus making it possible to compute, exactly, the DAD statistics. The DAD process, by nature, is very computationally intensive, hence forcing time-saving assumptions in storm studies conducted by the Weather Bureau. SPAS, however utilizes today's computer power and GIS algorithms to compute precise and perhaps more accurate DAD statistics.

SPAS utilizes the same general method for determining the storm-centered depth-area statistics as the World Meteorological Organization's Manual for Depth-Area-Duration

Analysis of Storm Precipitation. (WMO 1969) However, SPAS does not make the assumption that the hourly storm precipitation pattern is constant as dictated by a manually analyzed total storm isohyetal map – known as the "index map", but rather it changes from hour to hour.

In real storm cases, the SPAS DAD results were generally within +/-5% of the published Weather Bureau results for the Westfield, MA, storm of 1955 and Ritter, IA, storm of 1953 (See table 2). (U.S. Army Corps of Engineers, 1953; U.S. Army Corps of Engineers. 1955) These results confirm the reproducibility of not only the storm-centered DAD results, but also the spatial and temporal characteristics of the storm precipitation.

SPAS

Sq-Miles	6-hour	12-hour	24-hour	36-hour	48-hour	60-hour	Total
10	7.96	11.48	16.40	19.10	19.11	19.47	19.70
100	7.22	10.72	15.20	17.77	17.76	18.23	18.47
200	6.99	10.27	14.28	16.91	16.84	17.39	17.54
1000	5.97	9.06	12.55	14.97	15.08	15.40	15.95
5000	4.14	6.45	9.25	11.70	12.02	12.35	13.05
10000	3.23	5.46	7.63	9.60	9.91	10.26	10.86
20000	2.24	4.03	5.91	7.66	7.97	8.22	8.77

Weather Bureau

Sq-Miles	6-hour	12-hour	24-hour	36-hour	48-hour	60-hour	Total
10	7.80	11.10	16.40	18.90	19.40	19.40	19.40
100	7.60	10.50	14.60	18.10	18.80	19.00	19.00
200	7.40	10.20	14.20	17.60	18.20	18.40	18.40
1000	6.20	9.20	12.40	15.90	16.20	16.40	16.40
5000	4.00	6.30	9.50	12.10	12.60	13.00	13.00
10000	3.10	5.00	8.00	10.00	10.60	10.80	10.80
20000	2.10	3.60	6.30	7.90	8.30	8.50	8.50

Percent Difference

Sq-Miles	6-hour	12-hour	24-hour	36-hour	48-hour	60-hour	Total
10	2.1%	3.4%	0.0%	1.1%	-1.5%	0.4%	1.5%
100	-5.0%	2.1%	4.1%	-1.8%	-5.5%	-4.1%	-2.8%
200	-5.5%	0.7%	0.6%	-3.9%	-7.5%	-5.5%	-4.7%
1000	-3.7%	-1.5%	1.2%	-5.8%	-6.9%	-6.1%	-2.7%
5000	3.5%	2.4%	-2.6%	-3.3%	-4.6%	-5.0%	0.4%
10000	4.2%	9.2%	-4.6%	-4.0%	-6.5%	-5.0%	0.6%
20000	6.7%	11.9%	-6.2%	-3.0%	-4.0%	-3.3%	3.2%

Table 2. The comparison of DAD results from SPAS and the Weather Bureau published results for the Westfield, MA, storm of August 15-23, 1955.

SPAS Output

SPAS generates a number of products to aid in hydrologic modeling, Probable Maximum Precipitation (PMP) applications and other hydrologic studies. The SPAS output includes:

- High resolution (user defined, but typically 30-seconds or about 0.5 miles) hourly precipitation grids and/or Shapefiles.
- Mass curves for all of the stations (see Figure 11)
- A complete storm-centered DAD table and summary, including station density. (see Figures 12a and b)
- A complete station list.
- Color cartographic total storm precipitation map (see Figure 8)
- Other customized files/output

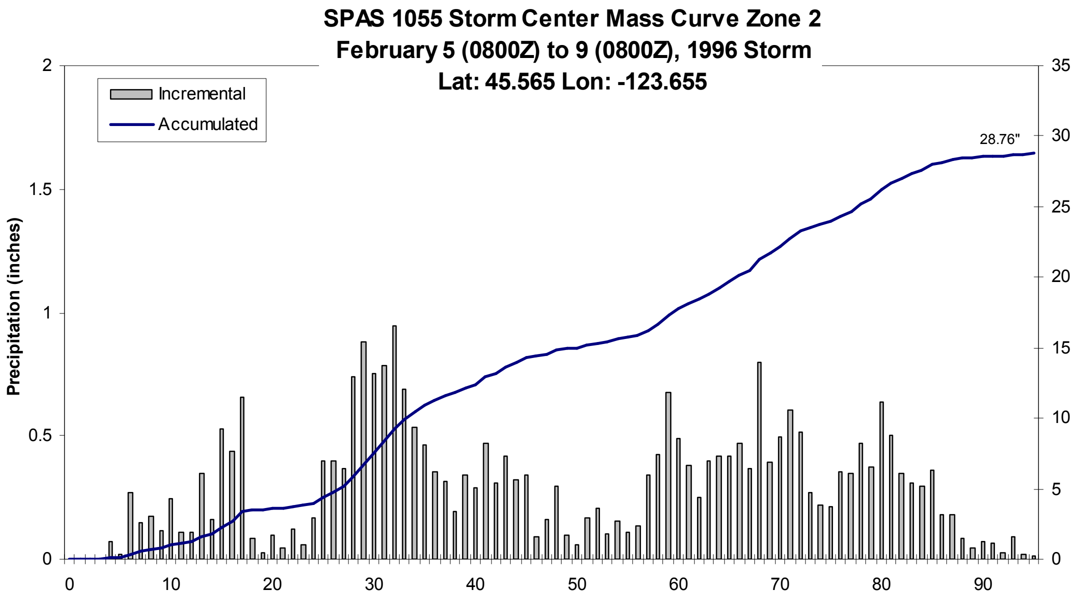
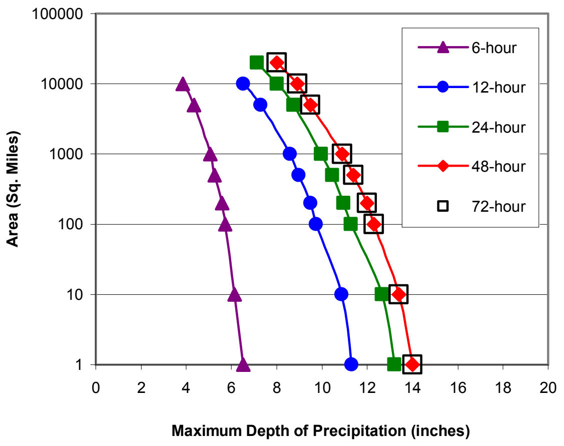


Figure **11.** Storm center mass curve.



a)

Area	Duration (hours)				
(sq. mi.)	6	12	24	48	72
1	6.5	11.3	13.2	14.0	14.0
10	6.1	10.9	12.7	13.4	13.4
100	5.7	9.8	11.3	12.3	12.3
200	5.6	9.5	11.0	12.0	12.0
500	5.3	9.0	10.5	11.4	11.4
1000	5.1	8.6	10.0	10.9	10.9
5000	4.4	7.3	8.8	9.5	9.5
10000	3.9	6.5	8.0	8.9	8.9
20000	3.3	5.6	7.1	8.0	8.0

b)

Figure 12 a) Depth-area duration plot and b) associated DAD table.

Summary

SPAS is based on the sound foundation of the storm analysis procedure used by the Weather Bureau, thereby providing consistency between storms already analyzed and those being analyzed today. However, SPAS has the ability to compute more precise and perhaps more accurate results by using a more sophisticated timing algorithm, a variety of base maps, a wider variety of data and fewer assumptions. Although largely automated, SPAS has been designed to be flexible such that it can be utilized for any storm situation. SPAS produces reproducible results and uses less subjectivity than previous storm analysis studies.

There is an extremely large backlog of extreme precipitation storm analyses that should be completed. With rare exception, extreme precipitation storms that have occurred in the last 50 years have not been analyzed. Without storm DADs, comparison of precipitation amounts from extreme precipitation storms for various area sizes and durations is not possible. The storm data bases in most of the current HMRs are significantly out of date. For example, the most recent storm used in HMR 51 occurred in 1972 (Schreiner, 1978). Using SPAS, this backlog in storm analyses can be addressed. Equally important, storm analyses can be provided in near real-time, utilizing precipitation observations that are not included in official archives and providing emergency managers with some measure of how extreme the storm precipitation amounts over various area sizes and for various durations were compared to other storms, to published return frequency values and to published PMP values.

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