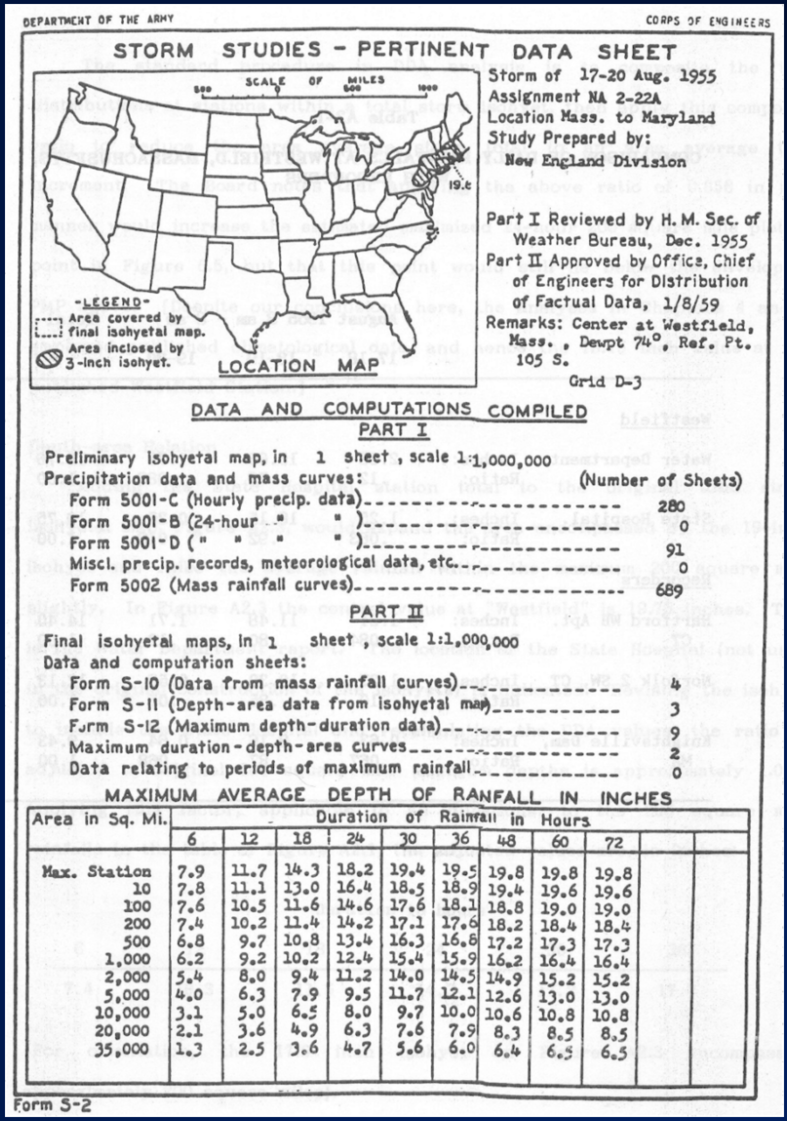
Storm Precipitation Analysis System (SPAS)

An Overview

Background

- The Weather Bureau (now the National Weather Service, NWS) and the Corps of Engineers have completed detailed storm analyses for storms that occurred from the 1880’s through the 1950’s
- Since then only a few selected storms have been analyzed by the NWS or USACE
- The resulting DAD tables utilized in PMP studies


DEPARTMENT OF THE ARMY — CORPS OF ENGINEERS

STORM STUDIES - PERTINENT DATA SHEET

Storm of 17-20 Aug. 1955
Assignment NA 2-22A
Location Mass. to Maryland
Study Prepared by:
New England Division

Part I Reviewed by H. M. Sec. of Weather Bureau, Dec. 1955
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 1/8/59
Remarks: Center at Westfield, Mass., Dewpt 74°, Ref. Pt. 105 S.
Grid D-3

DATA AND COMPUTATIONS COMPILED

PART I

Preliminary isohyetal map, in 1 sheet, scale 1:1,000,000
Precipitation data and mass curves: (Number of Sheets)
Form 5001-C (Hourly precip. data) ---------- 280
Form 5001-B (24-hour " ") ---------- 0
Form 5001-D (" " " ") ---------- 91
Miscl. precip. records, meteorological data, etc. ---------- 0
Form 5002 (Mass rainfall curves) ---------- 689

PART II

Final isohyetal maps, in 1 sheet, scale 1:1,000,000
Data and computation sheets:
Form S-10 (Data from mass rainfall curves) ---------- 4
Form S-11 (Depth-area data from isohyetal map) ---------- 3
Form S-12 (Maximum depth-duration data) ---------- 9
Maximum duration-depth-area curves ---------- 2
Data relating to periods of maximum rainfall ---------- 0

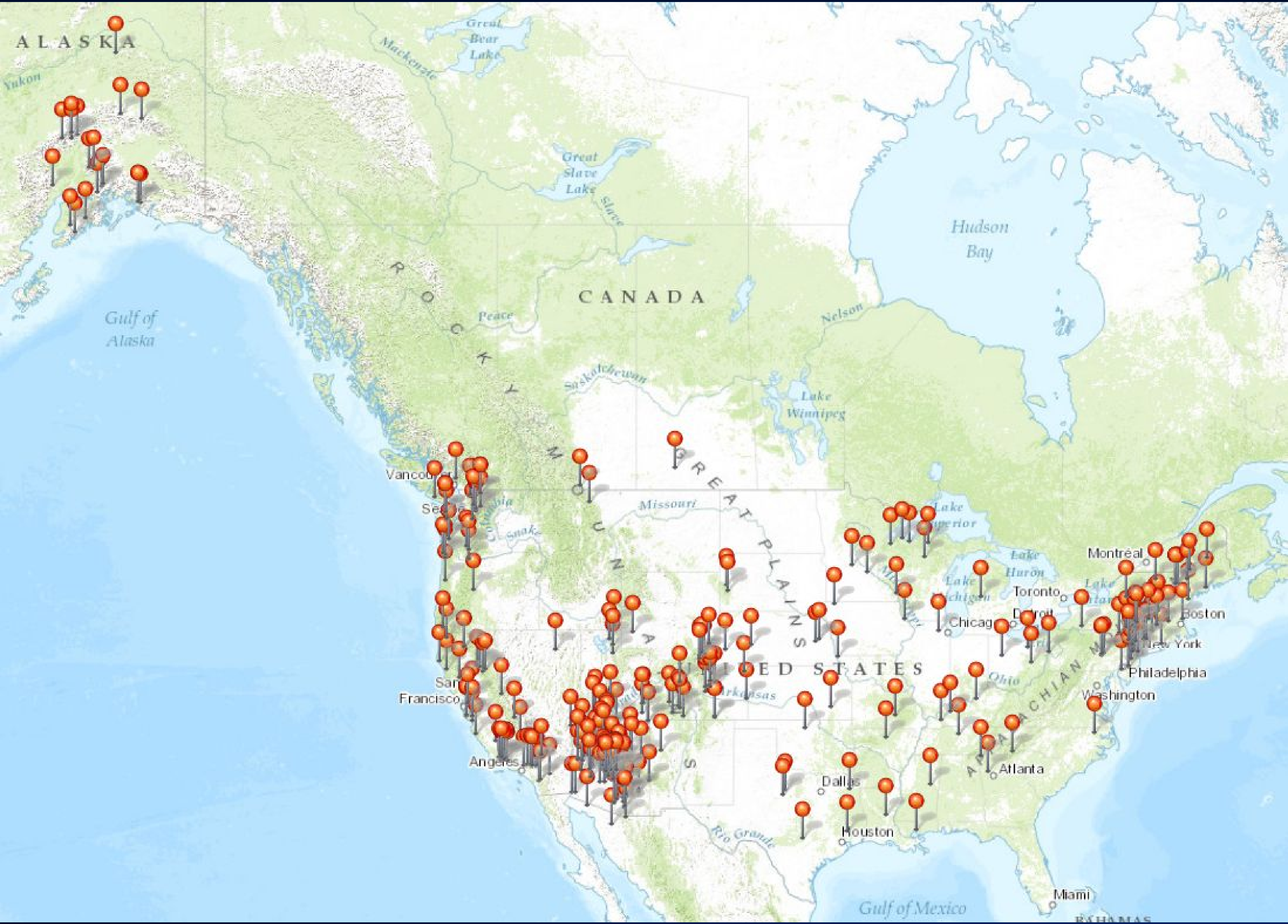
MAXIMUM AVERAGE DEPTH OF RANFALL IN INCHES

Area in Sq. Mi.	Duration of Rainfall in Hours										
	6	12	18	24	30	36	48	60	72		
Max. Station	7.9	11.7	14.3	18.2	19.4	19.5	19.8	19.8	19.8		
10	7.8	11.1	13.0	16.4	18.5	18.9	19.4	19.6	19.6		
100	7.6	10.5	11.6	14.6	17.6	18.1	18.8	19.0	19.0		
200	7.4	10.2	11.4	14.2	17.1	17.6	18.2	18.4	18.4		
500	6.8	9.7	10.8	13.4	16.3	16.8	17.2	17.3	17.3		
1,000	6.2	9.2	10.2	12.4	15.4	15.9	16.2	16.4	16.4		
2,000	5.4	8.0	9.4	11.2	14.0	14.5	14.9	15.2	15.2		
5,000	4.0	6.3	7.9	9.5	11.7	12.1	12.6	13.0	13.0		
10,000	3.1	5.0	6.5	8.0	9.7	10.0	10.6	10.8	10.8		
20,000	2.1	3.6	4.9	6.3	7.6	7.9	8.3	8.5	8.5		
35,000	1.3	2.5	3.6	4.7	5.6	6.0	6.4	6.5	6.5		

Form S-2

Background (cont.)

- “Storm analyses” quantify the spatial and temporal characteristics of a storm’s precipitation
  - Influence of terrain/orographics
  - Utilize all available precipitation data
  - Leverage NEXRAD data (if available)
  - Reproducible and consistent
- SPAS has been used to analyze over 240 storm centers in the U.S. and Canada



ALASKA
Yukon
Great Bear Lake
Mackenzie
Great Slave Lake
Slave
Gulf of Alaska
ROCKY MOUNTAINS
Peace
CANADA
Nelson
Hudson Bay
Saskatchewan
Lake Winnipeg
GREAT PLAINS
Missouri
Snake
Vancouver
Seattle
Lake Superior
Lake Huron
Lake Michigan
Montréal
Toronto
Detroit
Chicago
Boston
New York
Philadelphia
Washington
UNITED STATES
Ohio
Arkansas
San Francisco
Los Angeles
APPALACHIAN MTS.
Atlanta
Dallas
Houston
Rio Grande
Gulf of Mexico
Miami
BAHAMAS

Introduction (cont.)

- SPAS is …
  - A complete storm analysis software program
  - A unique state-of-the-art storm centered depth-area-duration (DAD) analysis system
  - Uses the latest advancements of GIS
  - Largely automated, yet requires and allows plenty of user intervention.
  - Uses same basic principles used by NWS, thereby achieving consistency

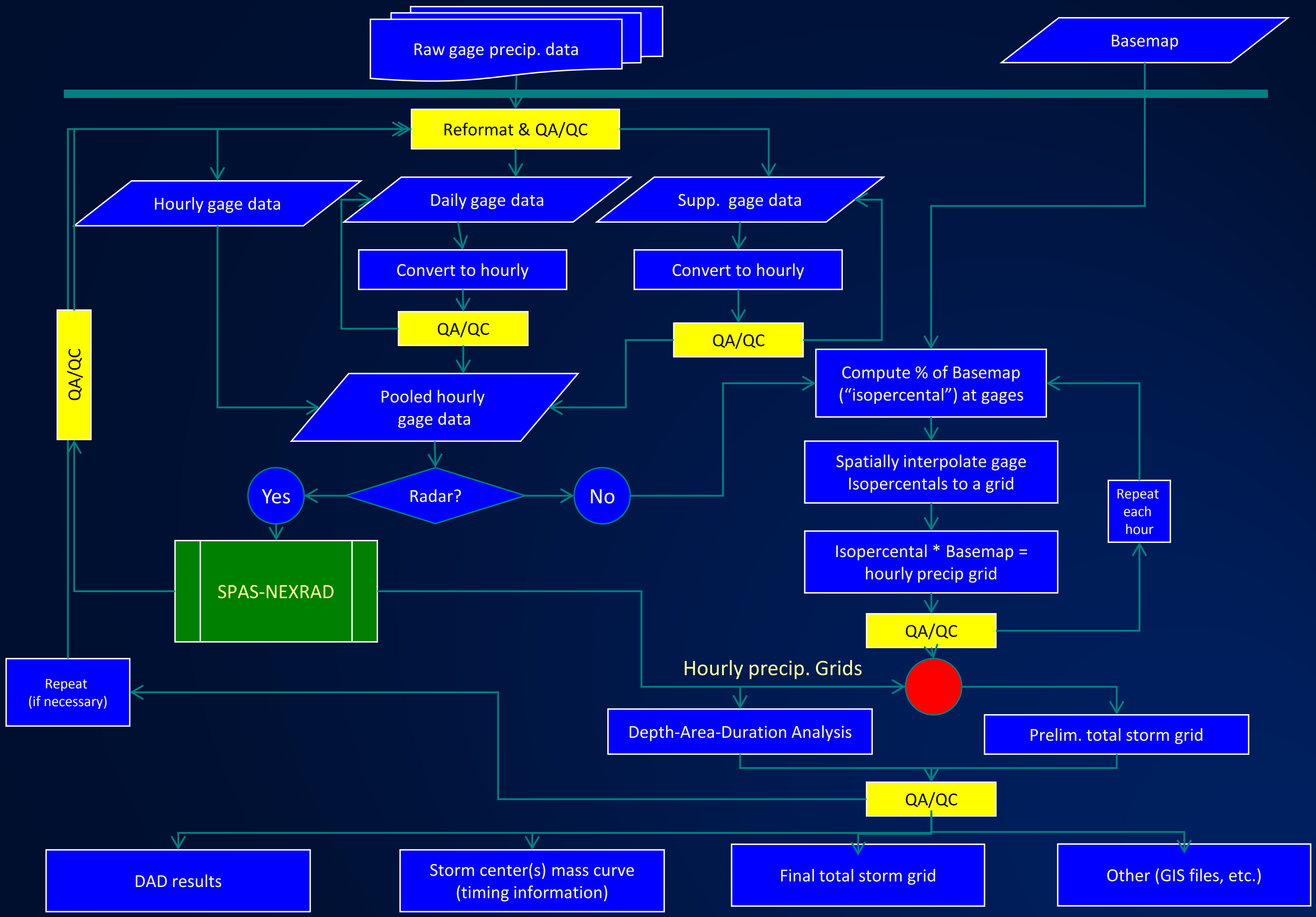
Introduction (cont.)

- SPAS operates in two modes
  - SPAS (pre-NEXRAD radar storms)
    - *Utilizes a "basemap" for interpolating hourly storm precipitation. Basemap options include:*
      - Precipitation Frequency grids (e.g. 100-year 24-hour) - NOAA Atlas 14, TP-40, NOAA Atlas 2, etc.)
      - Elevation - Digital Elevation Model (DEM)
      - Mean (1971-2000) monthly/annual precipitation - Parameter-elevation Regressions on Independent Slopes Model (PRISM)

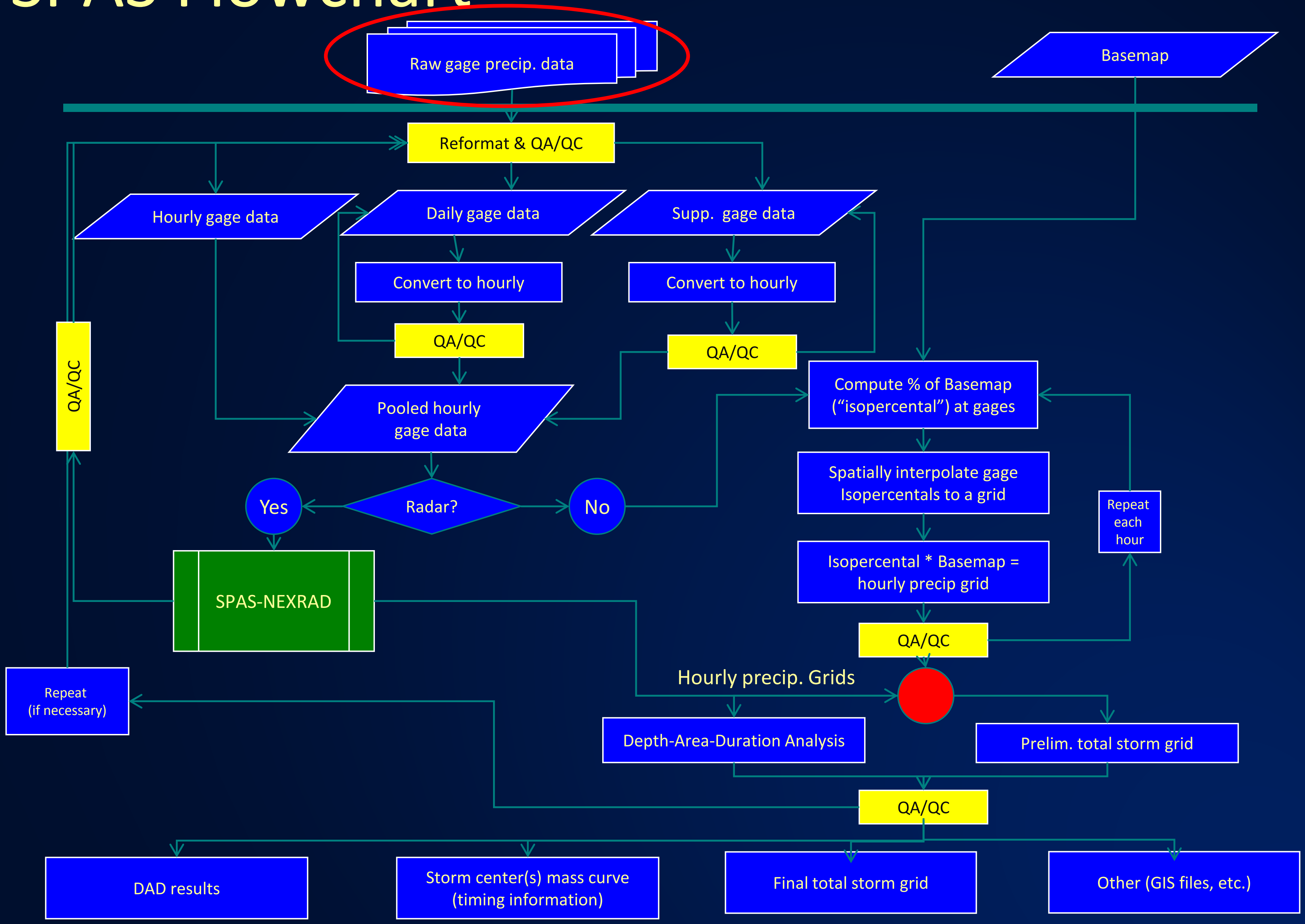
Introduction (cont.)

- SPAS-NEXRAD
  - *Requires SPAS to be run first*
  - *Uses calibrated radar data for interpolating n-min/hourly precipitation*
    - Uses radar+basemap for resolving precipitation <u>patterns</u>
    - Uses observed gauge precipitation for <u>magnitude</u>

SPAS Flowchart



SPAS Flowchart



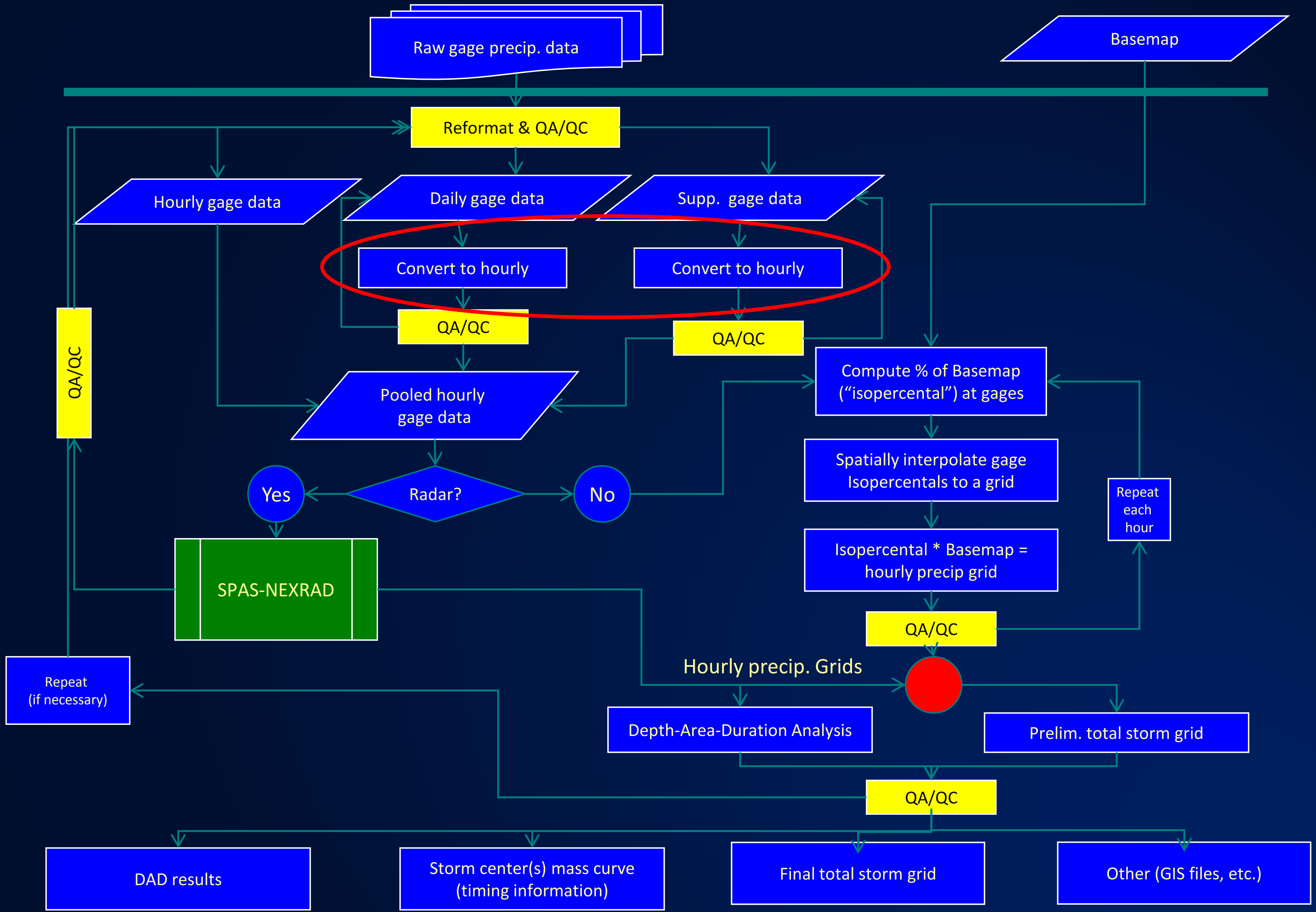
Precipitation Data

- SPAS utilizes a variety of precipitation data to achieve the highest level of spatial and temporal detail possible.
  - Hourly data
    - *In-house National Climatic Data Center (NCDC) database*
    - *Automated Local Evaluation in Real Time (ALERT) networks, Remote Automated Weather Stations (RAWS) stations, NWS's Automated Surface Observing Systems (ASOS), municipal networks, etc.*

Precipitation Data (cont.)

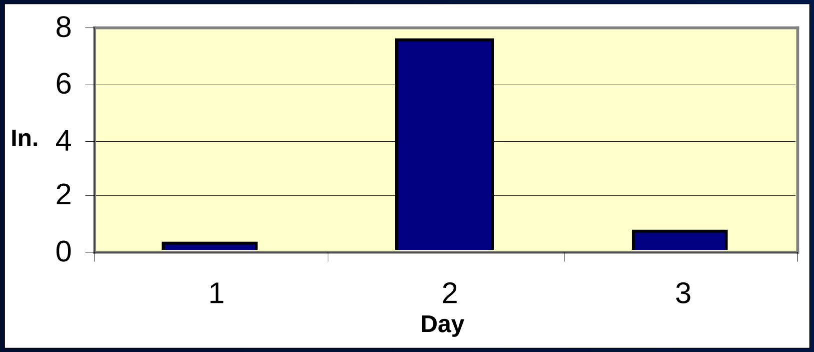
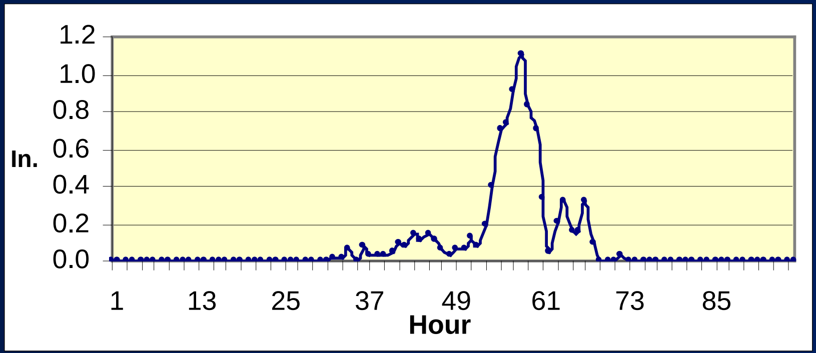
- Daily data
  - *In-house National Climatic Data Center (NCDC) database*
  - *SNOTEL*
  - *Municipal networks, etc*
  - *Citizen networks (e.g. CoCoRaHS)*
- Supplemental data – total or partial storm
  - *“Bucket survey’s”*
  - *Public/NWS reports*
  - *Storm Data*

SPAS Flowchart

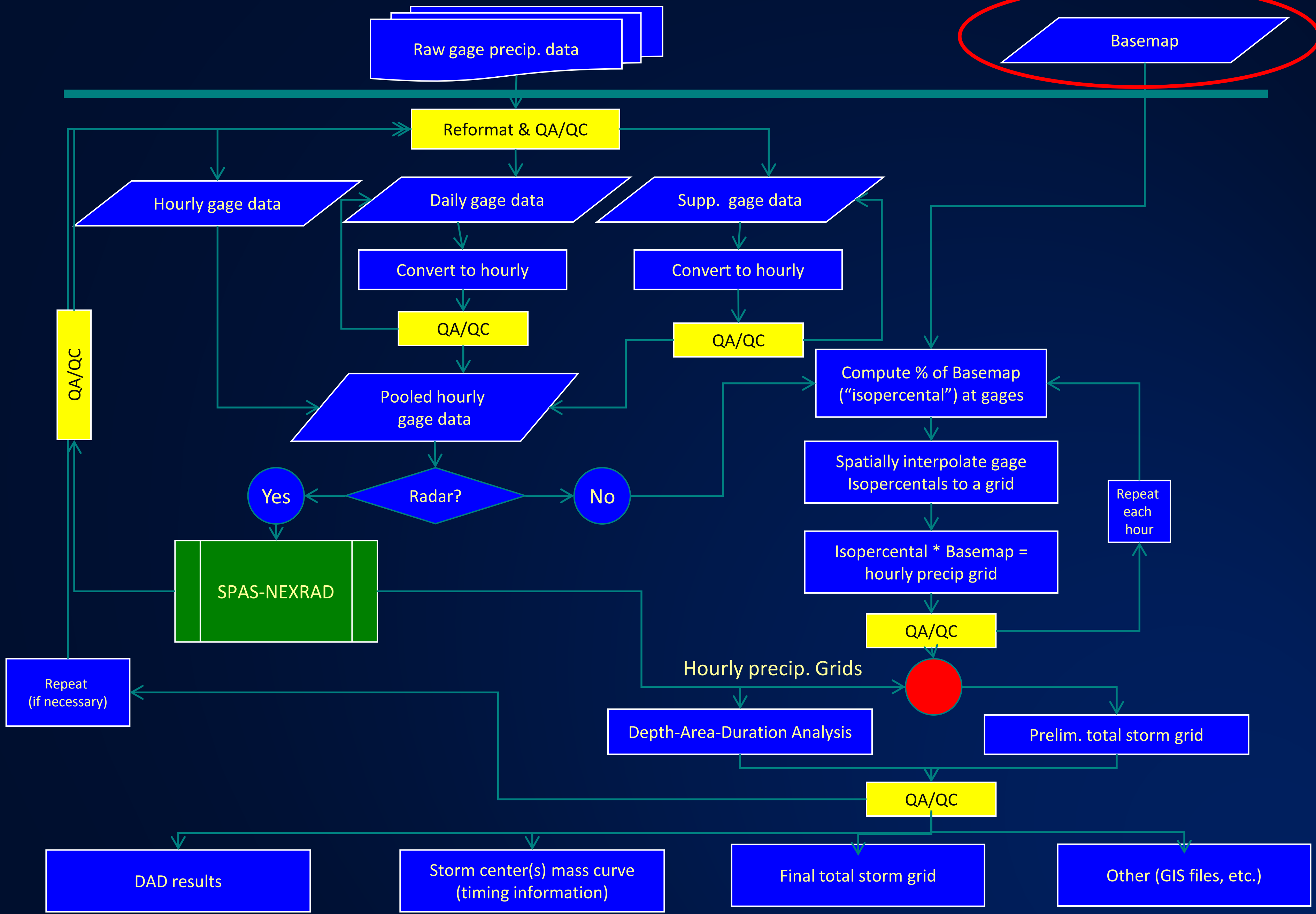


Daily to Hourly Precipitation

- To achieve an hourly time step at ALL stations, it's necessary to convert daily & supplemental stations into estimated hourly
  - SPAS uses several hourly stations
  - Radar data (if available)
  - Other known data (partial hourly station)

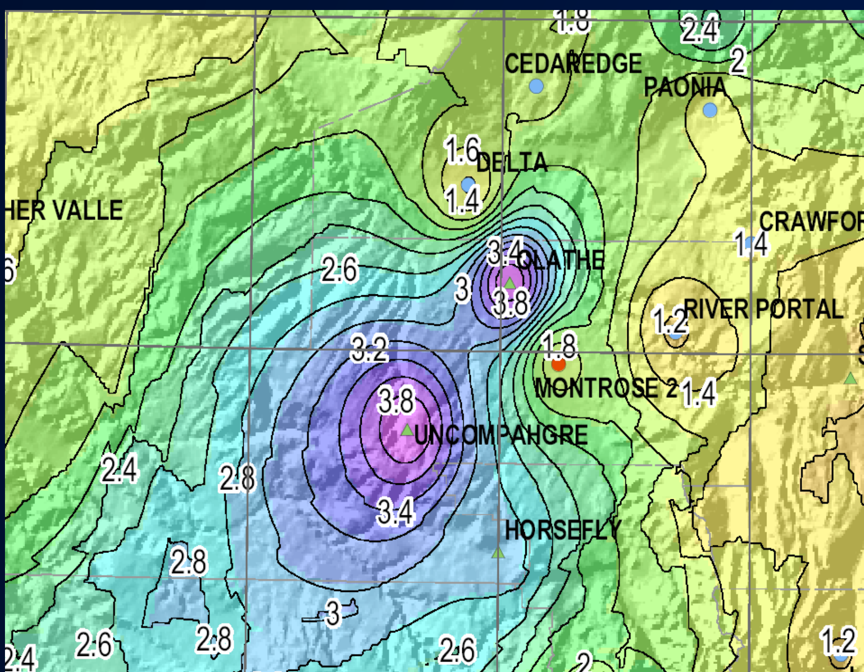
Daily data	→	Estimated hourly data
		

SPAS Flowchart

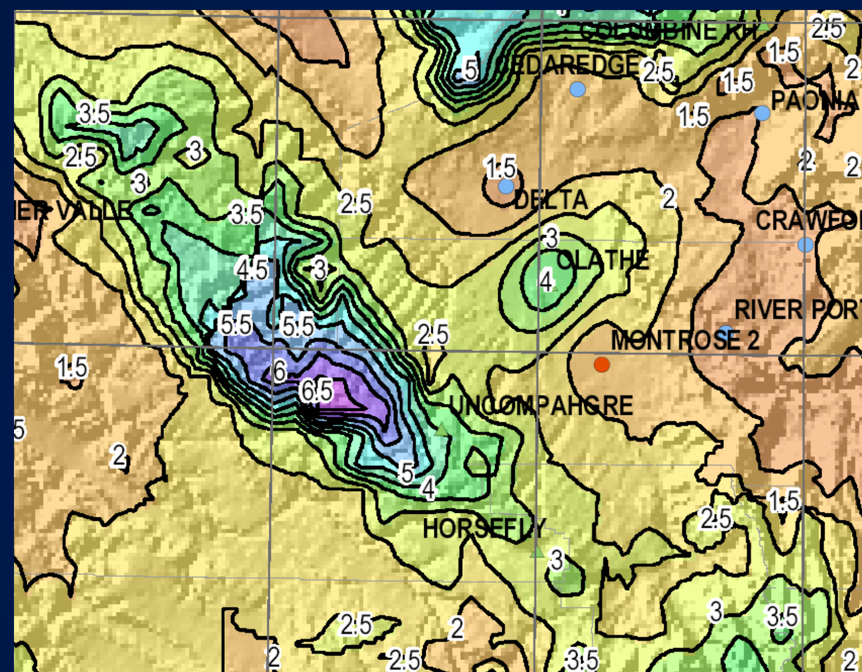


Basemap

- The base map helps interpolate precipitation values at ungauged locations in complex terrain.



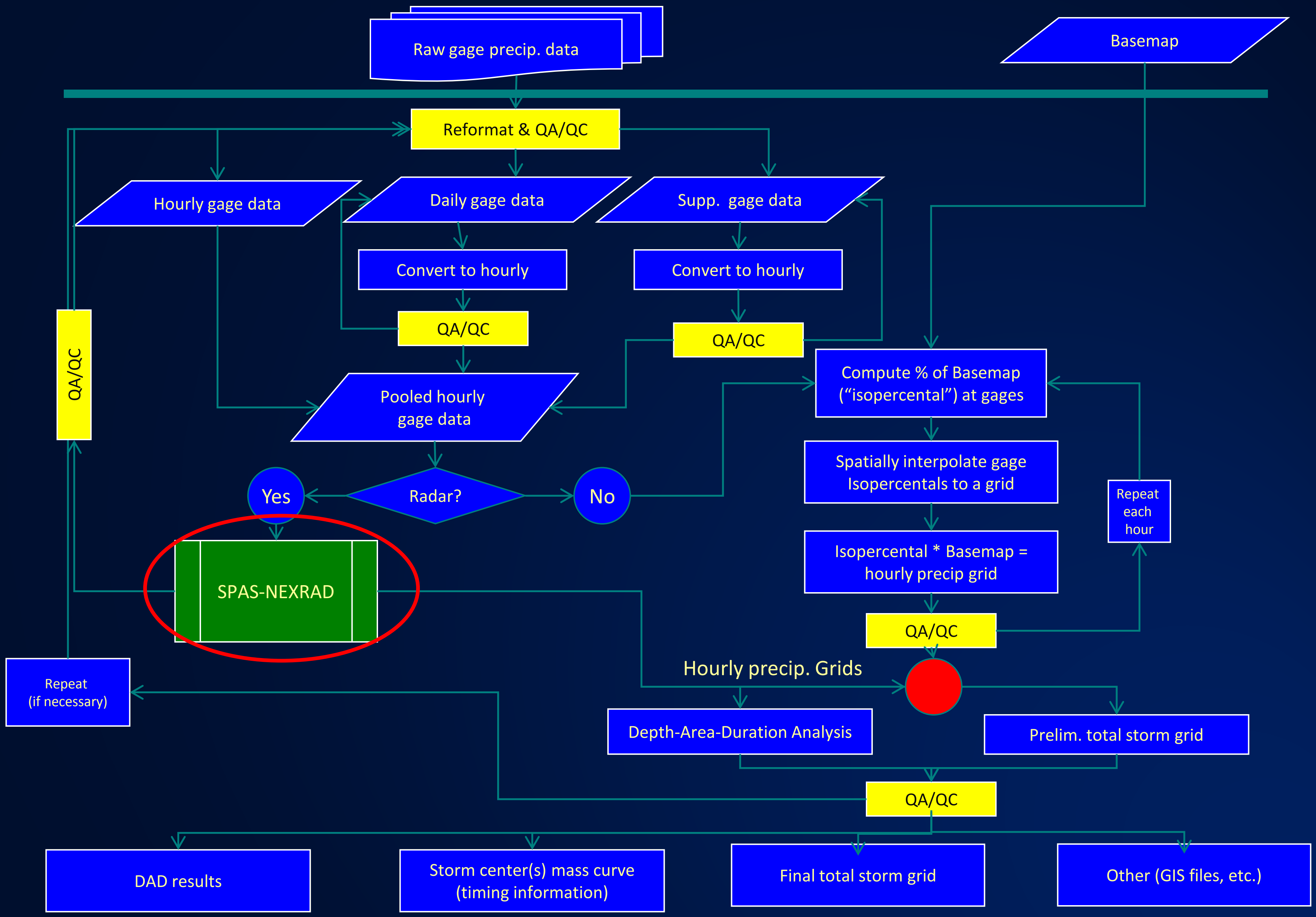
Total Storm Precipitation **Without** Basemap



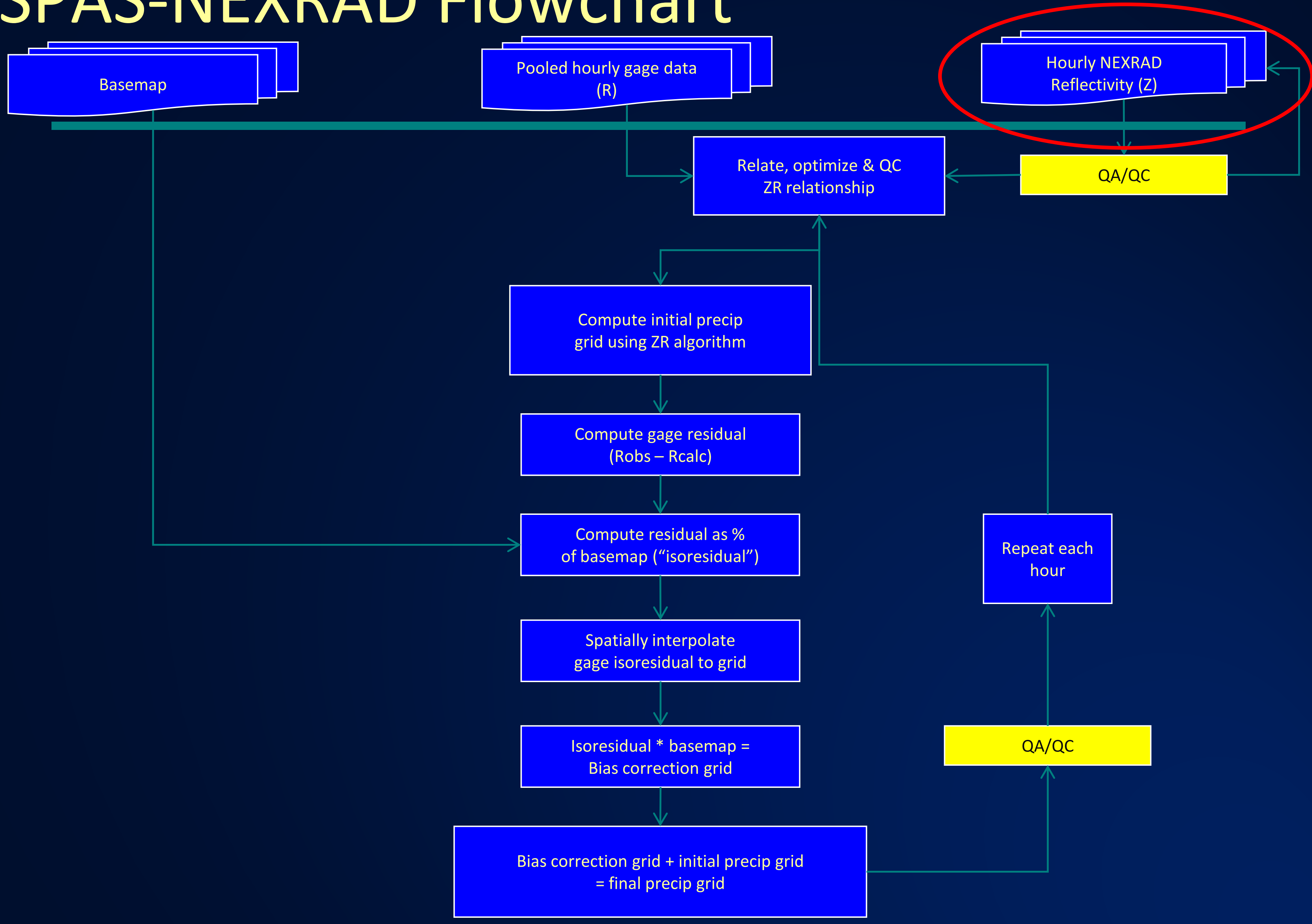
Total Storm Precipitation **With** Basemap

SPAS Flowchart

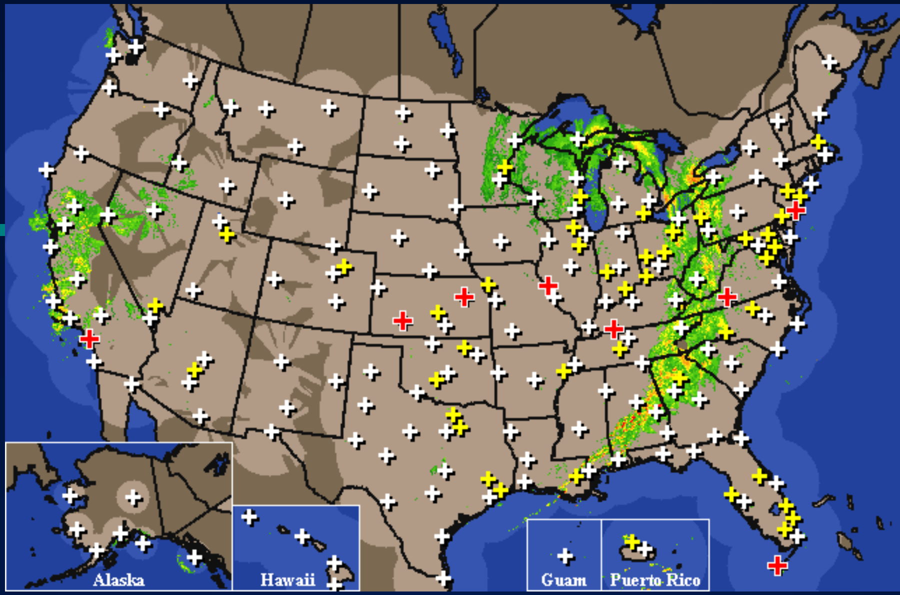
SPAS Flowchart



SPAS-NEXRAD Flowchart



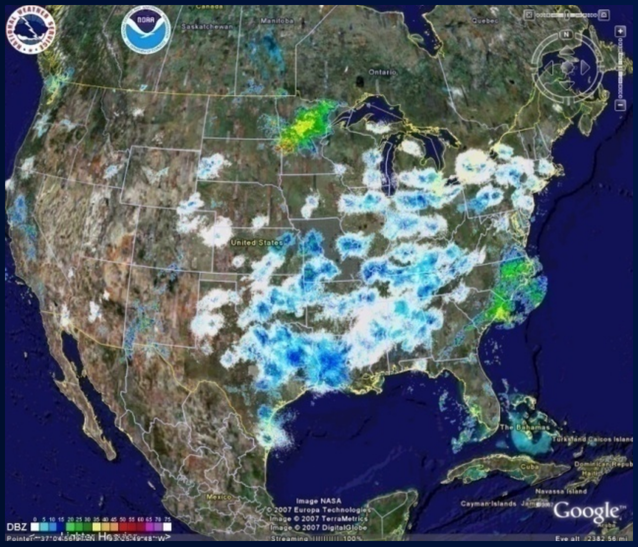
NEXRAD Radar Data

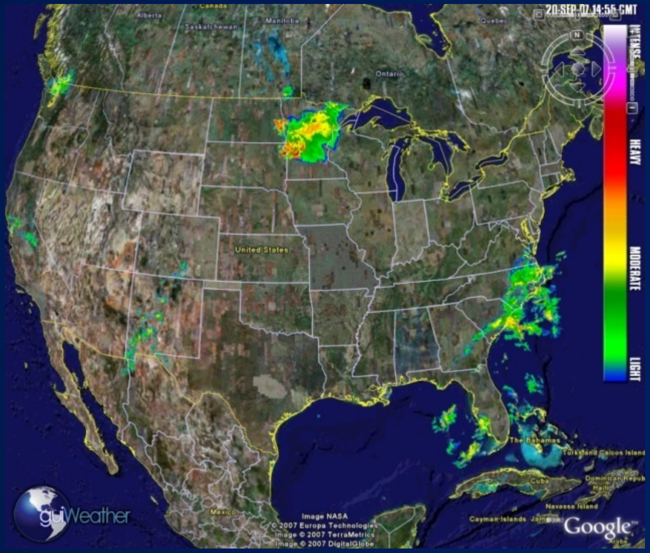


- Obtained from Weather Decision Technologies
- 155 U.S. and 30 Canadian Radars
- Blends multiple radars (distance weighting)
  - Selects reflectivity closest to the ground which is most representative of rainfall
- Advanced algorithms for mosaicing and QCing reflectivity (Z) data from multiple radar sites.

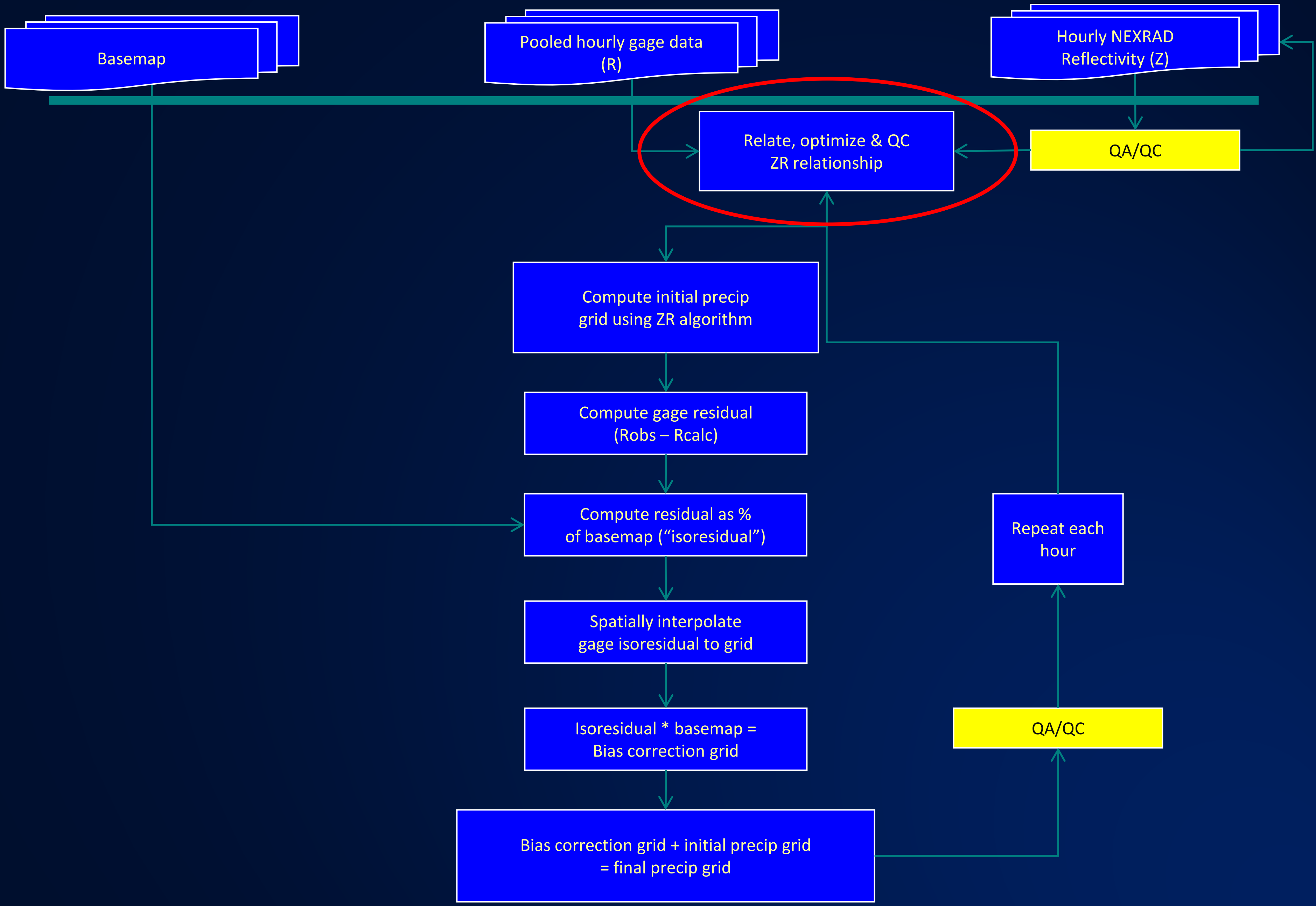
NEXRAD Radar Data (Contr.)

- Advanced algorithms for mosaicing and QCing reflectivity (Z) data from multiple radar sites
  - Spatial: ~ 1km x ~1 km
  - Temporal: Every 5-minutes (10-mins Canada)



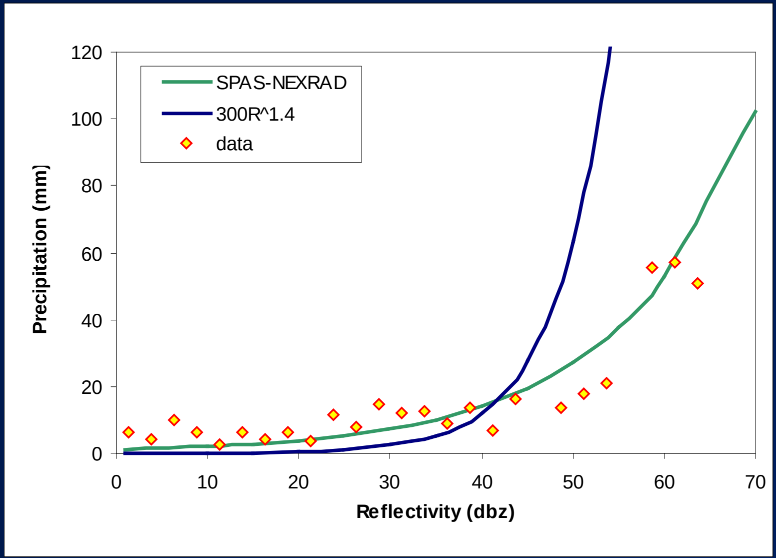


SPAS-NEXRAD Flowchart



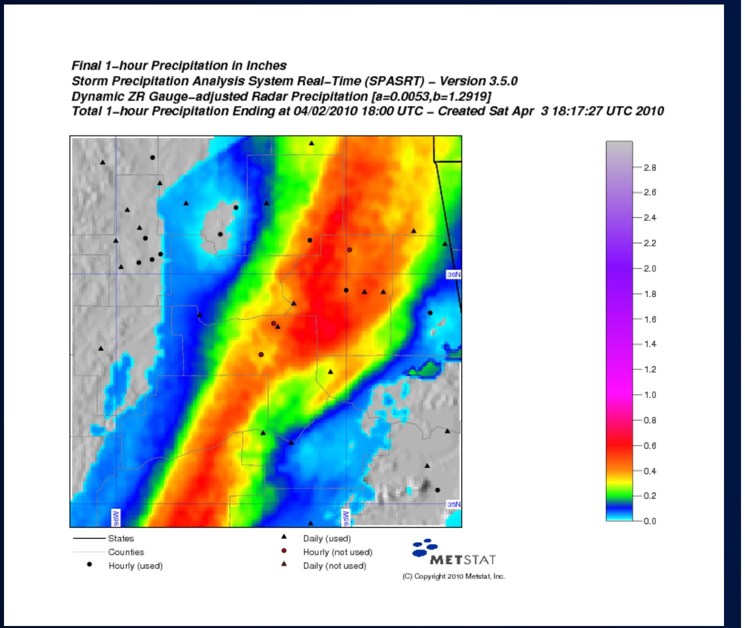
Radar Reflectivity-Rainfall (Z-R) relationships

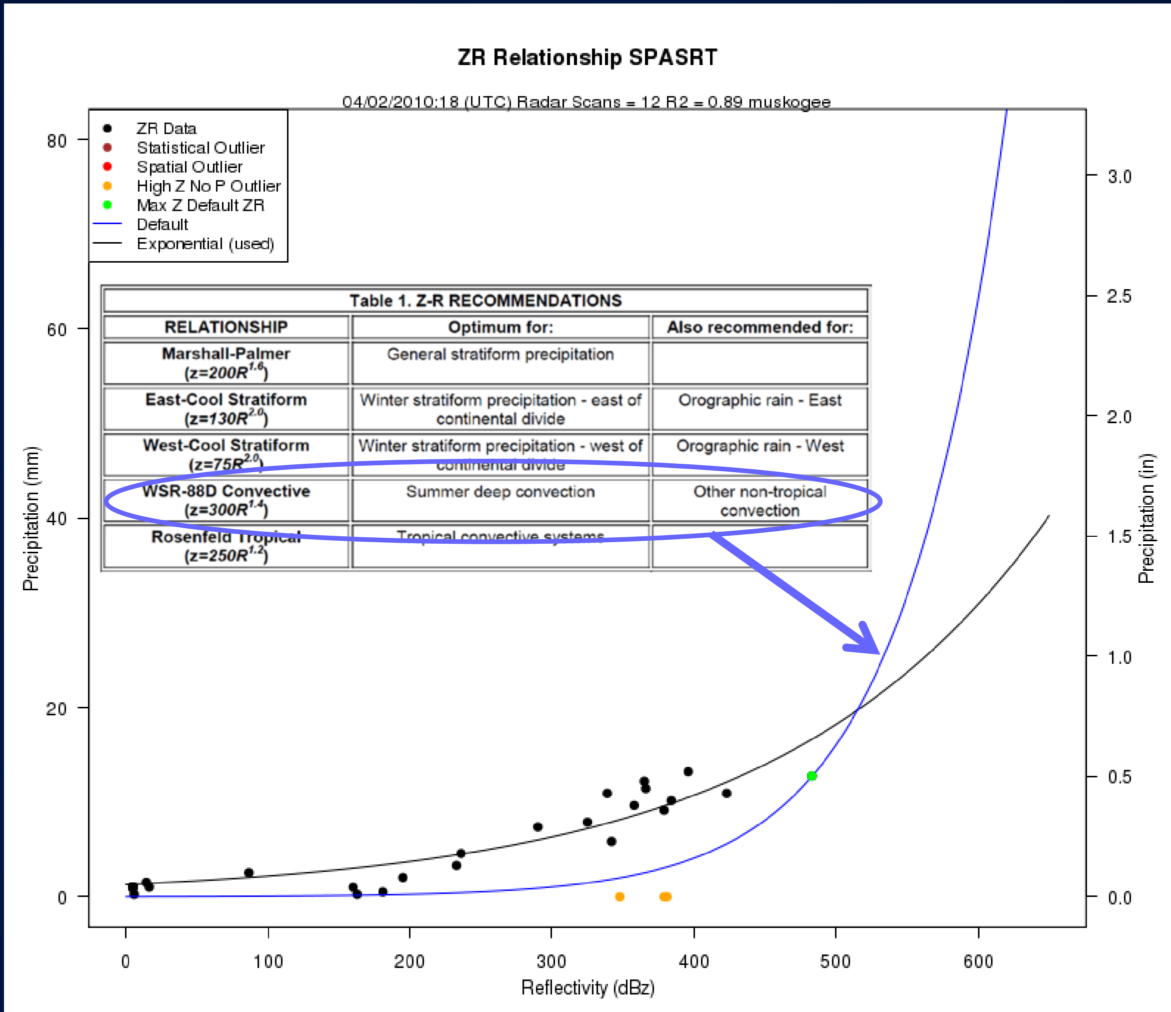
- Radar **R**eflectivity-**R**ainfall (Z-R) relationships are used to translate reflectivity into rainfall rates.
- Instead of adopting a default Z-R, SPAS determines a best-fit Z-R based on measured 1-hour precipitation and reflectivity data
  - Outliers are identified and QCed



ZR Relationship

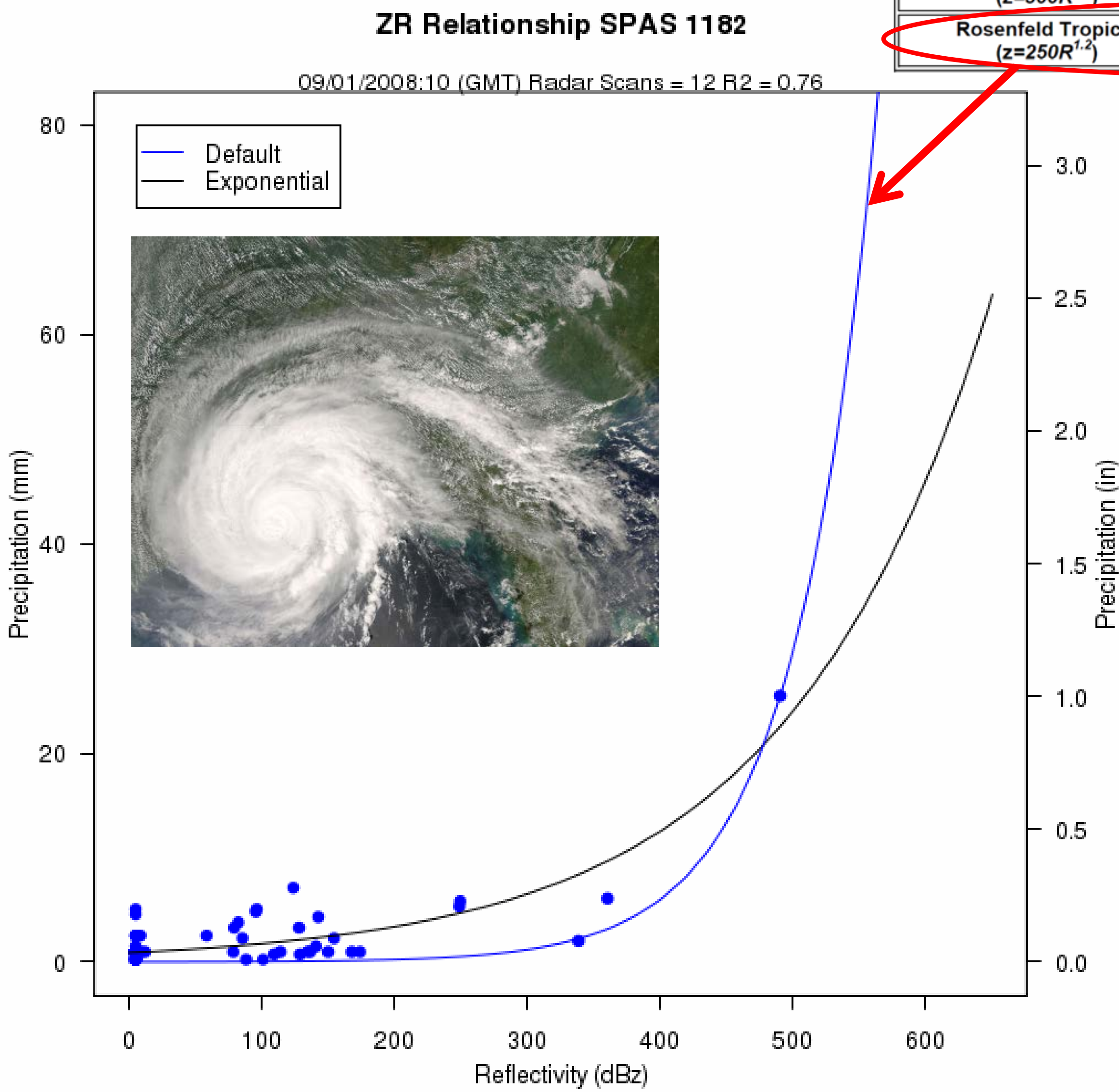
- Reflectivity-rainfall (ZR) relationships are computed using a weighted best-fit exponential function and thresholds in order to compute rainfall rates from radar reflectivity
  - Instead of adopting a standard (e.g. 300^1.4) ZR relationship, SPASRT computes and applies a ZR relationship <u>each hour</u>



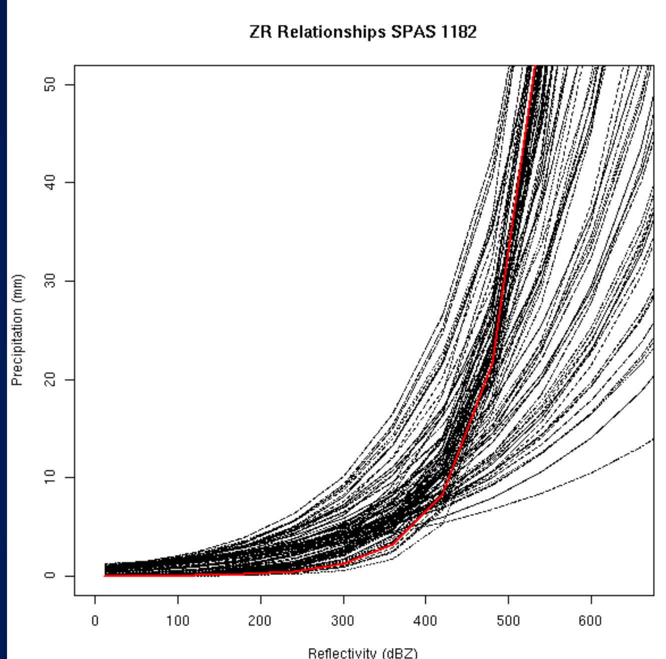


Dynamic ZR Relationship

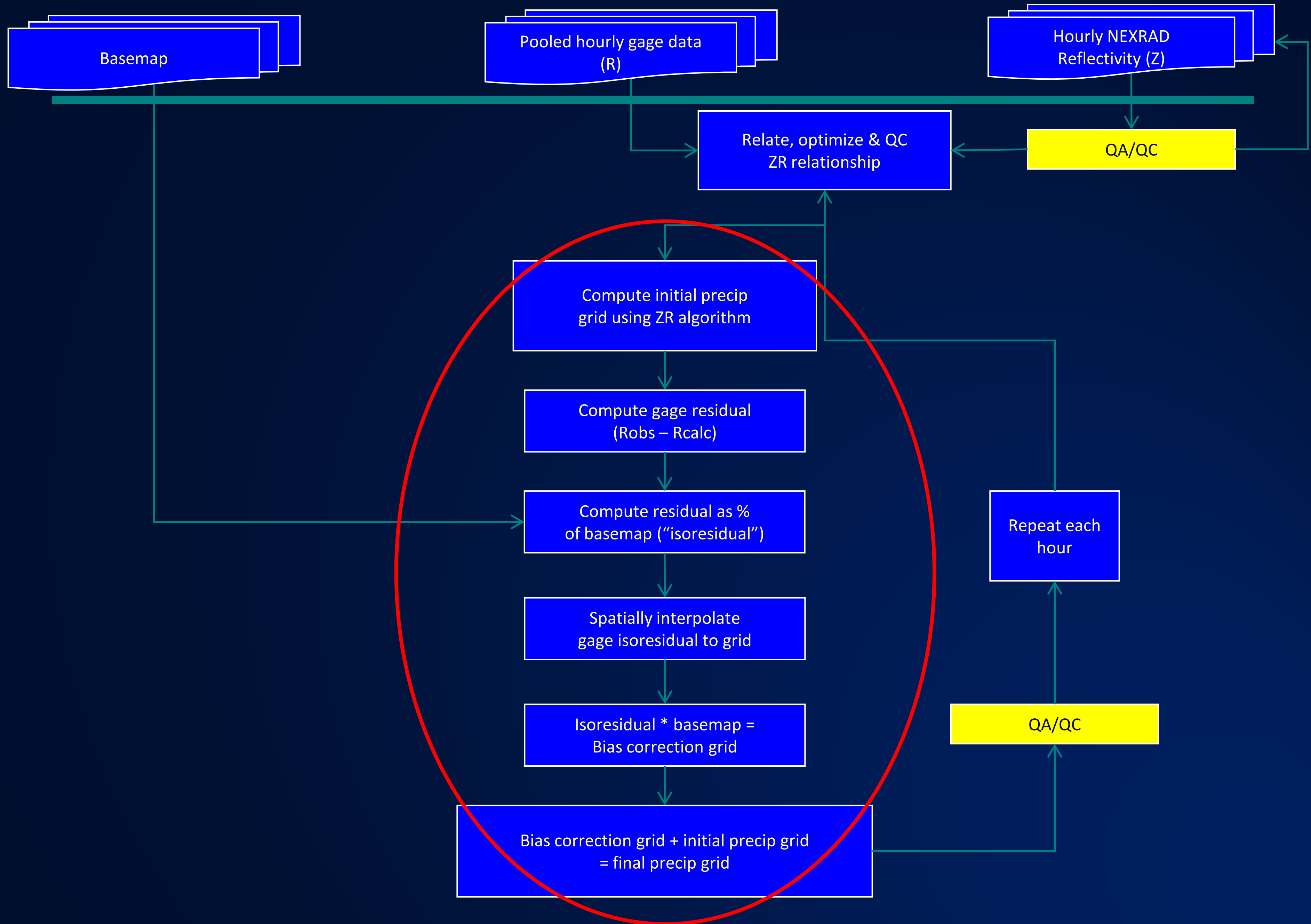
Table 1. Z-R RECOMMENDATIONS		
RELATIONSHIP	Optimum for:	Also recommended for:
Marshall-Palmer ($z=200R^{1.6}$)	General stratiform precipitation	
East-Cool Stratiform ($z=130R^{2.0}$)	Winter stratiform precipitation - east of continental divide	Orographic rain - East
West-Cool Stratiform ($z=75R^{2.0}$)	Winter stratiform precipitation - west of continental divide	Orographic rain - West
WSR-88D Convective ($z=300R^{1.4}$)	Summer deep convection	Other non-tropical convection
Rosenfeld Tropical ($z=250R^{1.2}$)	Tropical convective systems	



The standard Z-R can be considerably different than the SPAS data-driven, optimized Z-R
Resulting in higher accuracy

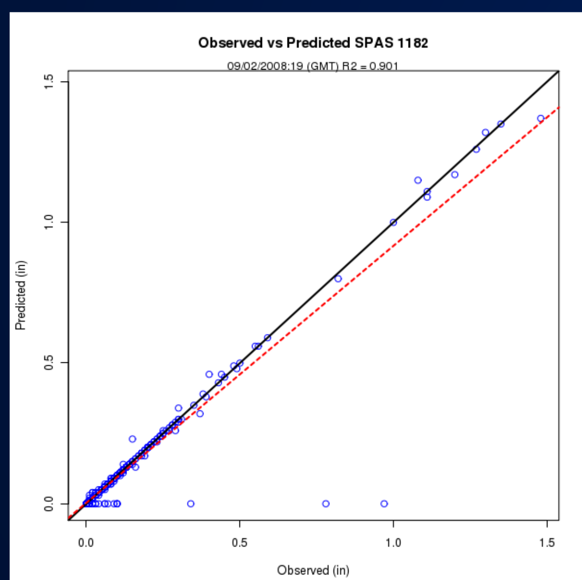


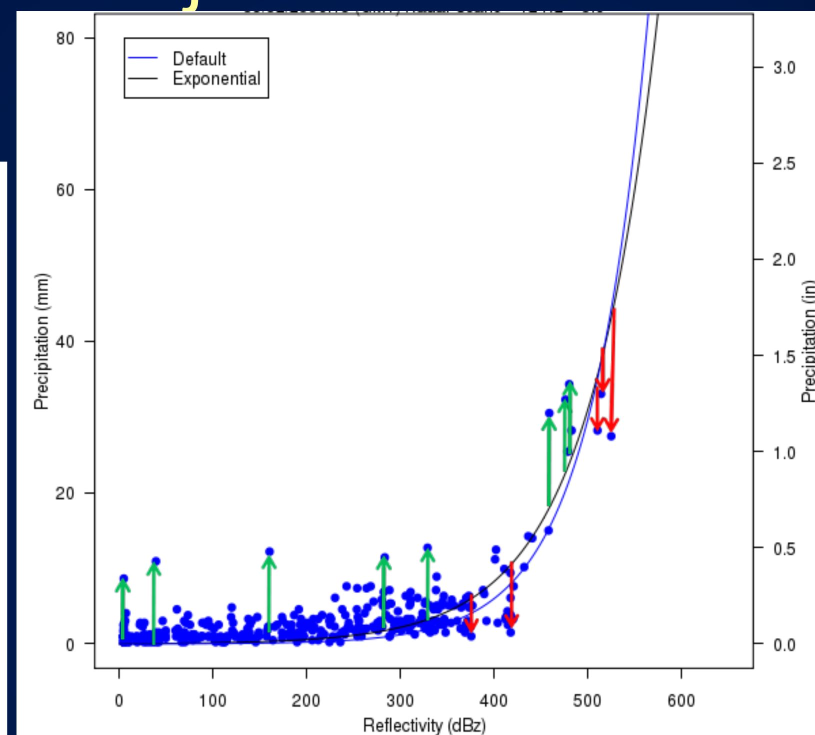
SPAS-NEXRAD Flowchart



Bias Adjustment

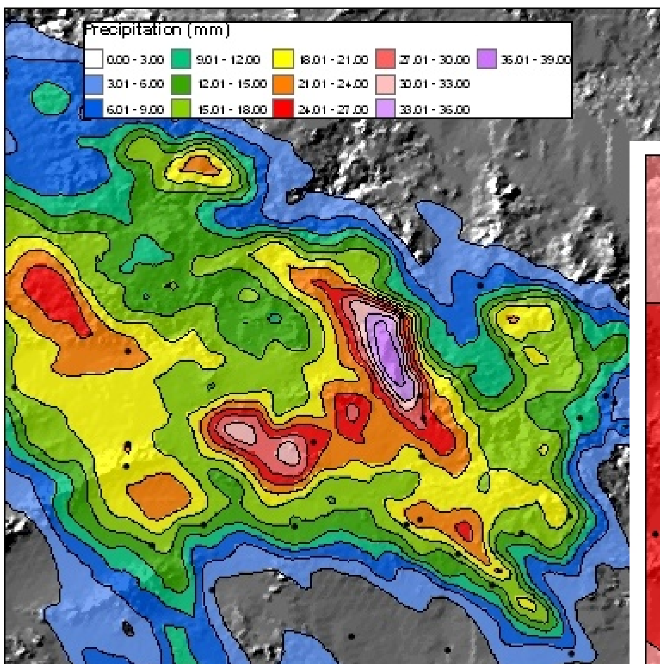
- The bias at each gauge is spatially interpolated and applied to initial rainfall grid
  - Allows for local variation in the bias field instead of applying a mean field bias adjustment
  - Ensures gauge and grid rainfall are equal



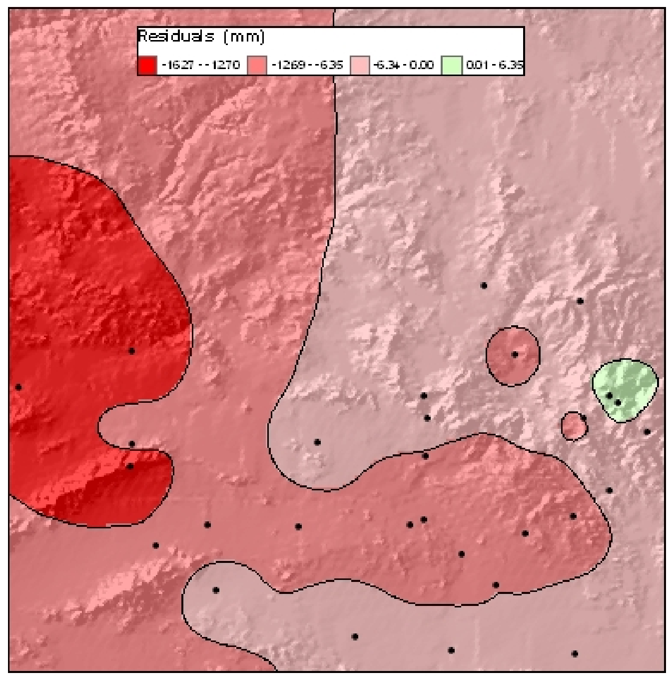


Bias Correction

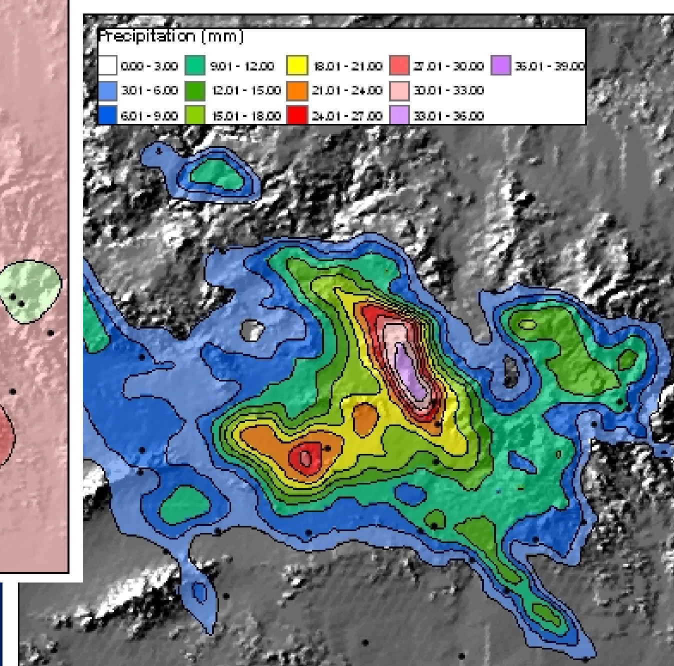
Apply ZR to QC'ed Z grid (initial grid)



Compute and interpolate "isoresiduals" at gages

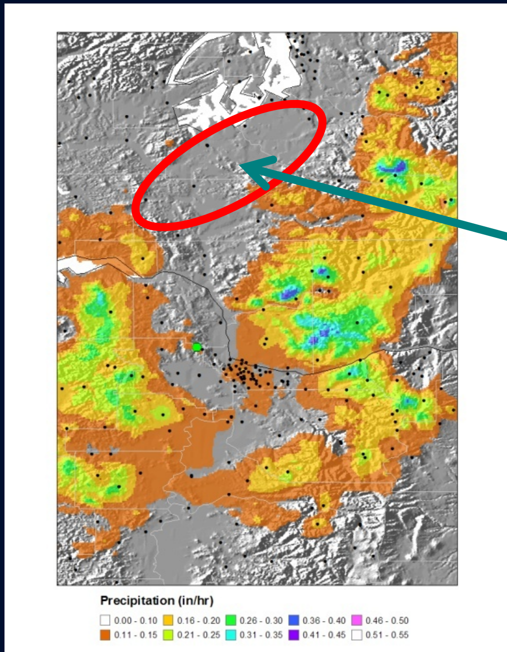


Add initial to residuals to create final grid



Radar+Basemap

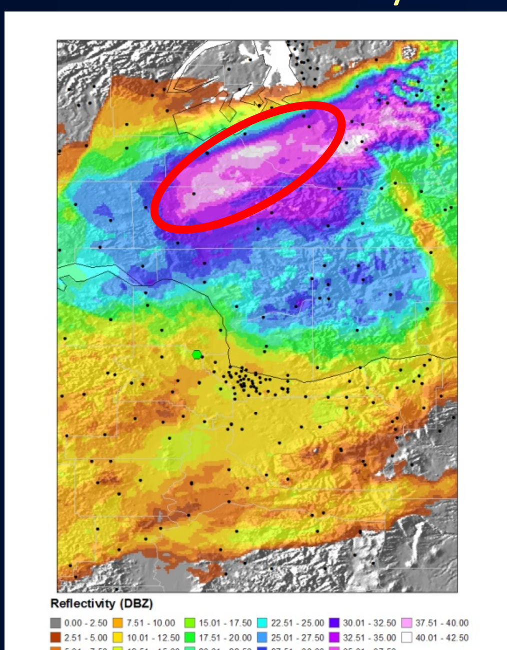
SPAS basemap, no radar



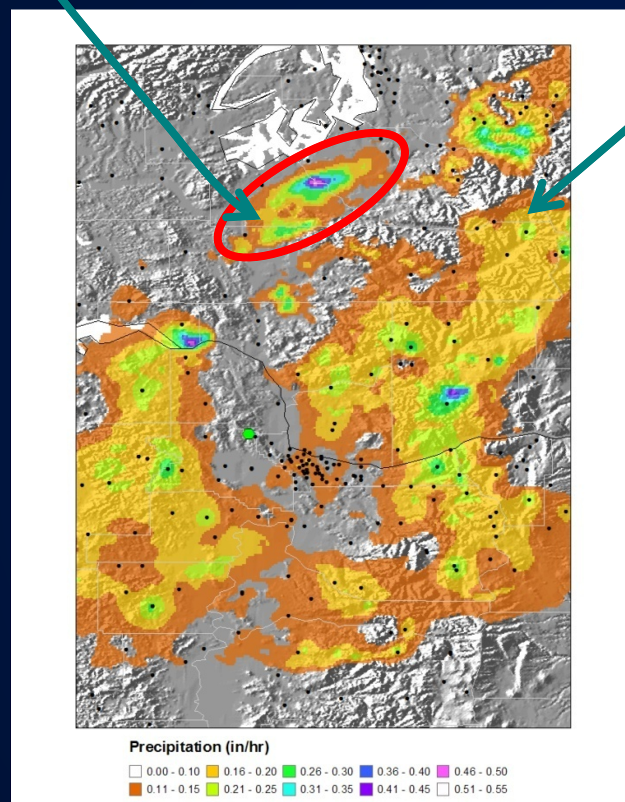
The value of radar

The value of a basemap

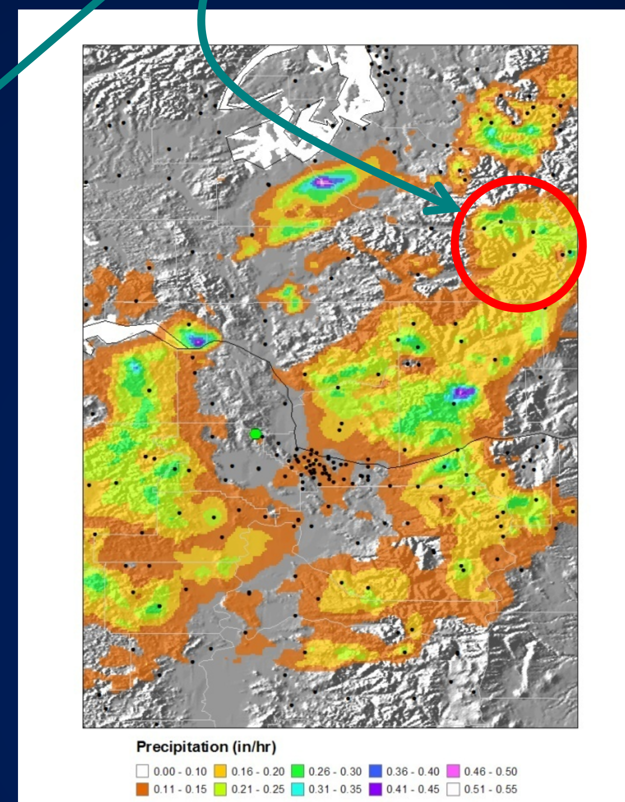
Radar reflectivity



SPAS-NEXRAD <u>no</u> basemap



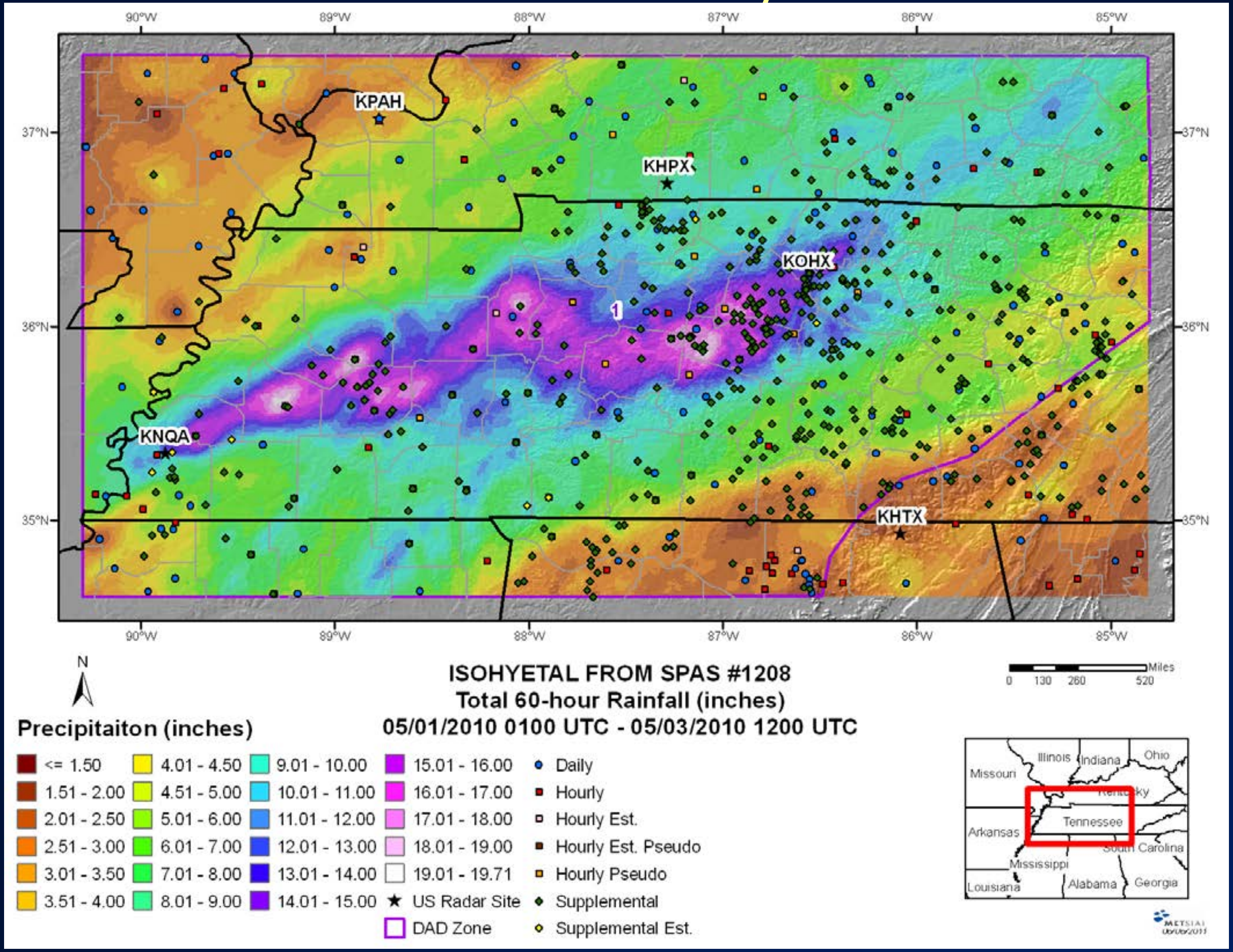
SPAS-NEXRAD with basemap



SPAS Output

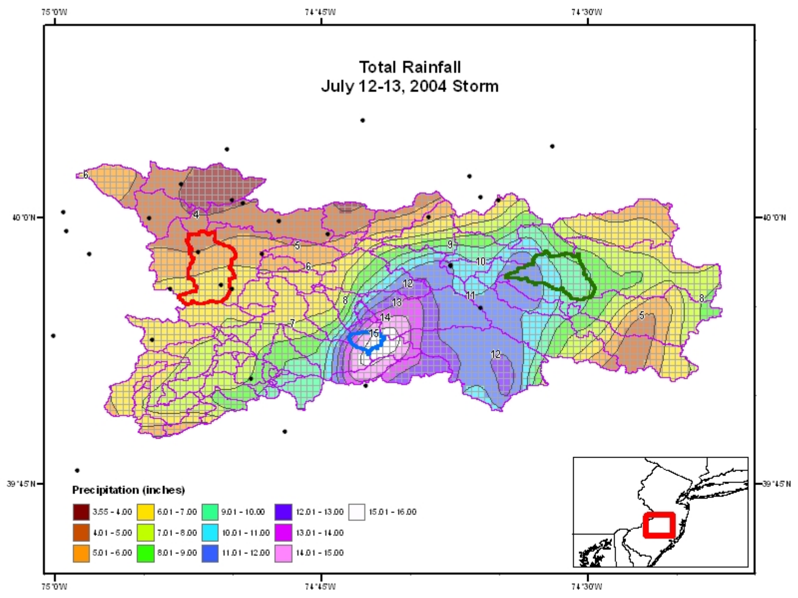
- Isohyetal
  - Total storm and hourly
    - *Maps*
    - *GIS ASCII grids*

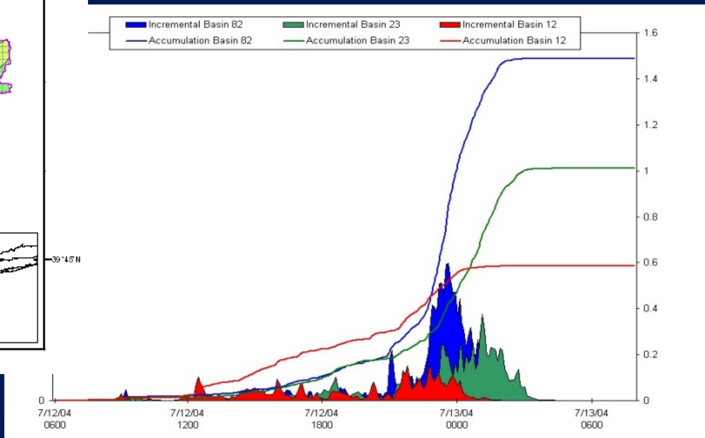
Nashville – May 2010



SPAS Output

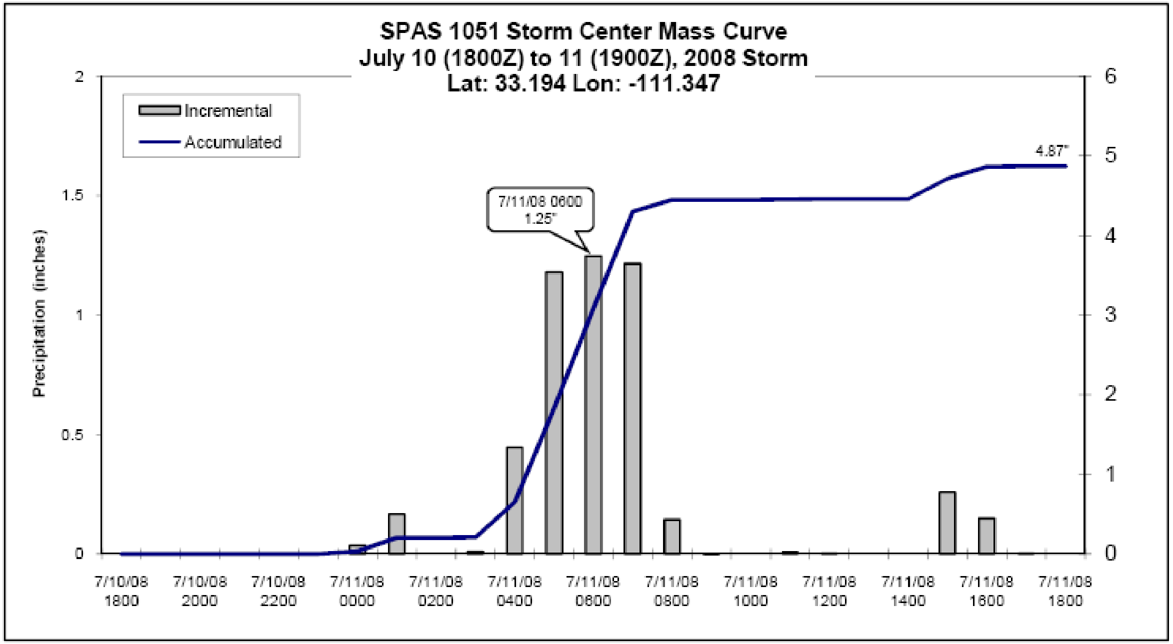
- Output
  - Station lists and errors stats
  - Storm summary/documentation
  - Storm precipitation animations
  - Basin averages

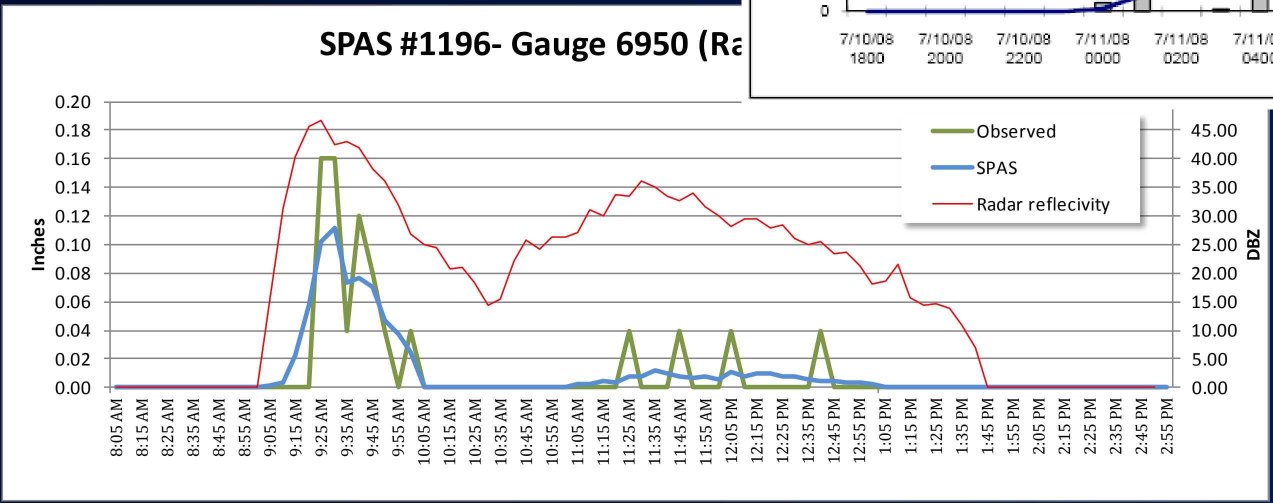




SPAS Output

- Incremental and mass curve plots
  - Any location
  - At 1-hour or x-min intervals

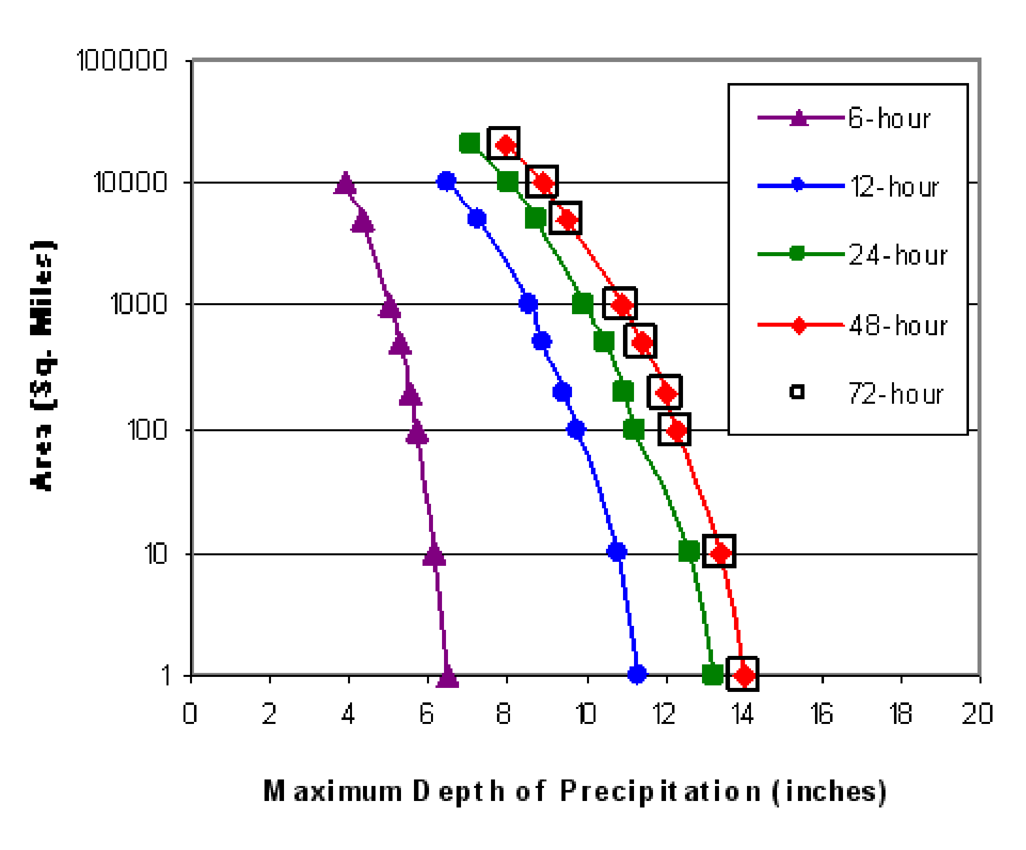




Depth-Area-Duration (DAD) Tables/Curves

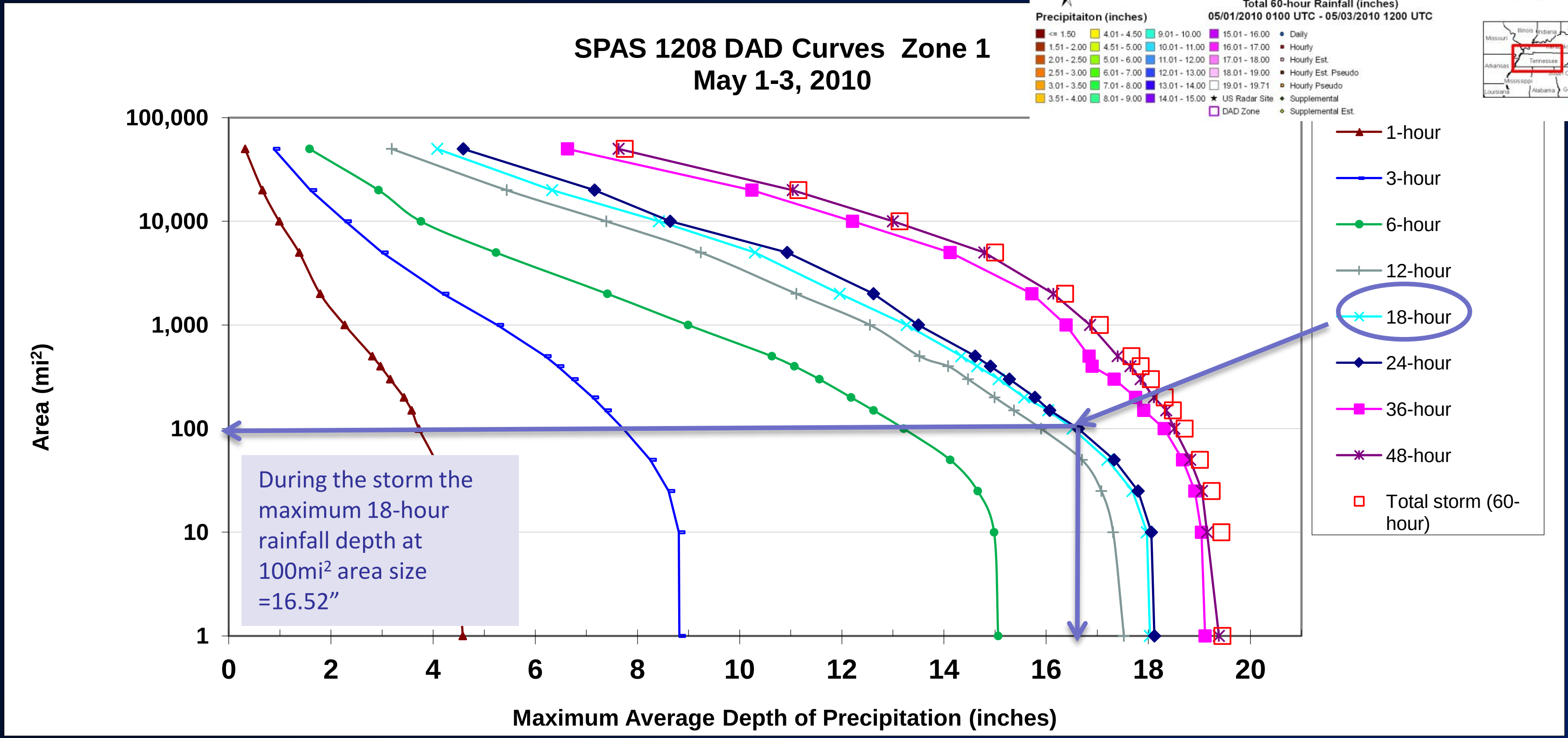
- Storm-centered DADs
  - Quantify storm precipitation in 3 Dimensions
    - *Time (duration)*
    - *Space (area size)*

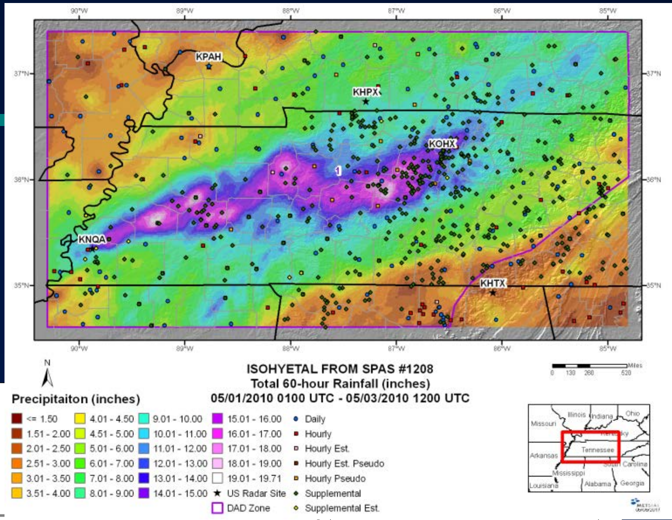
Area	Duration (hours)				
(sq. mi.)	6	12	24	48	72
1	6.5	11.3	13.2	14.0	14.0
10	6.1	10.9	12.7	13.4	13.4
100	5.7	9.8	11.3	12.3	12.3
200	5.6	9.5	11.0	12.0	12.0
500	5.3	9.0	10.5	11.4	11.4
1000	5.1	8.6	10.0	10.9	10.9
5000	4.4	7.3	8.8	9.5	9.5
10000	3.9	6.5	8.0	8.9	8.9
20000	3.3	5.6	7.1	8.0	8.0



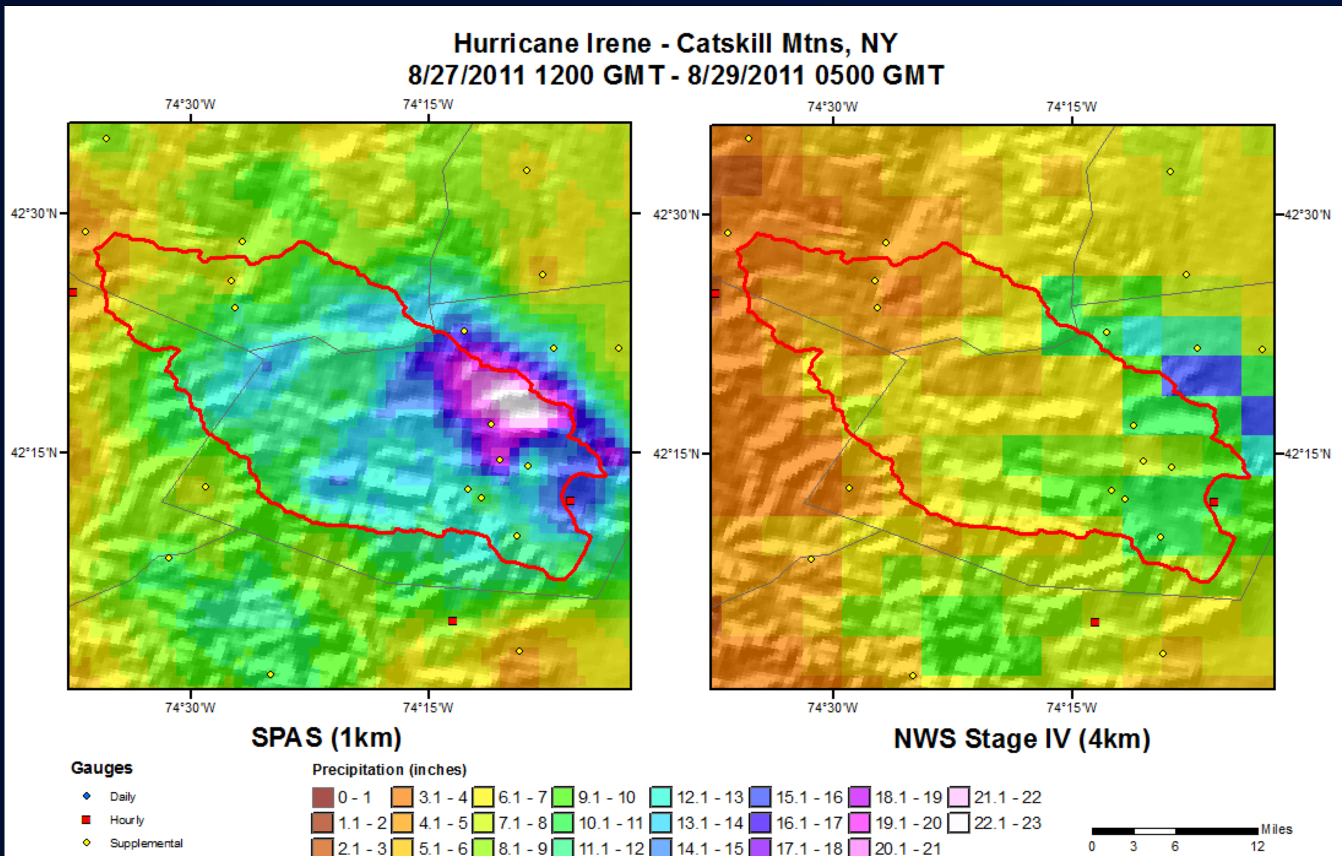
Depth-Area-Duration (DAD) Tables/Curves (Cont.)

- Sample DAD analysis





SPAS vs NWS MPE

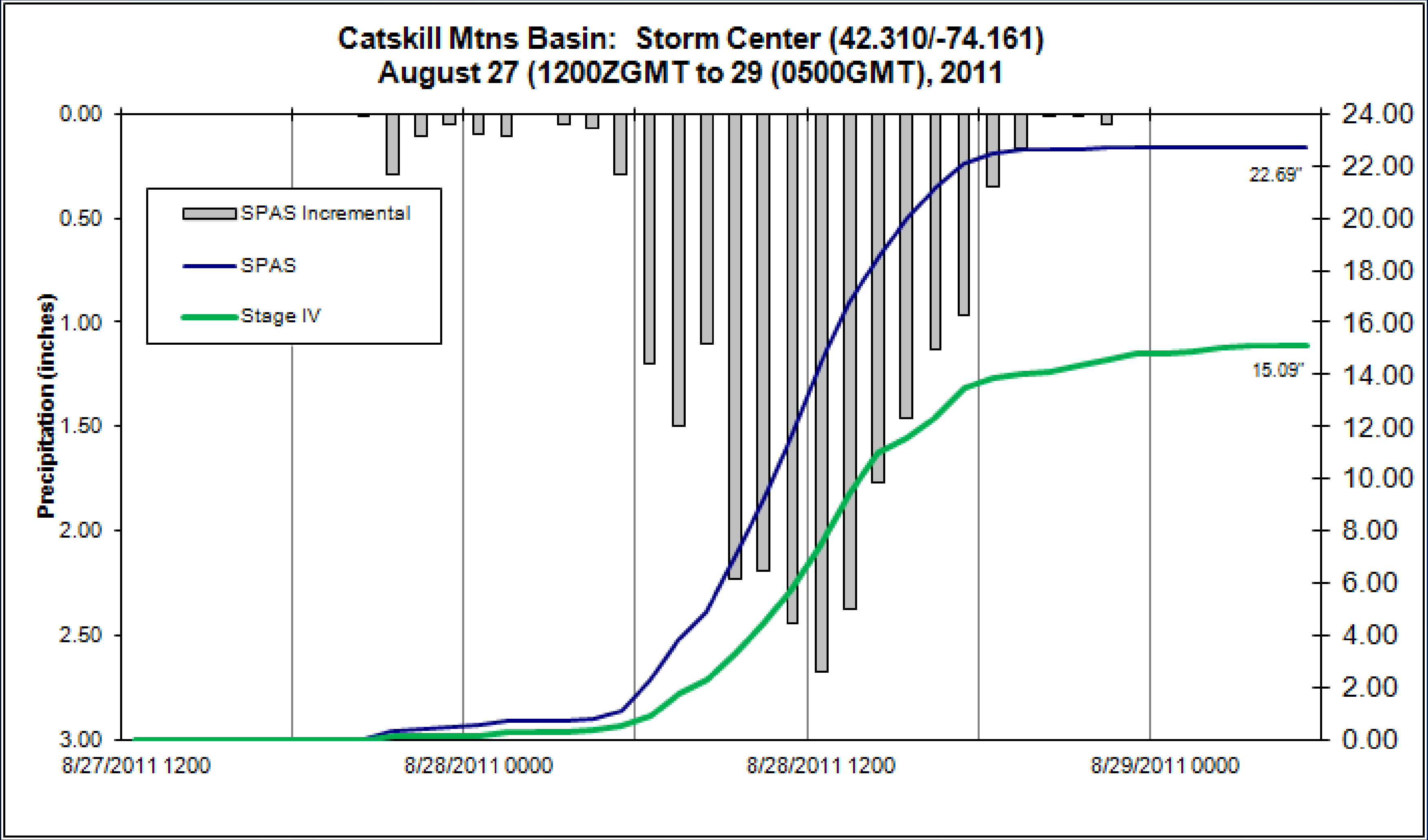


Basin Average Comparison

Precipiation (in)

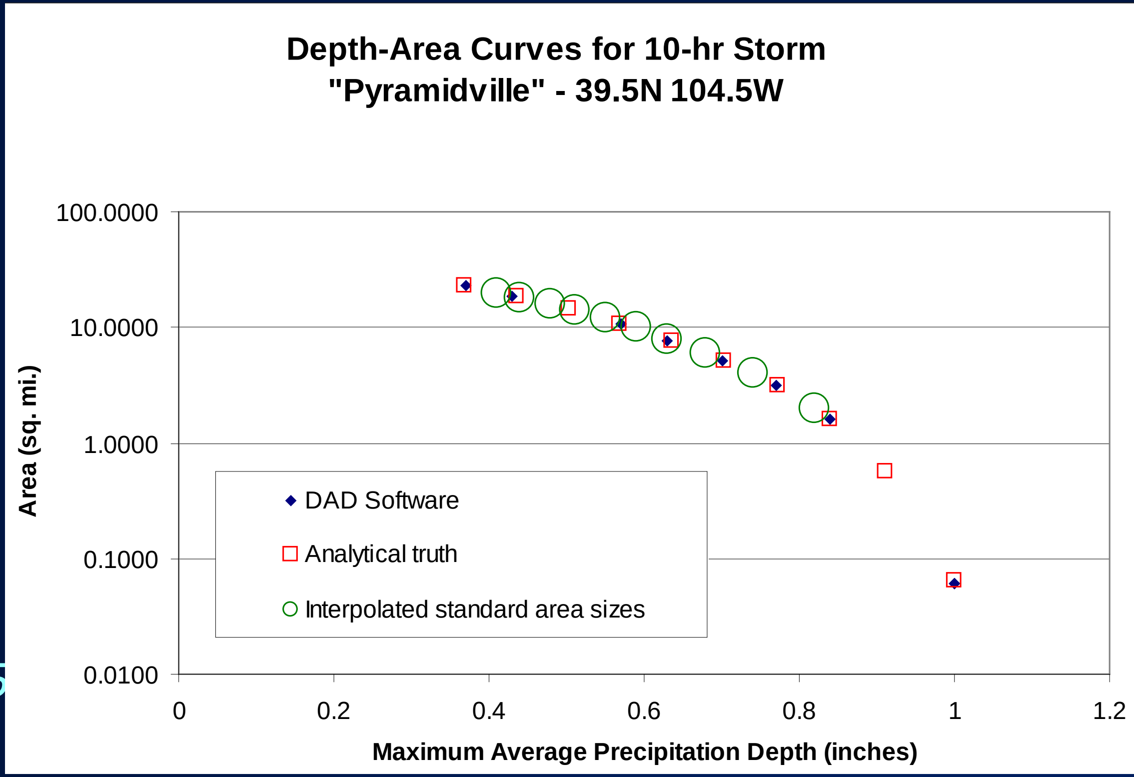
	1hr Max.	1hr Min.	1hr Avg.	Total
SPAS	1.32	0.00	0.30	*12.39*
Stage IV	0.78	0.00	0.17	*7.25*
% Diff	*-41%*	-	*-41%*	*-41%*

SPAS vs NWS MPE



Depth-Area-Duration (DAD) Tables/Curves (Cont.)

- The DAD functionality was subjected to extensive testing
  - Correctly computed the analytical truth
    - *"Pyramidville"*
  - Compared <u>favorably</u> to previously analyzed storms/DADs
    - *Westfield, MA; Aug-1955*
    - *Ritter, IA; Jun-1953*



Storm Precipitation Analysis System in Real-Time (SPASRT)

- Utilizes most of the post-storm capabilities, but in a automatic real-time environment

- Real-time capability evolved in 2009

- Results in the same outputs, high-resolution rainfall grids

- Generates output for a variety of hydrologic applications

Gauge Input

- SPASRT uses daily/hourly precipitation data
  - MADIS (Meteorological Assimilation Data Ingest System)
    - A operational clearinghouse of data from a variety of sources, including:
      - Automated Local Evaluation in Real Time (ALERT) networks, Remote Automated Weather Stations (RAWS) stations, NOAA/National Weather Service networks, Automated Surface Observing Systems (ASOS), municipal networks, flood control districts, utility companies, CoCoRaHS, etc.


National Oceanic and Atmospheric Administration | Earth Systems Research Laboratory

MADIS

Meteorological Assimilation Data Ingest System

DOC | NOAA | NOAA Research | ESRL | GSD | MADIS HOME

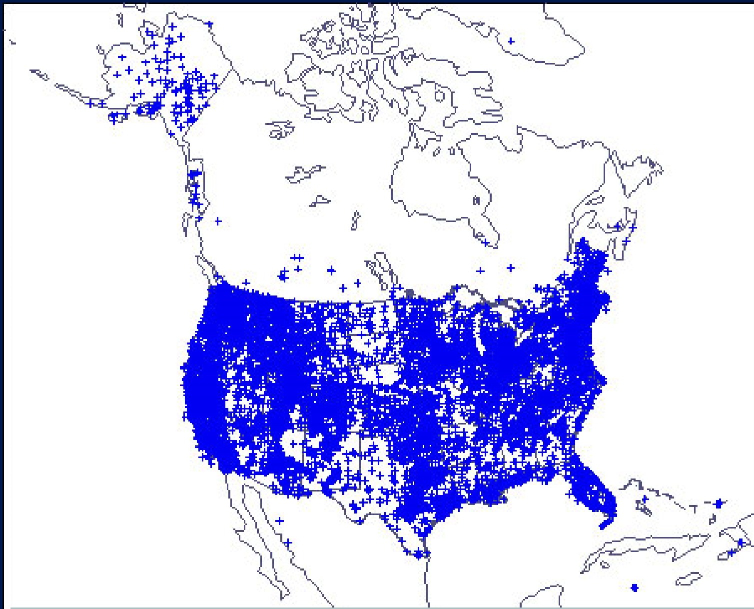
The Meteorological Assimilation Data Ingest System (MADIS) is dedicated toward making value-added data available from the National Oceanic and Atmospheric Administration's (NOAA) Earth System Research Laboratory (ESRL) Global Systems Division (GSD) (formerly the Forecast Systems Laboratory (FSL)) for the purpose of improving weather forecasting, by providing support for data assimilation, numerical weather prediction, and other hydrometeorological applications.

MADIS subscribers have access to an integrated, reliable, and easy-to-use database containing the real-time and archived observational datasets described below. Also available are real-time gridded surface analyses that assimilate all of the MADIS surface datasets (including the highly-dense integrated mesonet data). The grids are produced by the Rapid Update Cycle (RUC) Surface Assimilation System (RSAS) that runs at ESRL/GSD, which incorporates a 15-km grid stretching from Alaska in the north to Central America in the south, and also covers significant oceanic areas. The RSAS grids are valid at the top of each hour, and are updated every 15 minutes.

The ESRL/GSD database is available via ftp, by using Unidata's Local Data Manager (LDM) software, through the use of OPen source project for Network Data Access Protocol (OPeNDAP (formerly DODS)) clients, or for the surface datasets through the Text/XML Viewer web service found below. Users can subscribe to the entire database, or ask for only particular datasets of interest.

Quality Control (QC) of MADIS observations is also provided, since considerable evidence exists that the retention of erroneous data, or the rejection of too many good data, can substantially distort forecast products. Observations in the ESRL/GSD database are stored with a series of flags indicating the quality of the observation from a variety of perspectives (e.g. temporal consistency and spatial consistency), or more precisely, a series of flags indicating the results of various QC checks. Users of MADIS can then inspect the flags and decide whether or not to ingest the observation.

http://madis.noaa.gov/



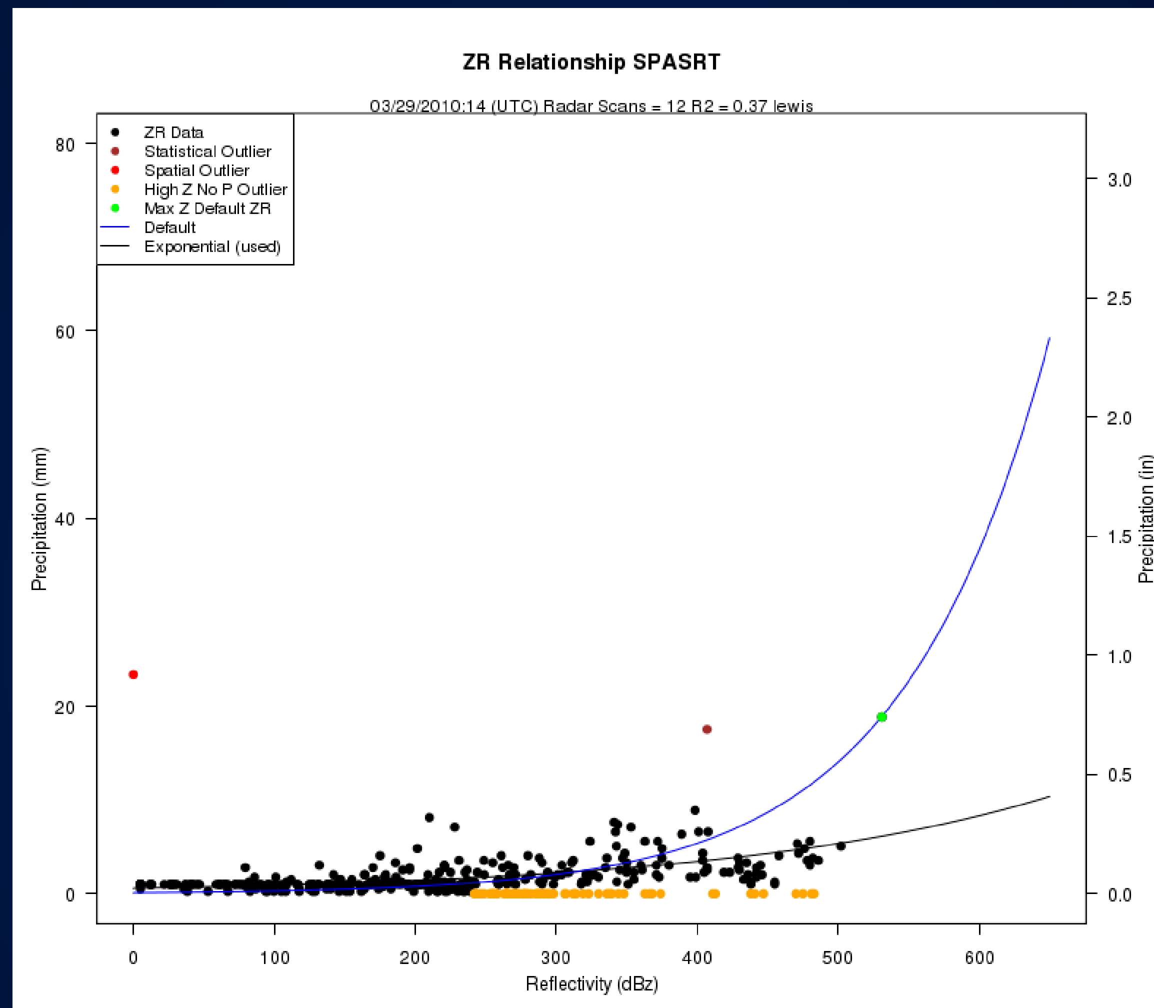
MADIS mesonet stations in the North American domain. http://madis.noaa.gov/

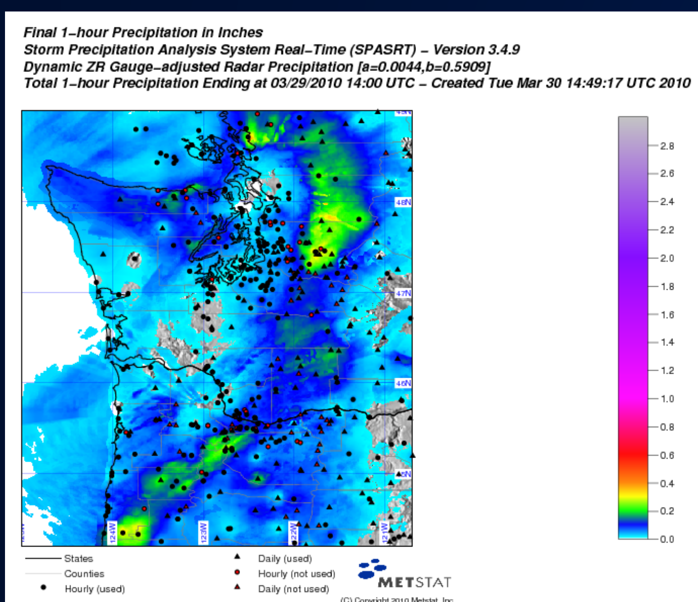
1-hour Precipitation Gauge QC

- Gauge data is subjected to 4 tiers of automatic quality control (QC)
  - ✓ MADIS “Level 1” QC – gross error check
    - The level 1 validity checks restrict each observation to falling within a specified set of tolerance limits
  - ✓ Spatial QC
    - Precipitation amounts that are vastly different than the overall magnitude as a of the percent of a basemap are identified and removed.
  - ✓ Statistical QC
    - A default ZR relationship is used to identify stations that are statistically inconsistent with the radar data.
  - ✓ High radar reflectivity, but no precipitation
    - Zero precipitation reports that are grossly inconsistent with the radar data are identified and removed

1-hour Precipitation Gauge QC (Cont.)

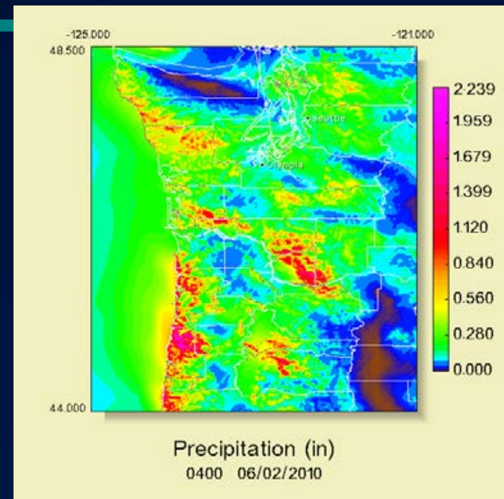
- MADIS “Level 1” QC – not shown
- Spatial QC – red dots
- Statistical QC – brown dots
- High radar reflectivity, but no precipitation – orange dots



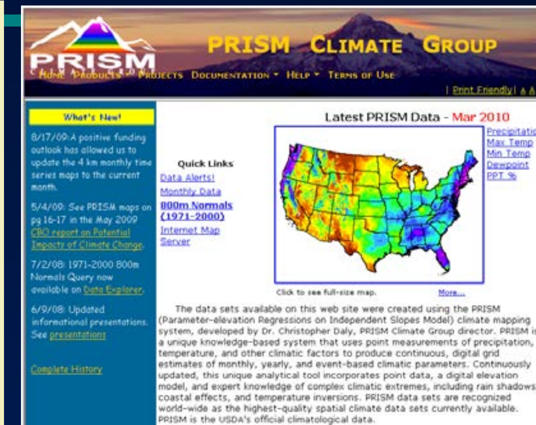


Basemap

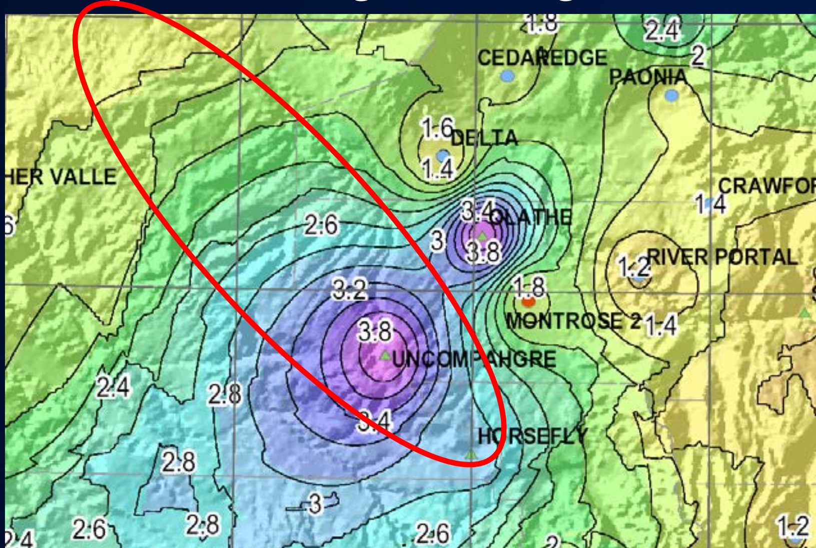
- Basemaps include:
  - ✓ Mean monthly precip. (PRISM)
  - ✓ QPFs
- Allows for climatologically- or QPF-aided spatial interpolation of precip.
  - ✓ Infuses the influence of orographics into the spatial interpolation/patterns
  - ✓ Provides reasonable spatial interpolation during radar outages

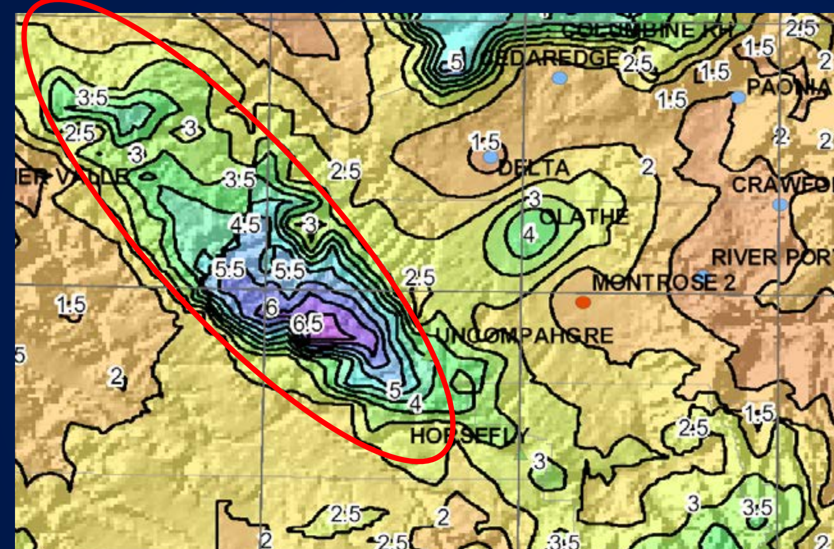


http://www.foxweather.com/



http://www.prism.oregonstate.edu/





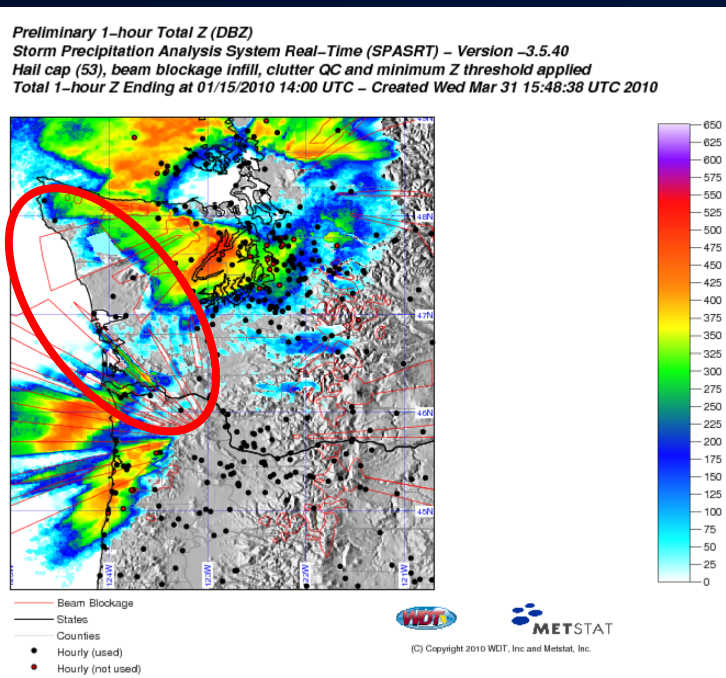
Precipitation Without Basemap

Precipitation With Basemap (Mean Monthly Precip.)

SPASRT–Radar Blockage

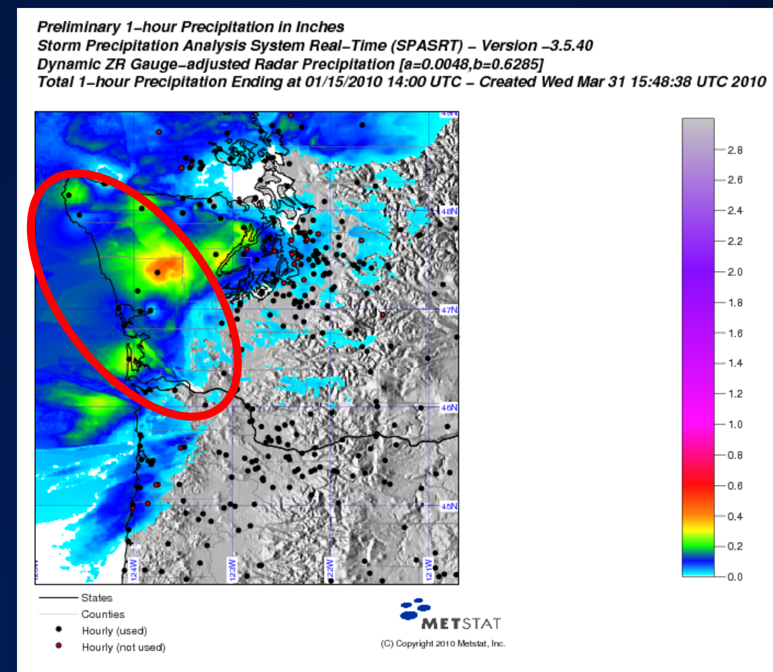
Basemap Concept

Radar Reflectivity



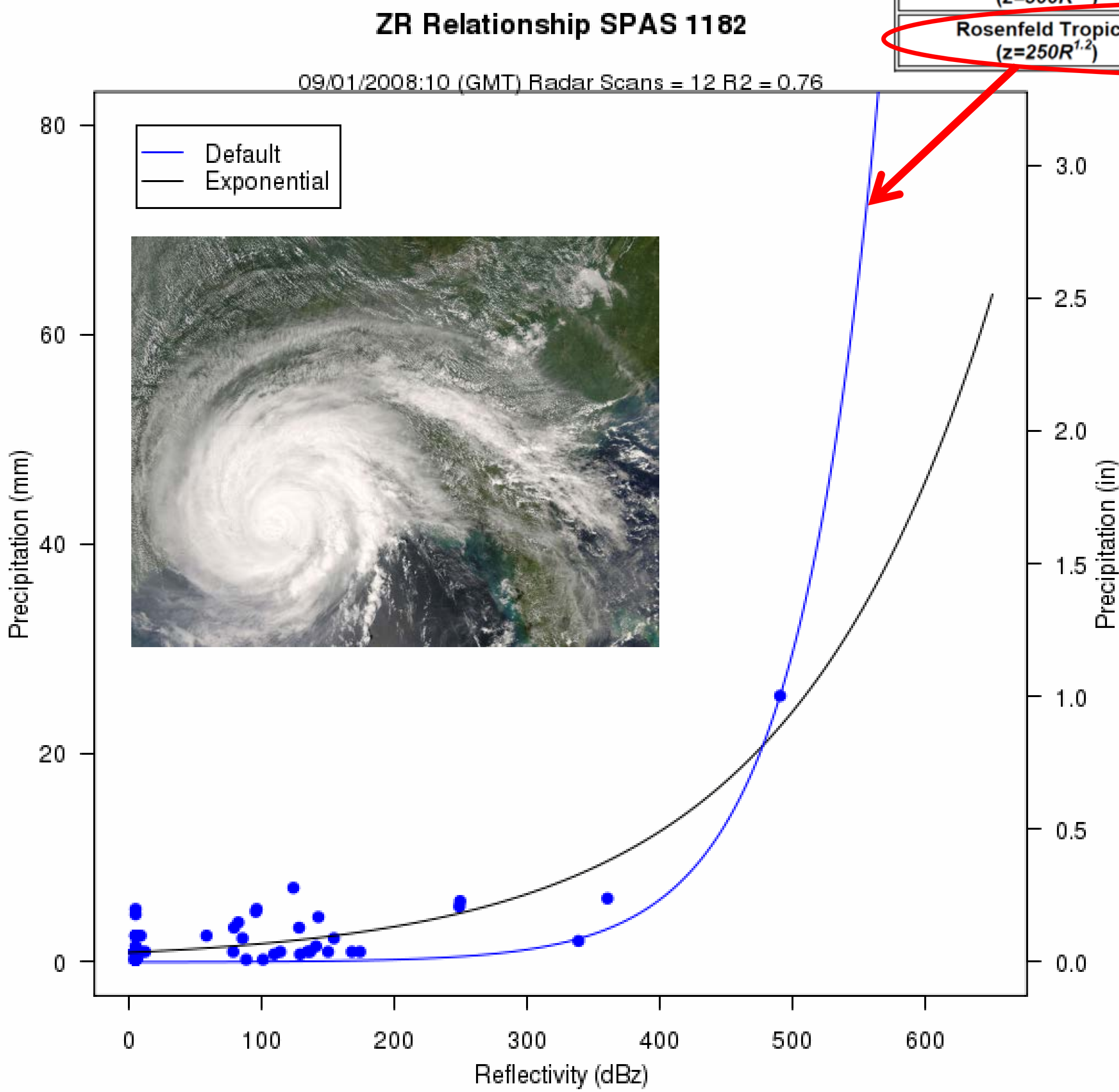
Western Washington, USA Jan. 15, 2010

SPASRT Precipitation



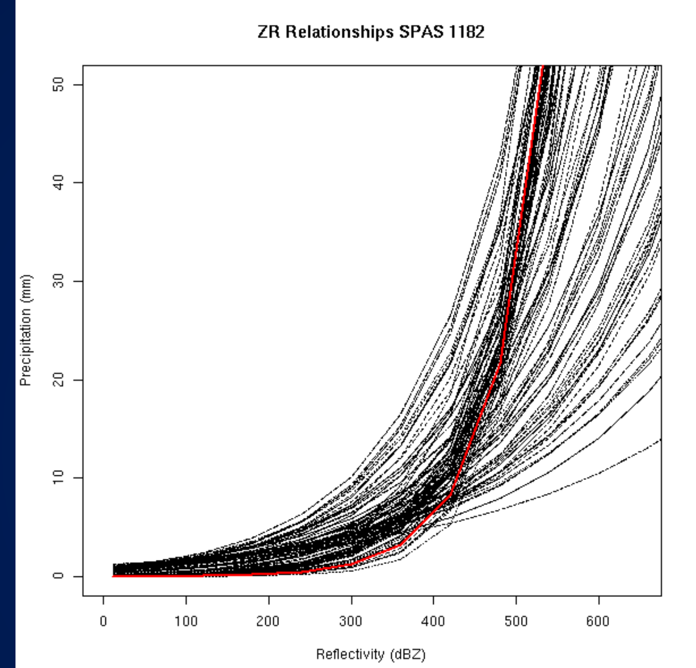
Dynamic ZR Relationship

Table 1. Z-R RECOMMENDATIONS		
RELATIONSHIP	**Optimum for:**	**Also recommended for:**
Marshall-Palmer ($z=200R^{1.6}$)	General stratiform precipitation	
East-Cool Stratiform ($z=130R^{2.0}$)	Winter stratiform precipitation - east of continental divide	Orographic rain - East
West-Cool Stratiform ($z=75R^{2.0}$)	Winter stratiform precipitation - west of continental divide	Orographic rain - West
WSR-88D Convective ($z=300R^{1.4}$)	Summer deep convection	Other non-tropical convection
Rosenfeld Tropical ($z=250R^{1.2}$)	Tropical convective systems	

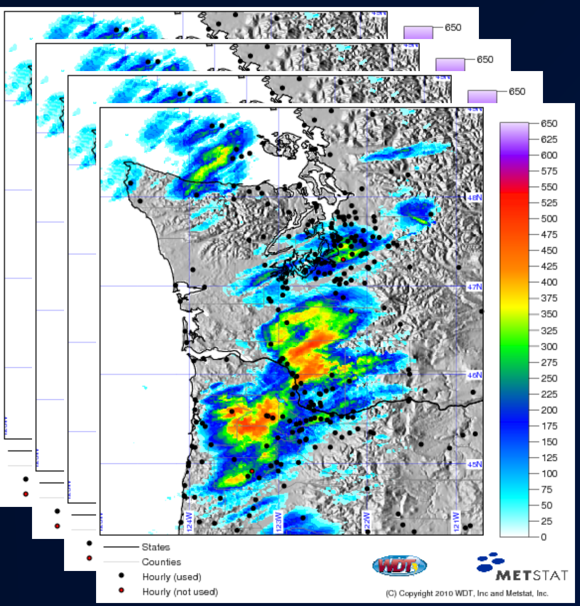


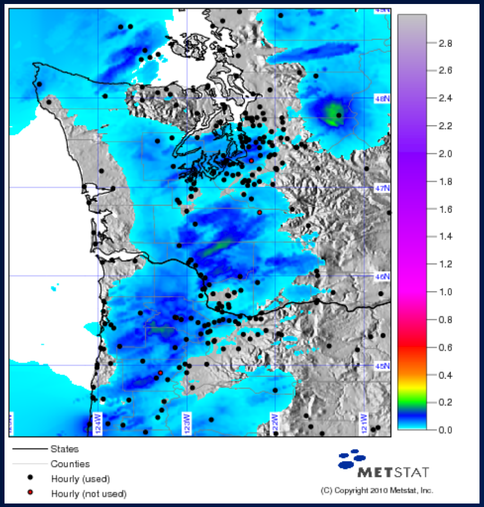
Hurricane Gustav
September 1 – 5, 2008

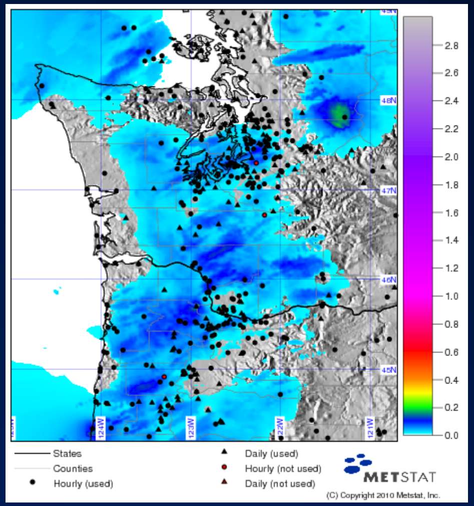
Southern Texas



SPASRT Modes







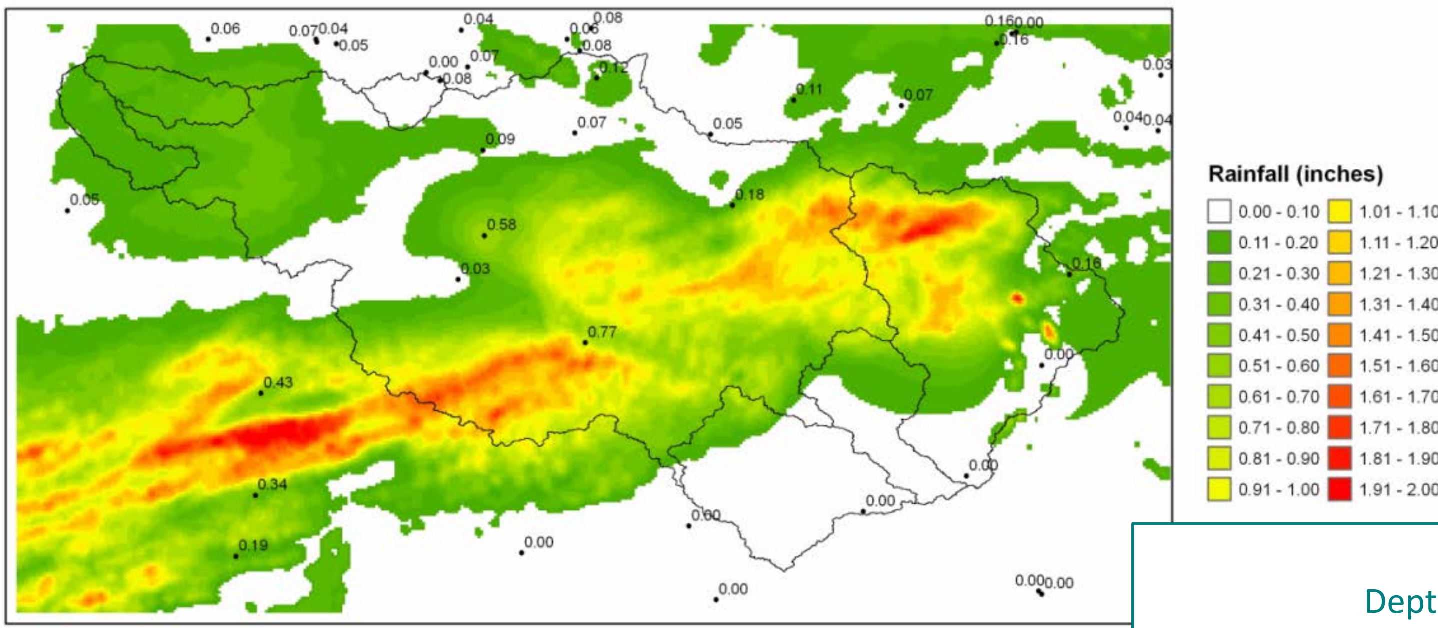
Quick-look
- Every 5-min
- Default ZR
- Latency: ~ 5-min.

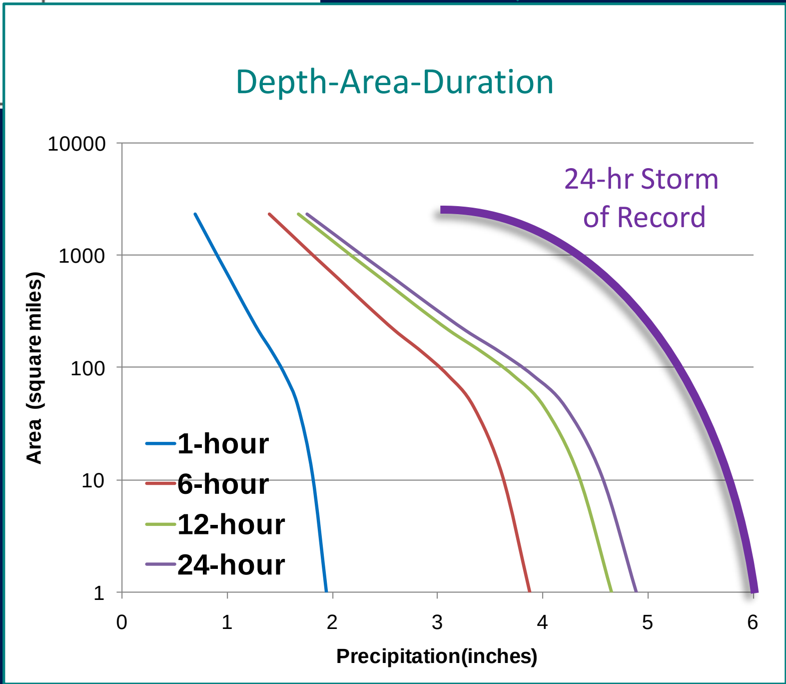
Prelim. 1-hour gauge-adjusted rainfall:
- Every 1-hour
- Hourly gauge data
- Optimized ZR
- Latency: ~20 min.

Final 1-hour gauge-adjusted rainfall:
- Every hour
- Hourly/daily gauge data
- Optimized ZR
- Latency: 20-min to 24-hr

SPASRT Output By-Product

Depth-Area-Duration (DAD)



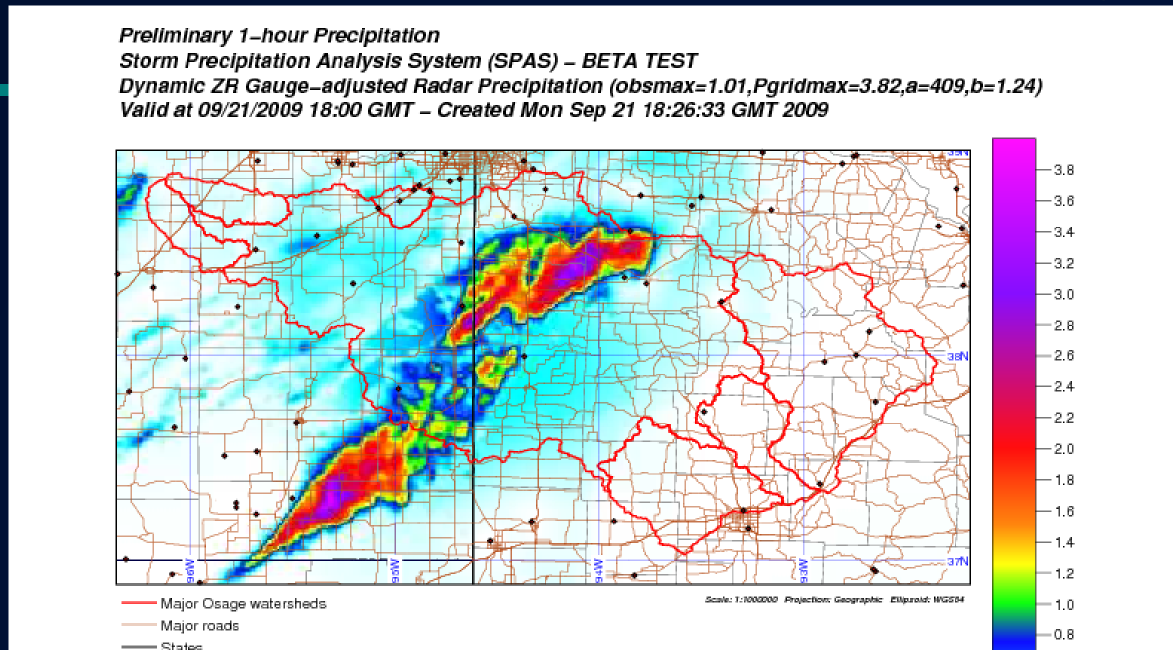


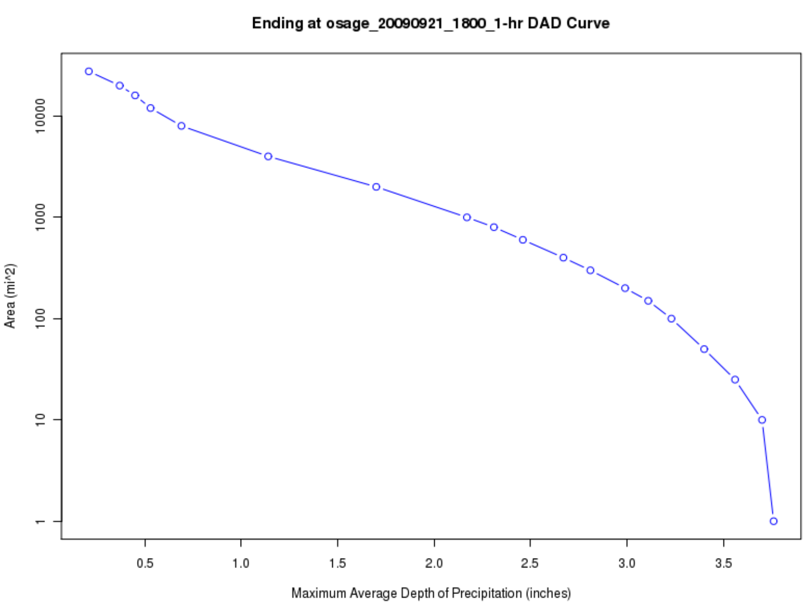
- Converting gridded precipitation into a three dimensional – DEPTH, AREA, DURATION - perspective helps to objectively qualify the precipitation
- DADs are either storm-centered or constrained to basin/watershed

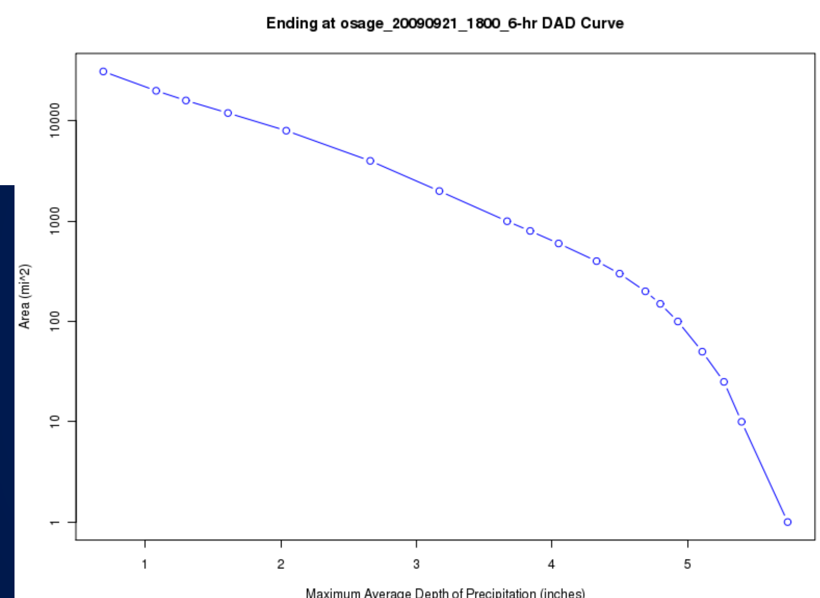
Two Types of DADs

- Storm-centered
  - ✓ Analysis is centered on the area with maximum precipitation
  - ✓ Used in PMP determination/applications
- Geographically-fixed
  - ✓ Analysis is geographically constrained to a specific area or watershed, regardless of where the maximum precipitation fell

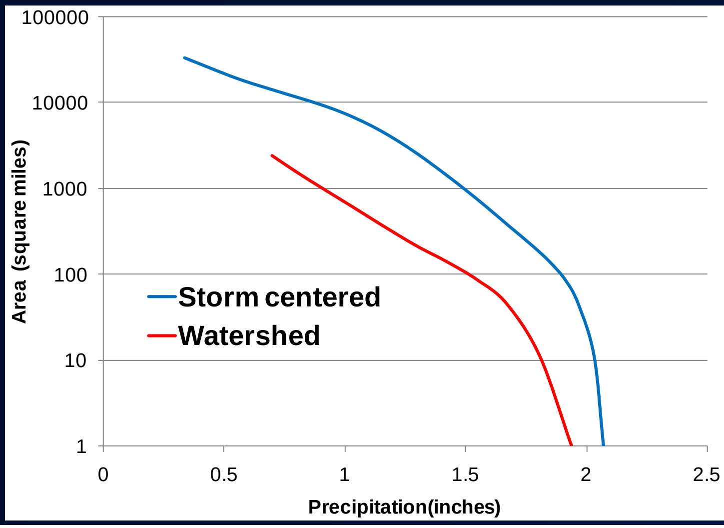
Storm-centered DAD Analysis

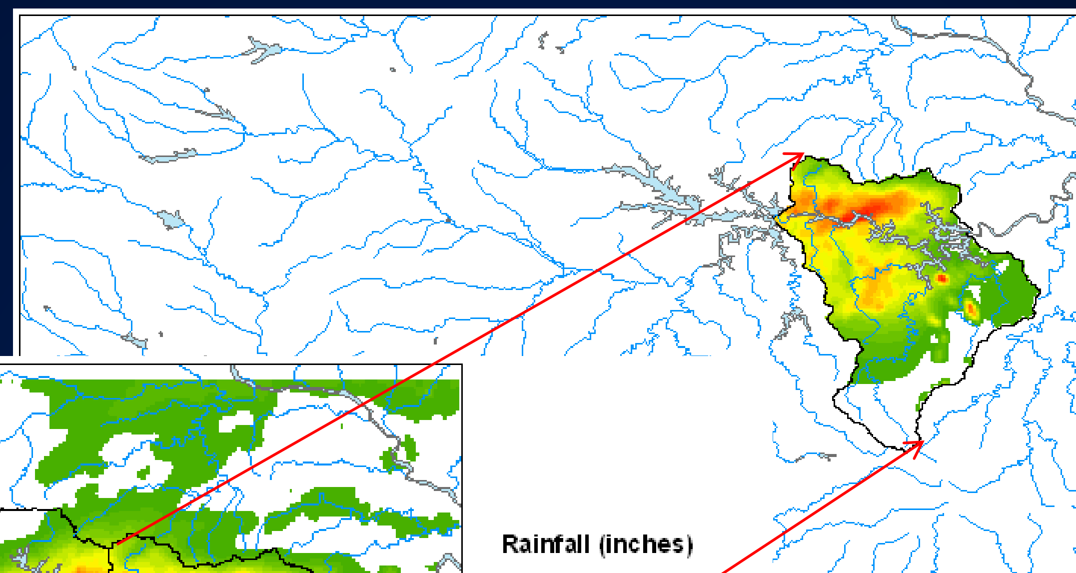


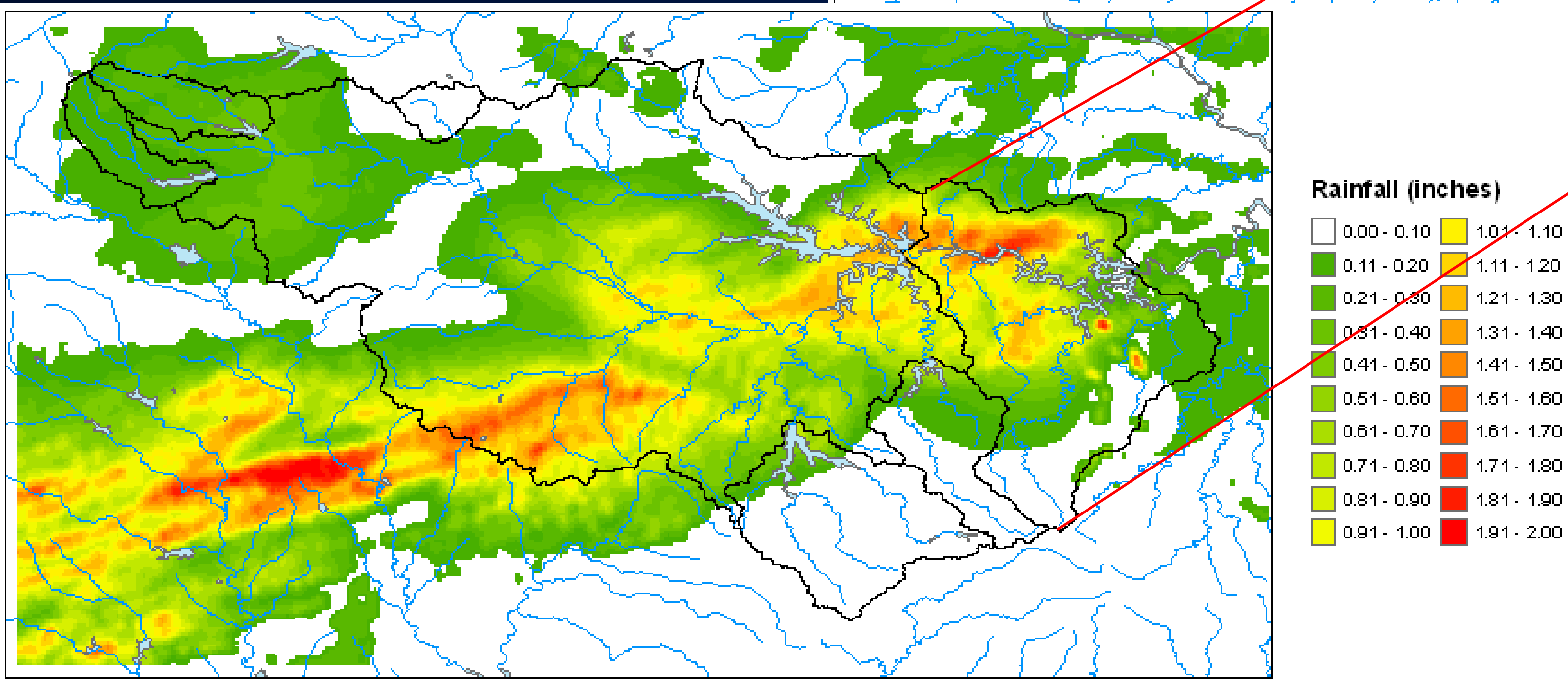




Geographically-Fixed DAD Analysis

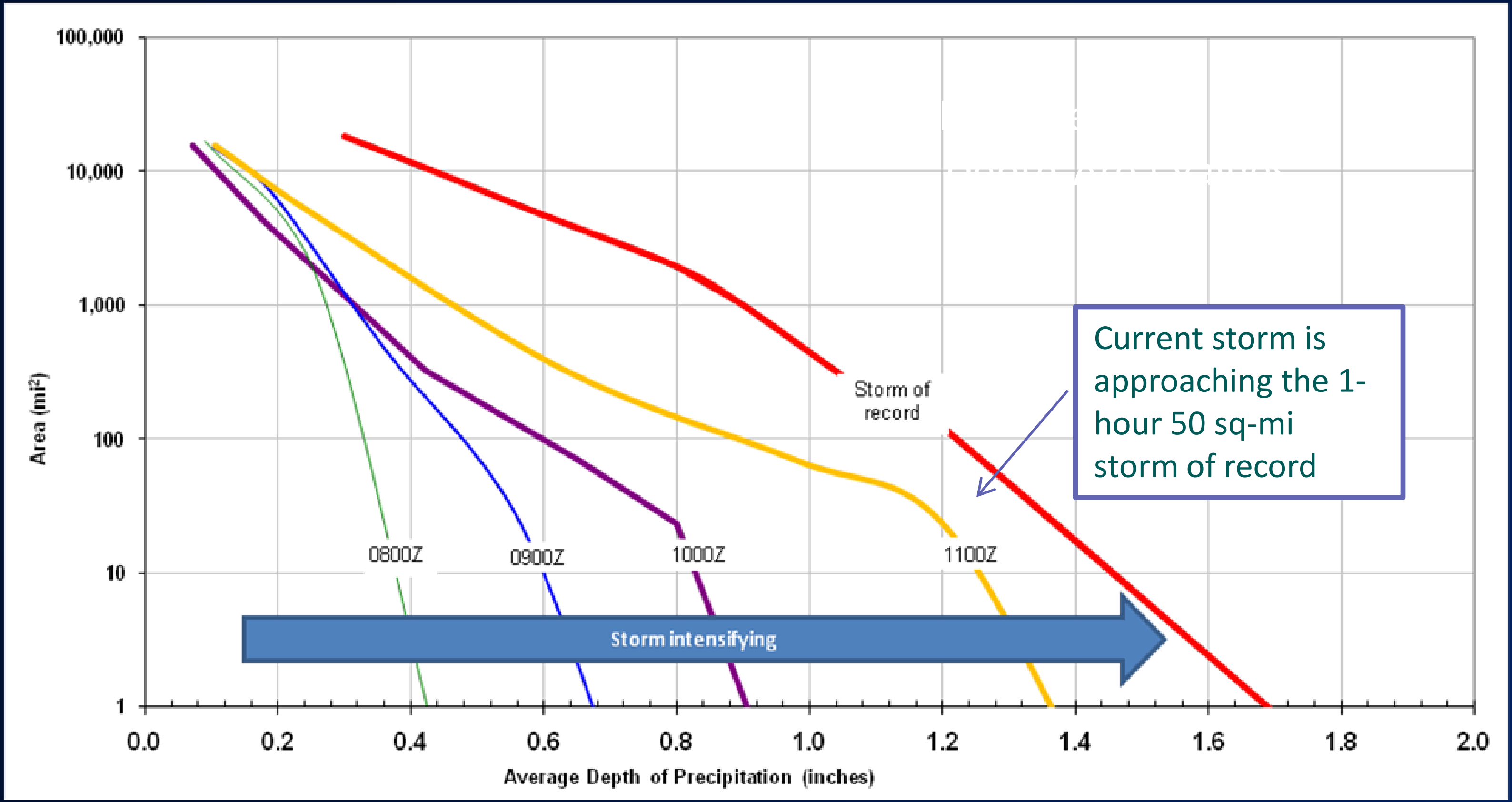






Near Real-time DADs

- DAD values approaching (or exceeding) the storm of record or other pre-defined threshold can trigger River Operations, EAPs or flood alert systems.



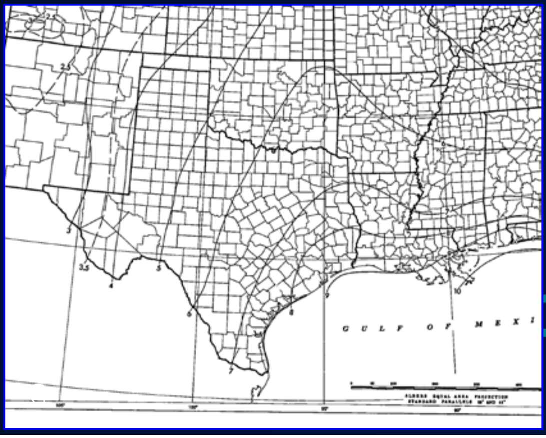
SPASRT Output By-Product

Average Recurrence Interval (ARI)

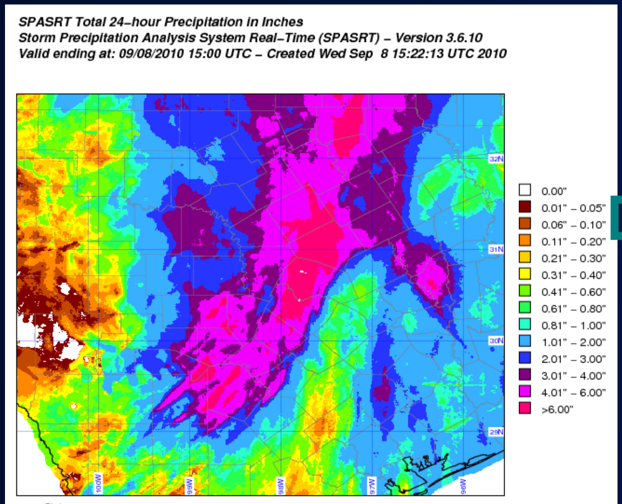
• To make near real-time precipitation data more meaningful, it can be translated into an Average Recurrence Interval (ARI) based on published Precipitation Frequency Atlases from the NWS (http://hdsc.nws.noaa.gov/hdsc/).

✓ ARI = the average period between events of a particular magnitude and duration

✓ Probability in any given year = 1/ARI (e.g. 1/50-year = 0.2% chance)



NWS –Precipitation Frequency Estimates



24-hour QPE