Session 6B:
Extreme and Unusual Events

PANELIST: Bill Kappel

President/Chief Meteorologist

Applied Weather Associates

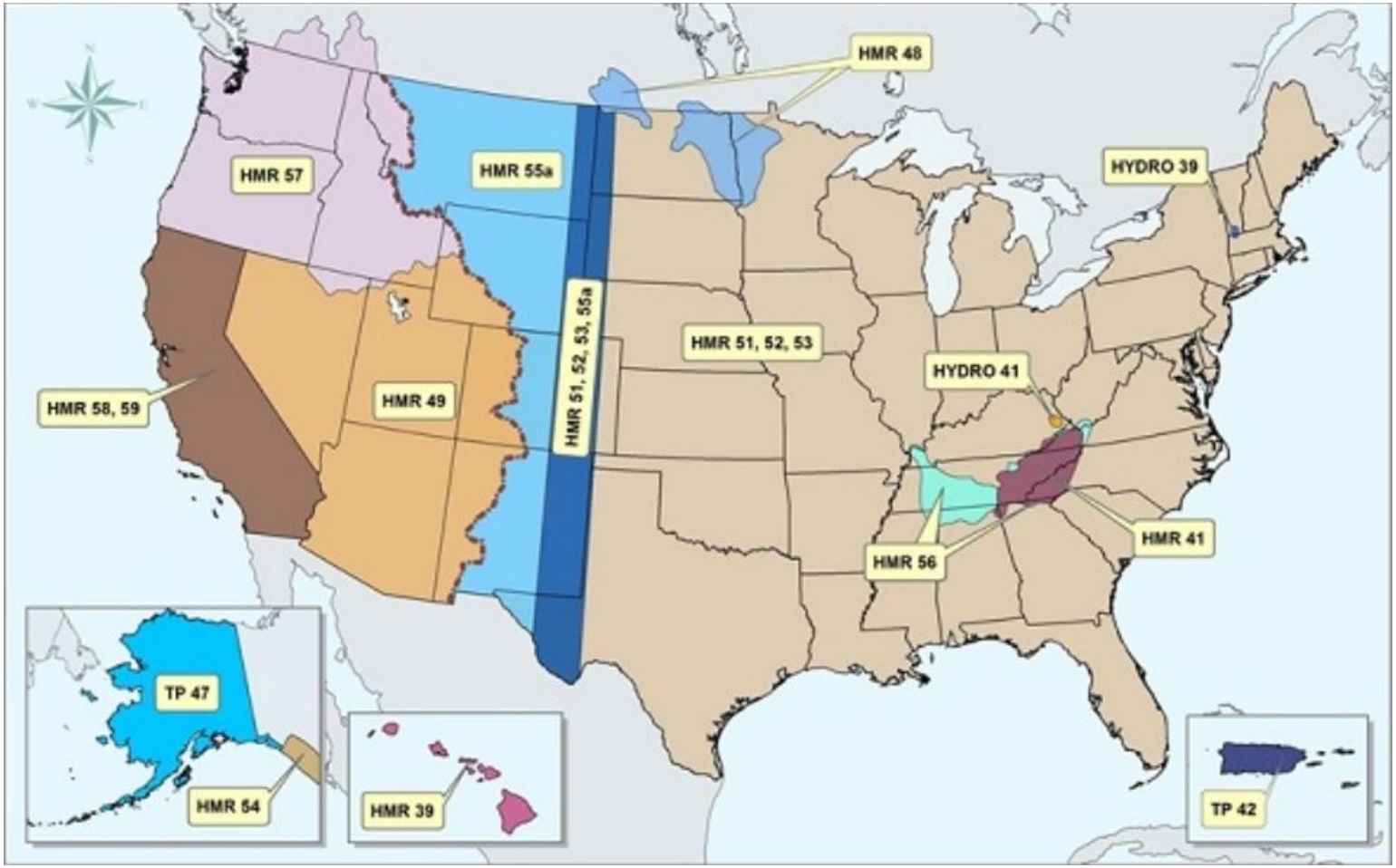
Probable Maximum Precipitation

Definition: The ***theoretically*** greatest depth of precipitation for a given duration that is ***physically possible*** over a given storm area at a particular ***geographic location*** at a certain time of year (HMR 59, 1999)

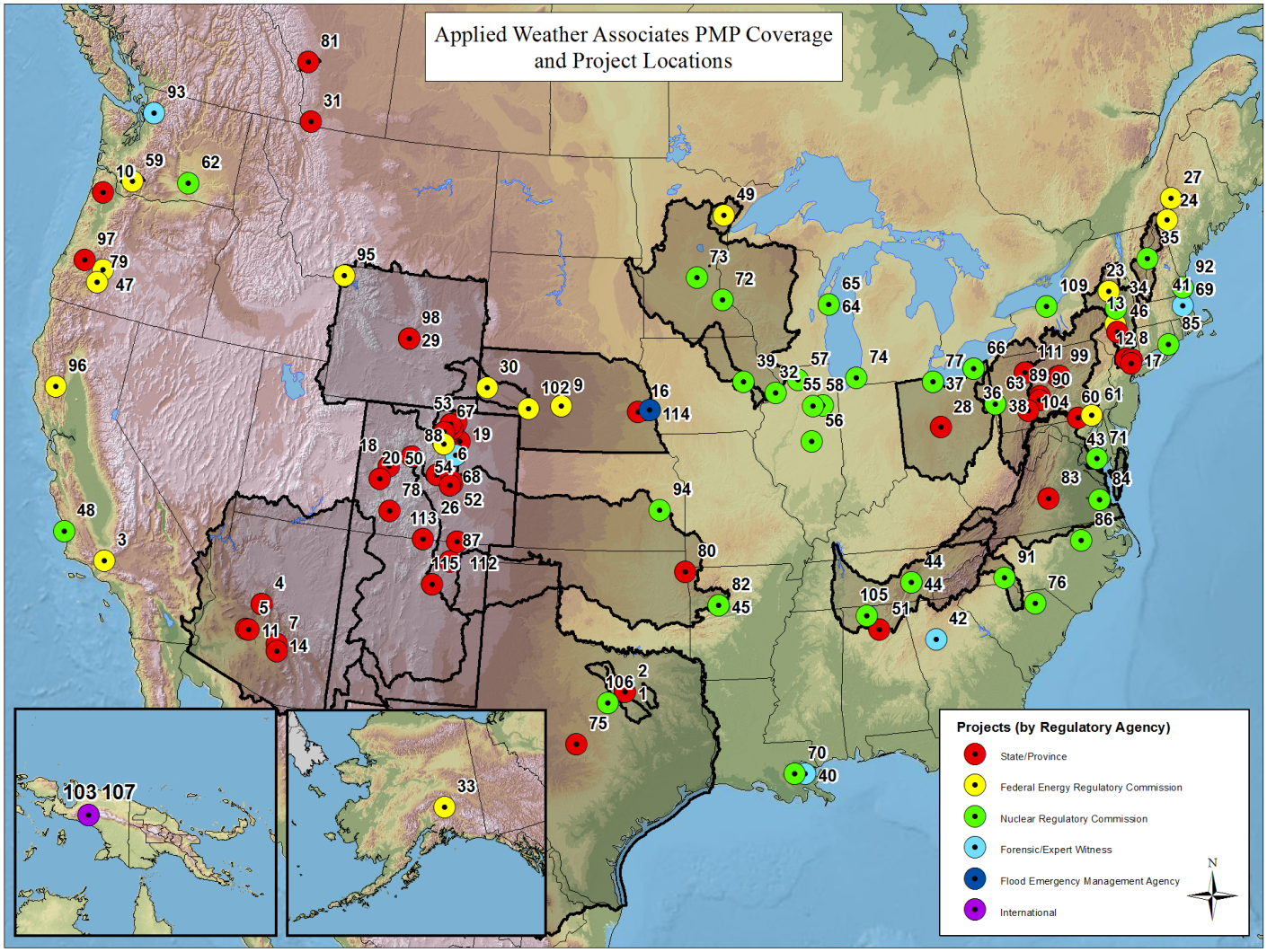
Types of PMP studies:

- Generalized (Hydrometeorological Reports)
  - Provides PMP values for a region
  - HMR 51 - East of the 105th Meridian from Canada to Mexico
- Regional/Statewide
  - Provide PMP values over regions with varying topography
  - Individual basins are included in the regional/statewide results
- Site-Specific
  - Provides PMP values for individual drainage basins
  - Considers unique meteorology and topography

NWS HMR Coverage



AWA PMP Study Locations



Probable Maximum Precipitation

- Weather Bureau (now National Weather Service) published first HMR in 1940
  - HMR 1-Ompompanoosuc Basin, Vermont
- Latest HMR published in 1999
  - HMR 59-California
- All followed the storm-based approach
- Significant advancement applied throughout the years
- Storms continually analyzed and added
  - HMR 51-only through 1972
  - HMR 55A, HMR 57, HMR 59 added storms relevant to their regions
- All HMRs can be downloaded from NWS HDSC PMP website

Probable Maximum Precipitation

- Storm Based Approach-Deterministic
  - Maximize storms
  - Transposition storms
  - Combine into PMP design storm
    - By storm type
- Subjective decisions involved

Probable Maximum Precipitation

- HMRs have become out-of-date
  - Based on outdated methods and techniques
    - Better understanding of meteorology
  - Storm datasets not updated
    - More than 40 years missing from HMR 51
- Effect of topography not accurate
  - Subjective
  - Lack of empirical data-unknowns
- Many processes subjective and not reproducible
  - Several inconsistencies between each report
  - Not clear how storm data used to develop the PMP values
  - No or limited working papers/notes
  - Limited to no external/independent review

Example HMR 51 PMP Contours

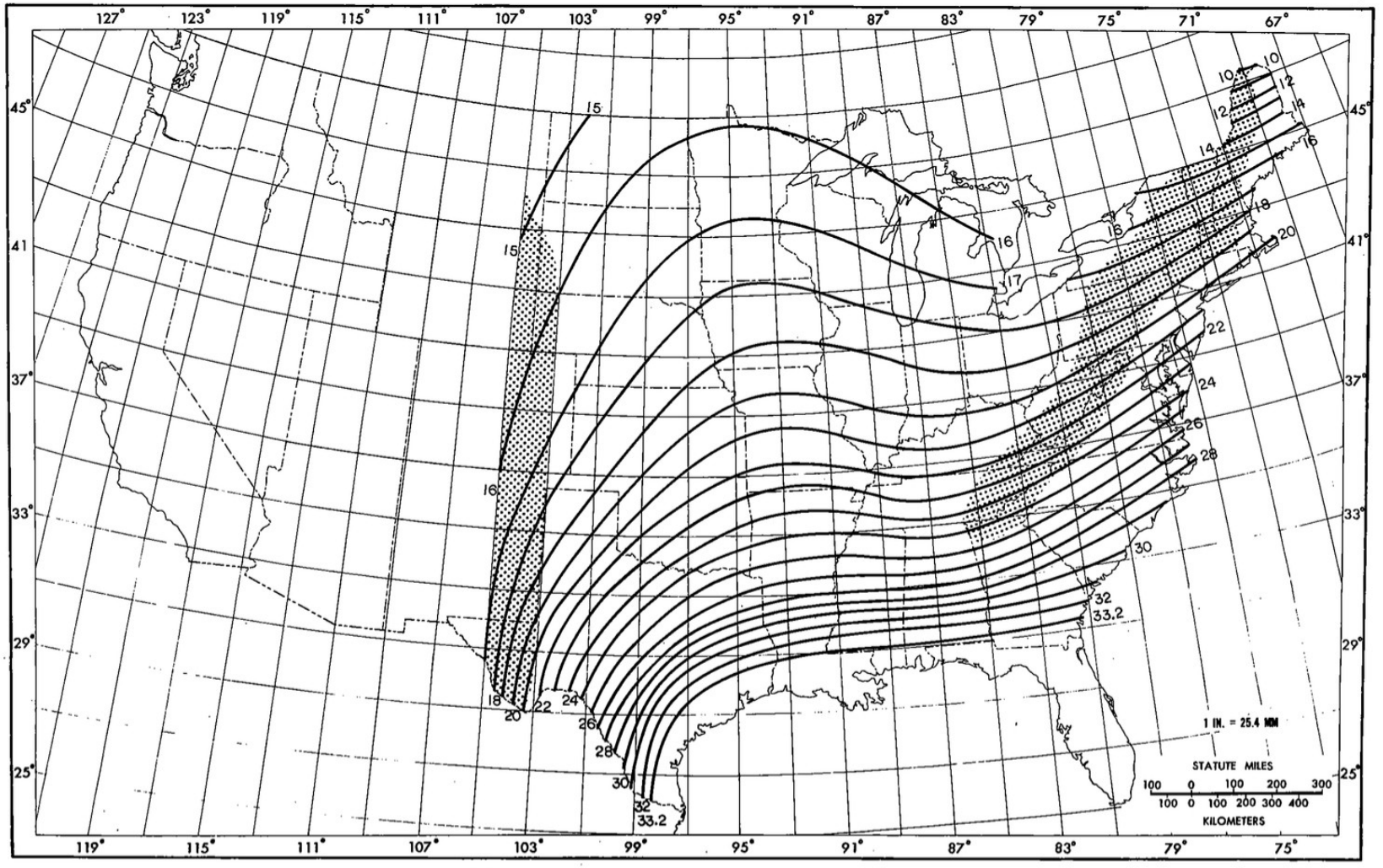
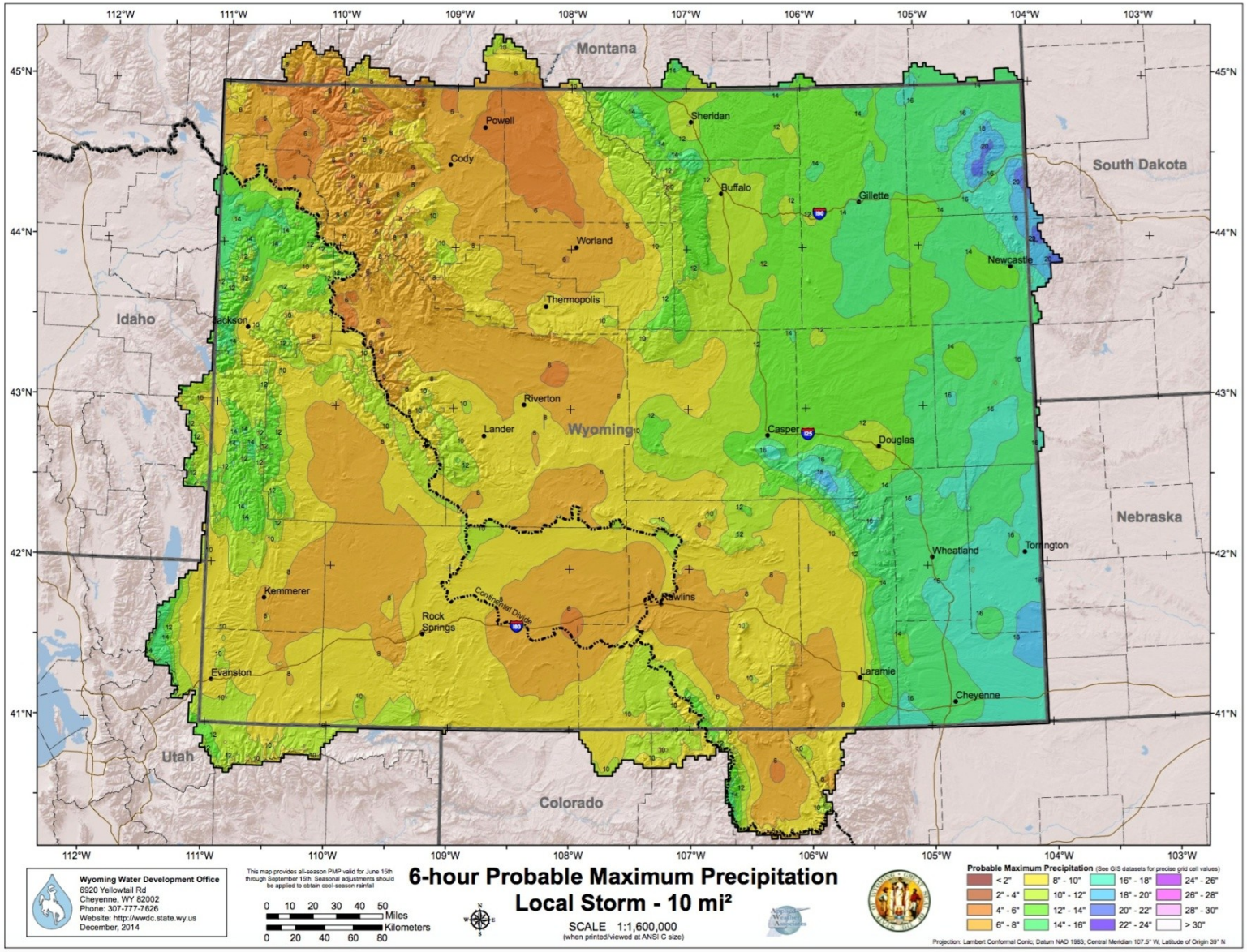
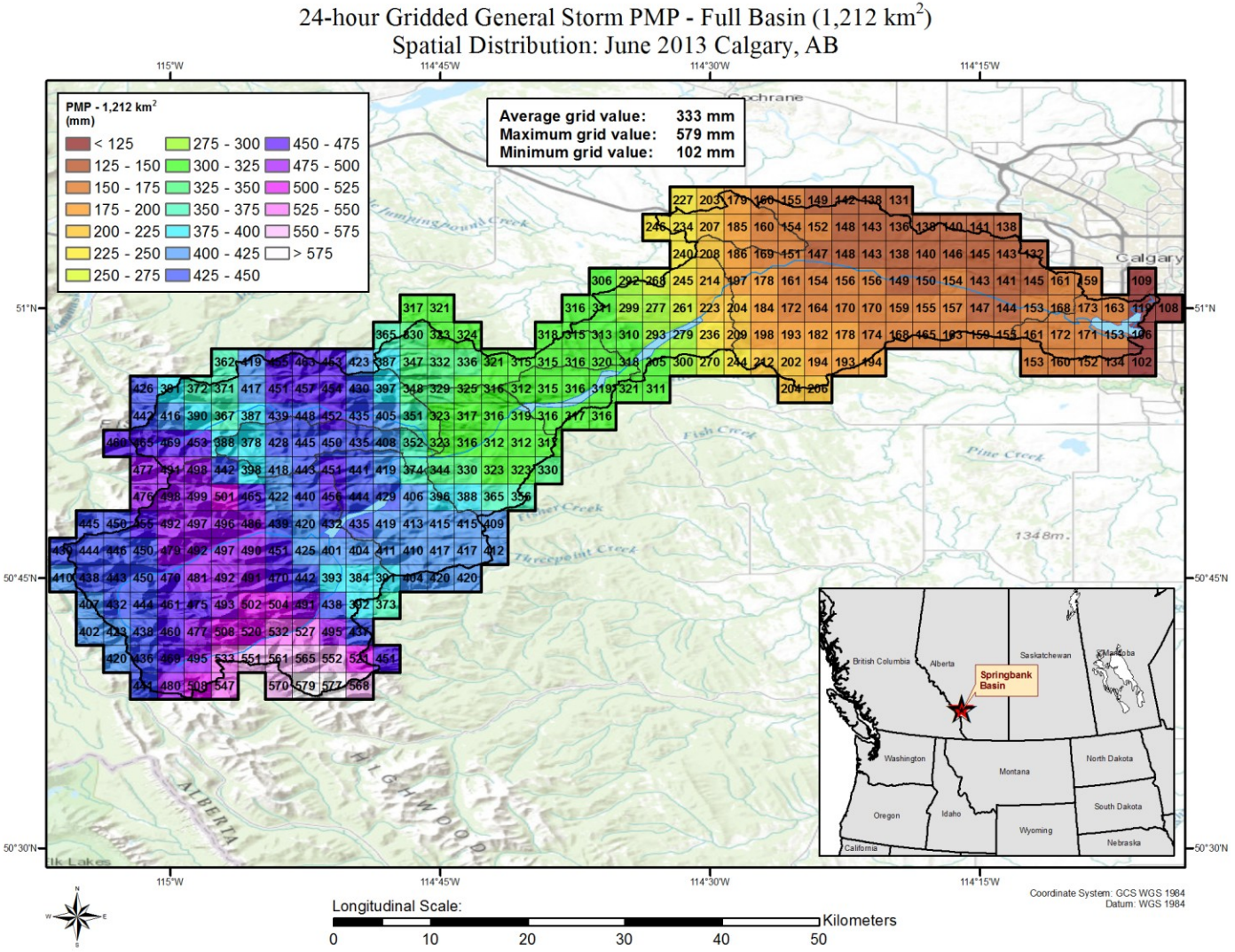


Figure 30.--All-season PMP (in.) for 24 hr 1,000 mi^2 (2,590 km^2).

Wyoming Statewide PMP Example



Site-Specific PMP Example



Improvements in the PMP Process

- NEXRAD weather radar
  - Very important for spatial distribution
  - Must be calibrated first
- GIS
- Computing power/speed
- Updated understanding of rainfall
- Updated understanding of topographic effects
- Updated climatologies for maximization

PMP Since the HMRs

- Many PMP studies completed last 30 years
  - Private industry-numerous site-specific, statewide, regional studies
  - Need for updating PMP to better design/update spillways
  - Understand flood hydrology/PMF
  - State dam safety, FERC, NRC main users
  - Bureau of Reclamation, Corps of Engineers
  - NWS no longer involved

PMP Since the HMRs

- Storm database updated continuously
- Use of current meteorology
  - NEXRAD
  - GIS
  - Updated climatologies
  - Trajectory models
- Latest technology continue to be employed
- What about modeling?
- Still subjectivity/uncertainty

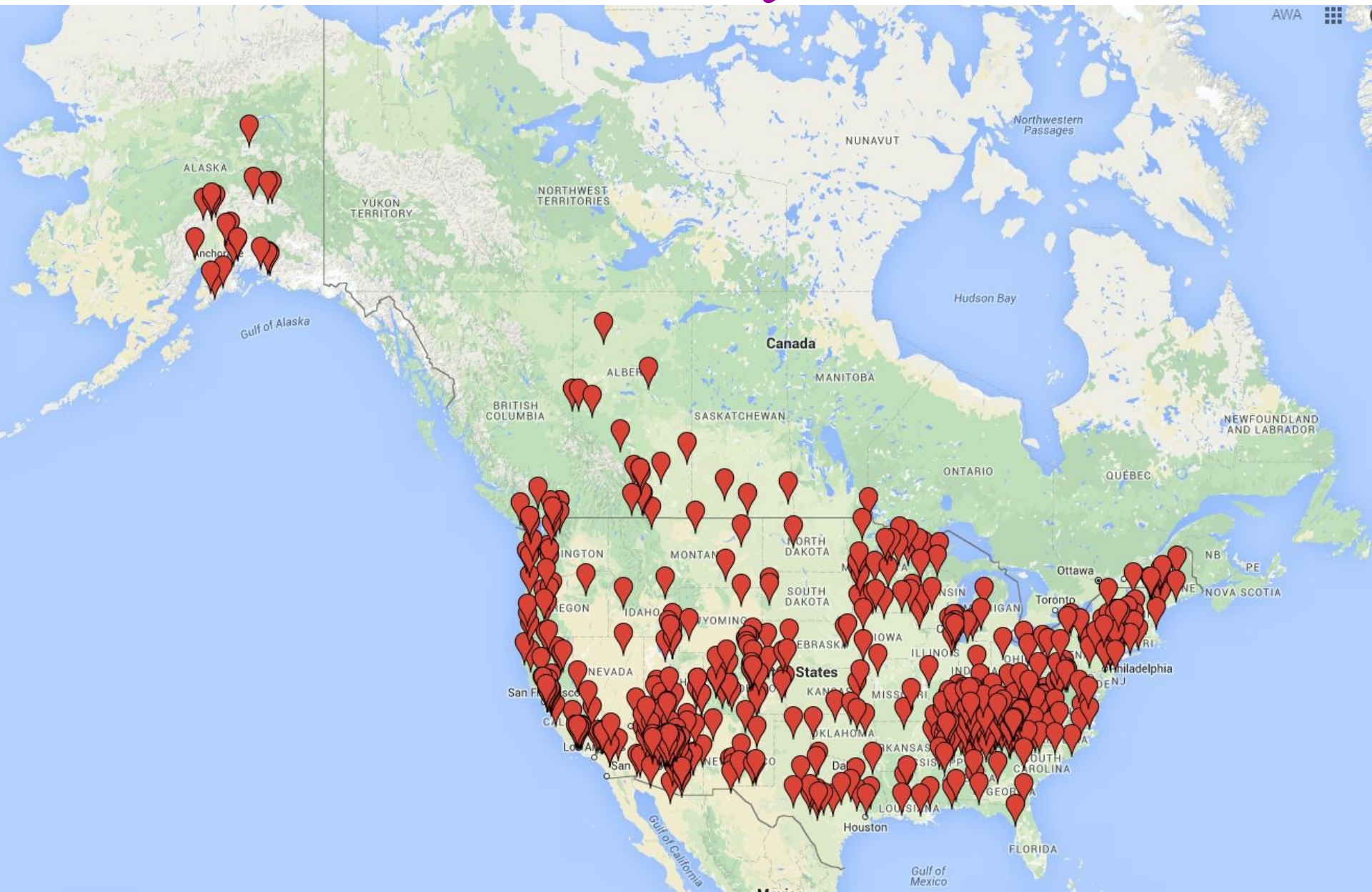
Uncertainty in the PMP Estimation Process

- Areas of Uncertainty
  - Storm selection
  - Storm transpostion
  - Storm adjustments
  - Topography
  - Representativeness of historical record
  - Maximum storm efficiency
  - Surface dew points representing saturated atmosphere
  - Accuracy of storm analyses
    - Rain gauges
    - Radar coverage
  - Others

END OF INTRO SECTION

- End of Intro Section

AWA SPAS Analysis Locations



Catskill, NY July 1819

Catskill, NY 1819

- 10+ inches in 1-hour
- American Journal of Science
- Enough data to analyze today-not used in HMRs

Unofficial observations very important

- Bucket surveys
- Anecdotal

Catskill, NY July 1819

ART. XII.—*An account of a remarkable storm which occurred at Catskill, July 26, 1819.*

[Read before the Catskill Lyceum.]

TO PROF. SILLIMAN,

Dear Sir—Agreeably to your request, I now transmit to you an account of the great storm, which occurred here on Monday afternoon the 26th July, 1819. At that time I was absent on a journey, in the state of Pennsylvania. Of course I am indebted to others for that class of facts which relate to the immediate phenomena of the storm. I reached home on the following Monday; and during that week spent much of the time in collecting facts relative to it; and have since from time to time, visited various places, where uncommon ravages were occasioned, and have spared no pains in obtaining all the information of an interesting nature which could be collected. Every fact communicated by others, or observed by myself, was immediately committed to writing. The manuscript has lain by me about fifteen months. I have more than once, visited several of the places, where peculiar ravages exist, and believe the account to be in no degree exaggerated.

I am respectfully, yours, &c.

BENJAMIN W. DWIGHT.

Catskill, February 5, 1821.

ACCOUNT OF A STORM, &c.

IN several places in the mountainous country of New-England, it has been supposed by many of the inhabitants, that *clouds have in various instances burst*, or suddenly discharged great quantities of water. As the phenomena indicated by this phraseology have, in almost all instances, in which they have occurred, in that section of the country, existed in thinly settled regions, or in the night, in consequence of which the accounts given of them are imperfect; I suppose that it may be gratifying to some of your readers, to see a detailed account of the storm, which occurred here.

This storm exhibited phenomena analagous to those, which have occurred from what is called the bursting of a cloud, and in some respects more remarkable than any, of which I have heard.

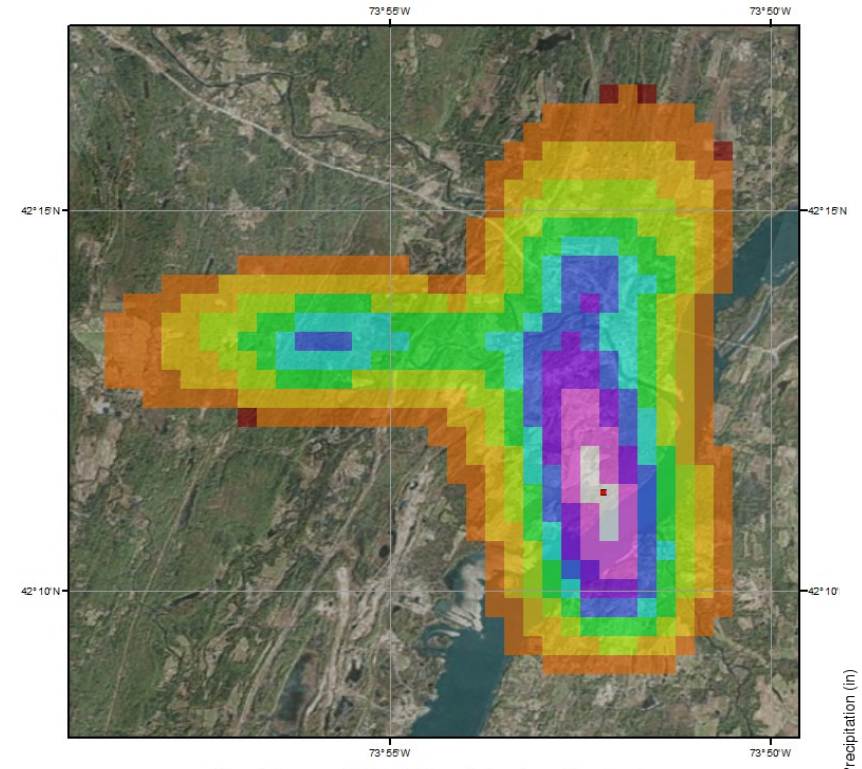
To render the description more intelligible, a few explanatory observations may be useful.

The *township* of Catskill is situated on the West side of the Hudson, and is bounded on the East by that river; on the North by the township of Athens; on the West by Cairo; and on the South by Saugerties. The *town* is estimated to be about one hundred and twenty miles north from the city of New-York. Three rivers, or creeks, as they are here customarily called, have their courses in part, through this township; the Kistatom, the Kaaterskill, and the Catskill. The Kiskatom rises, if I am correctly informed, between the Catskill mountains and the Round Top,* a mountain in Cairo; and runs about five miles in the township of Catskill, and empties into the Kaaterskill. The Kaaterskill is a fine mill stream, which rises in the Catskill mountains, and empties into the Catskill, about two miles from the mouth of the latter stream.

The Catskill, which I shall usually denominate the *Creek*, rises in Middleburgh, in Scoharie County, and empties after a course of about forty miles, into the Hudson. The Catskill mountains lie westward from the town, and are distant from it in their nearest part, about seven or eight miles. *The town* is situated along the creek, and commences at

* The highest peak of the Catskill mountains is also called Round Top.

Catskill, NY July 1819



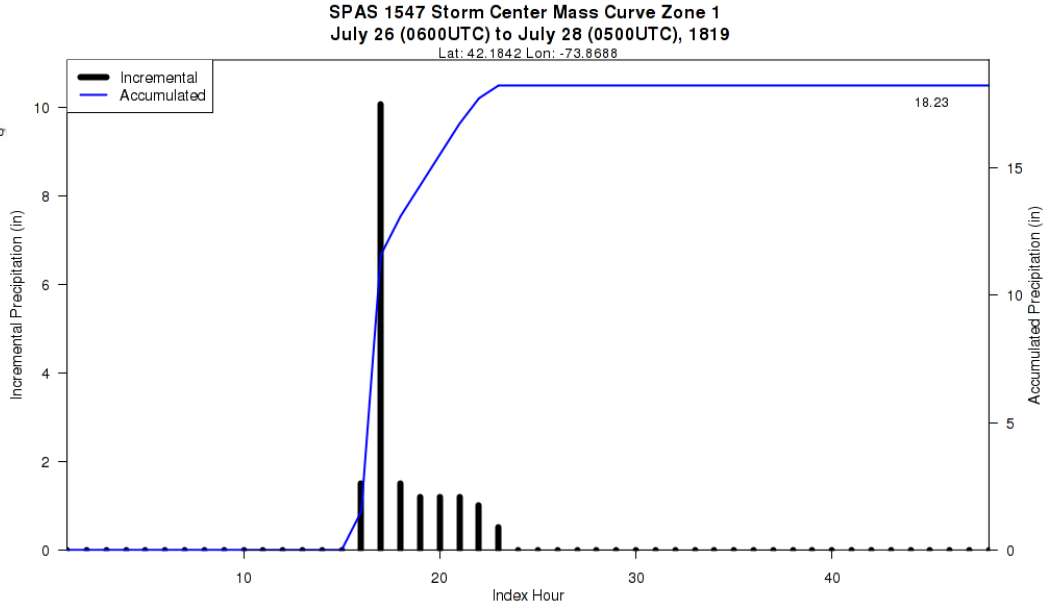
Total Storm (48-hr) Precipitation (inches)
07/26/1819 0600 UTC - 07/28/1819 0500 UTC
SPAS #1547

Gauges
Hourly Estimated

Miles 0 0.75 1.5 3
Kilometers 0 1.75 3.5 7

Precipitation (inches)
1.96 - 2.00 | 2.01 - 4.00 | 4.01 - 6.00 | 6.01 - 8.00 | 8.01 - 10.00 | 10.01 - 12.00 | 12.01 - 14.00 | 14.01 - 16.00 | 16.01 - 18.00 | 18.01 - 20.00

6/25/2015



Smethport, PA July 1942

- World record rainfall at 4.5 and 6 hours
- Hard to believe reports-but it rained a lot
- Lots of data for 1942

  Unofficial observations very important

  - Bucket surveys
  - Anecdotal

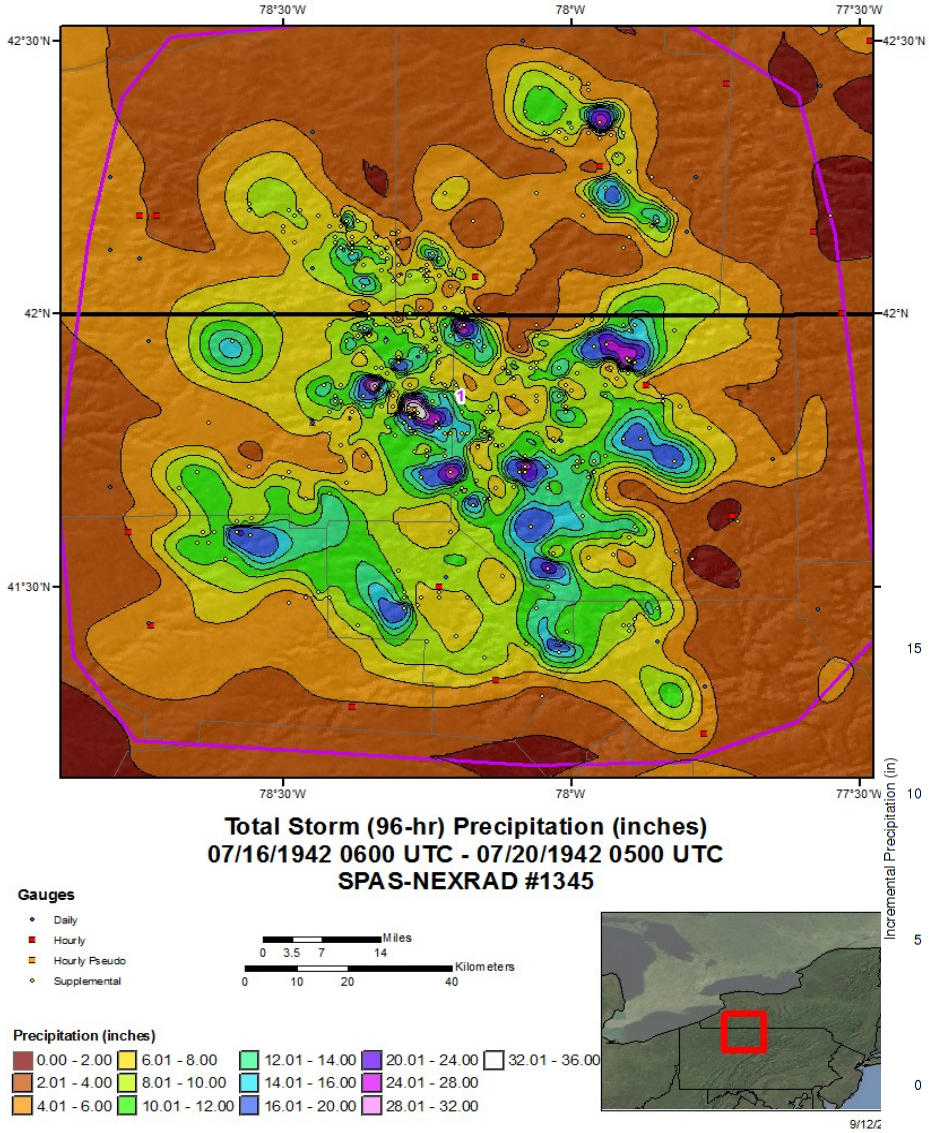
Smethport, PA July 1942

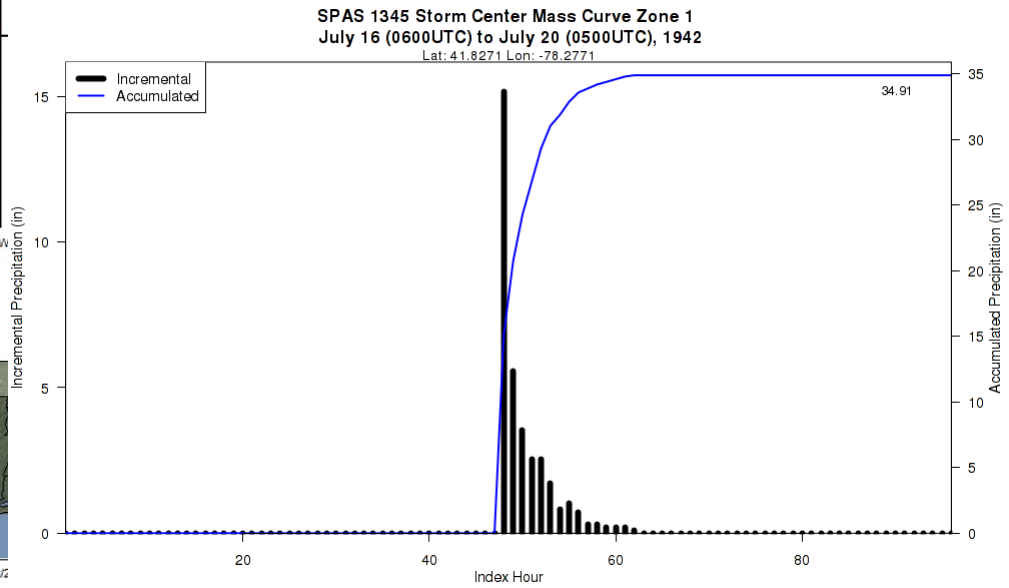
Rainfall observation site for the world

Record rainfall amount

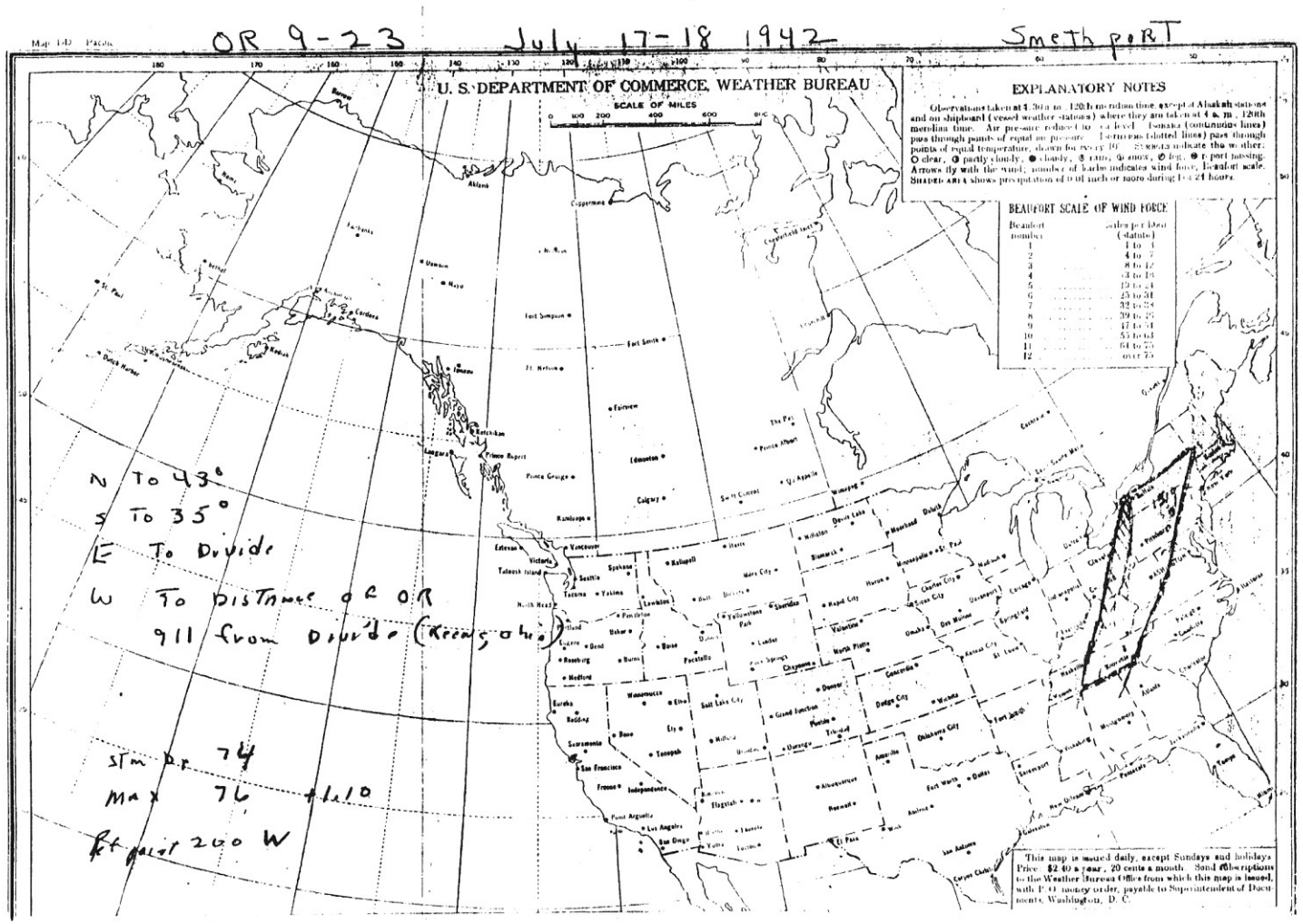
- 30.8 inches
- 4.5 hours
- 8” pickle jar with 3.5” opening!
- ~22” from roofline

Smethport, PA July 1942

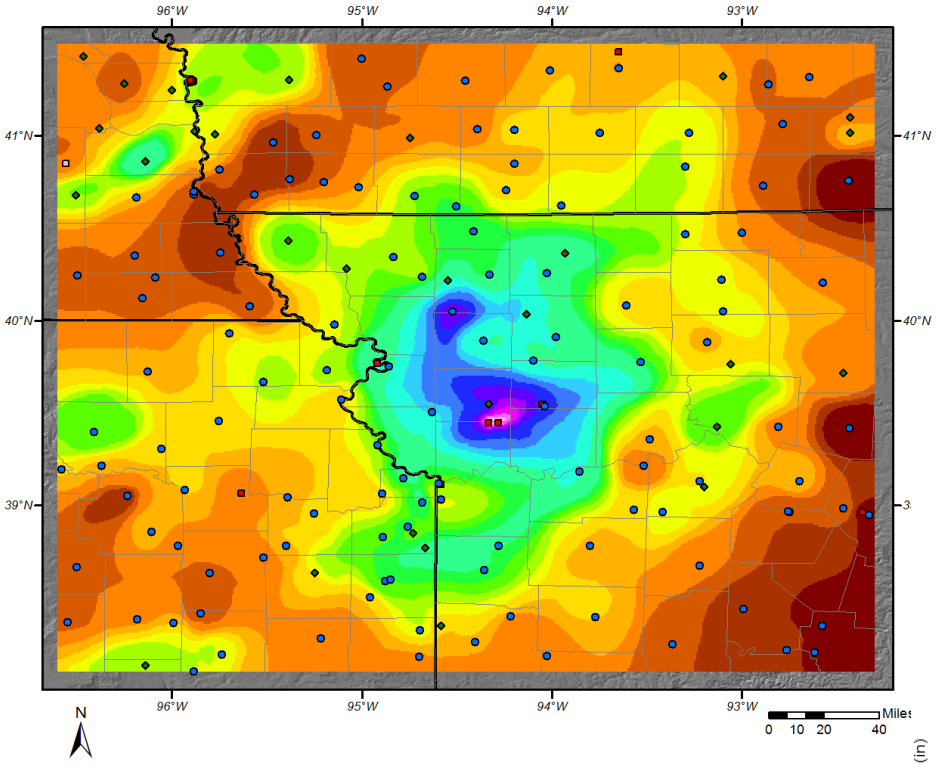




Smethport, PA July 1942



Holt, MO June 1942



Total 108-hour Precipitation (inches)
June 19, 1947 0000 UTC - June 23,1947 1200 UTC
SPAS #1434

Precipitation (inches)

0.00 - 0.50	2.51 - 3.00	5.01 - 6.00	10.1 - 11.5
0.51 - 1.00	3.01 - 3.50	6.01 - 7.00	11.6 - 13.0
1.01 - 1.50	3.51 - 4.00	7.01 - 8.00	13.1 - 14.5
1.51 - 2.00	4.01 - 4.50	8.01 - 9.00	14.6 - 16.0
2.01 - 2.50	4.51 - 5.00	9.01 - 10.0	16.1 - 17.5
			17.6 +

Stations
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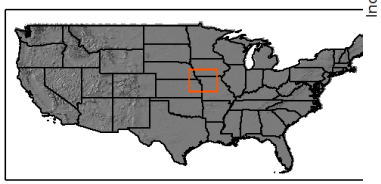
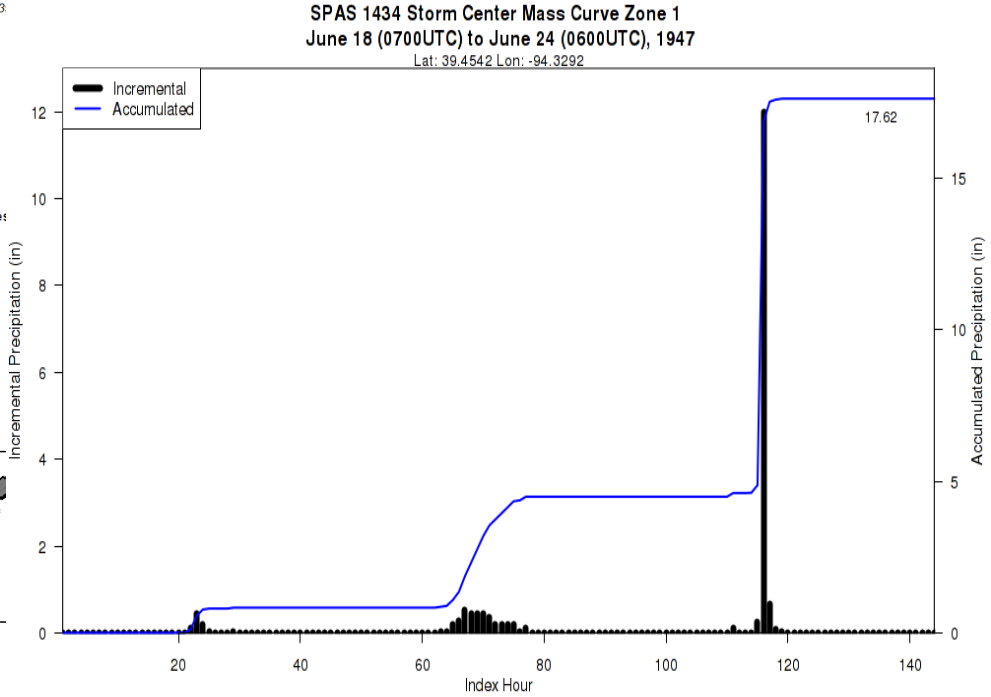


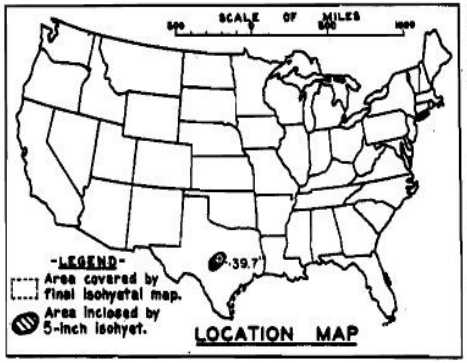
KLL 10/21/2014



Thrall, TX Sept 1921-USACE Analysis

WAR DEPARTMENT — CORPS OF ENGINEERS, U.S. ARMY

STORM STUDIES - PERTINENT DATA SHEET



Storm of 8-10 Sept. 1921
Assignment GM 4-12
Location Central Texas
Study Prepared by:
Southwestern Division
Galveston District Office
& Hydrometeorological Section
Part I Reviewed by H. M. Sec. of Weather Bureau, 8/20/45
Part II Approved by Office, Chief of Engineers for Distribution of Factual Data, 11/7/46
Remarks: Center near Thrall (Taylor), Texas

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)	7
Form 5001-B (24-hour " ")	23
Form 5001-D (" " " ")	2
Misc. precip. records, meteorological data, etc.	30
Form 5002 (Mass rainfall curves)	35

PART II

Final isohyetal maps, in 1 sheet, scale 1:500,000

Data and computation sheets:

Form S-10 (Data from mass rainfall curves)	2
Form S-11 (Depth-area data from isohyetal map)	2
Form S-12 (Maximum depth-duration data)	38
Maximum duration-depth-area curves	1
Data relating to periods of maximum rainfall	—

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

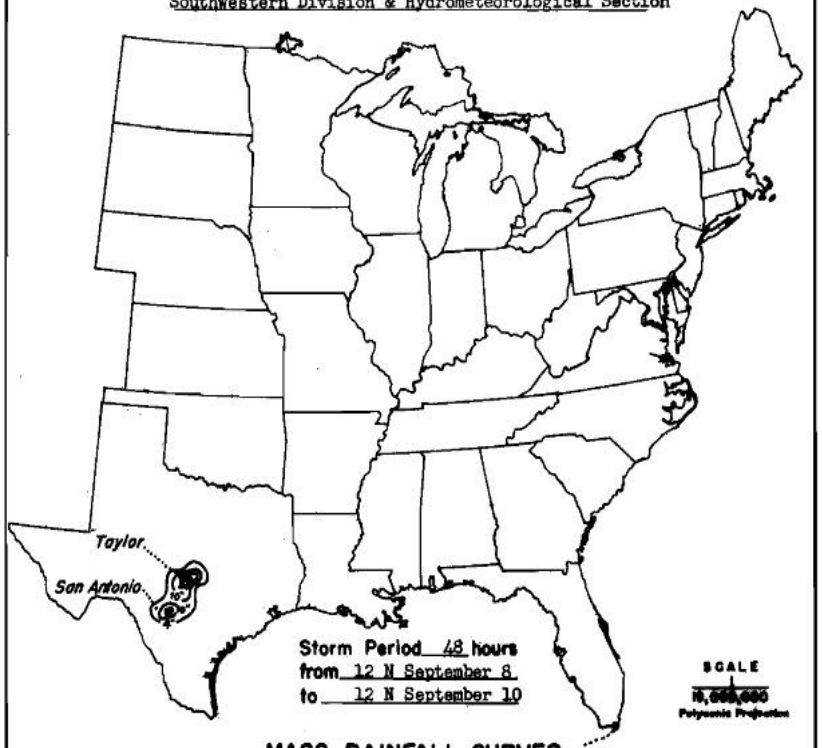
Area in Sq. Mi.	Duration of Rainfall in Hours						
	6	12	18	24	30	36	48
Max. Station	23.4	31.8	36.4	38.2	39.2	39.7	39.7
10	22.4	29.8	35.0	36.5	37.2	37.6	37.6
100	19.6	26.2	30.7	31.9	32.6	32.9	32.9
200	17.9	24.3	28.7	29.7	30.4	30.7	30.8
500	15.4	21.4	25.6	26.6	27.3	27.6	27.7
1,000	13.4	18.8	22.9	24.0	24.6	24.9	25.1
2,000	11.2	15.7	19.5	20.6	21.2	21.5	21.6
5,000	8.1	11.1	14.1	15.0	15.9	16.2	16.3
10,000	5.6	7.7	9.7	10.7	11.8	12.1	12.2
12,500	4.7	6.7	8.4	9.4	10.3	10.7	10.9

Form S-2

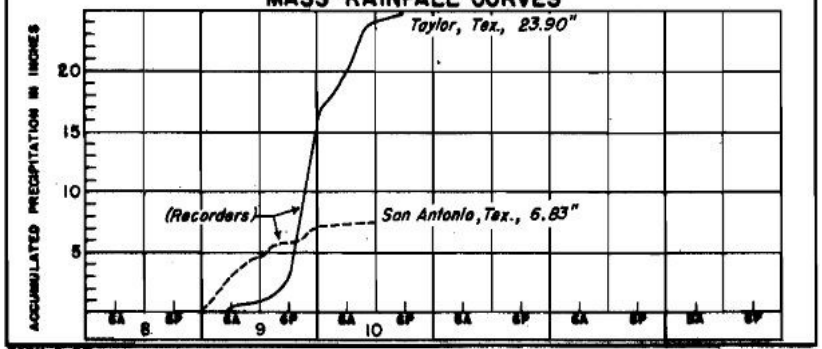
WAR DEPARTMENT — CORPS OF ENGINEERS, U. S. ARMY

STORM STUDIES - ISOHYETAL MAP

Storm of September 8-10, 1921 Assignment GM 4-12
Study Prepared by: Galveston, Tex. District
Southwestern Division & Hydrometeorological Section

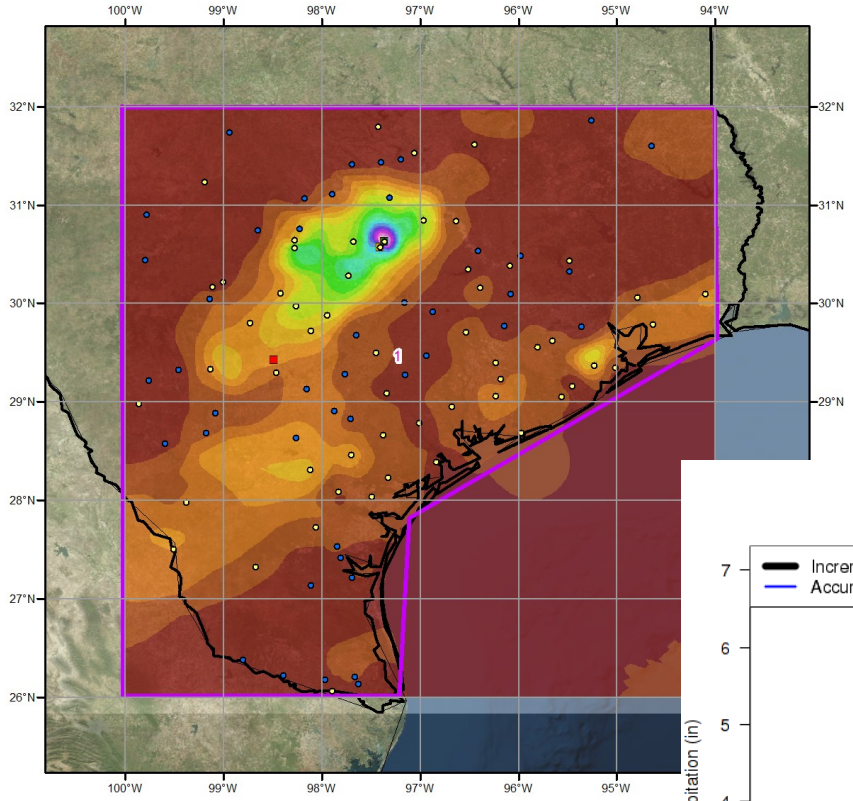


MASS RAINFALL CURVES



FORM S-12

Thrall, TX Sept 1921

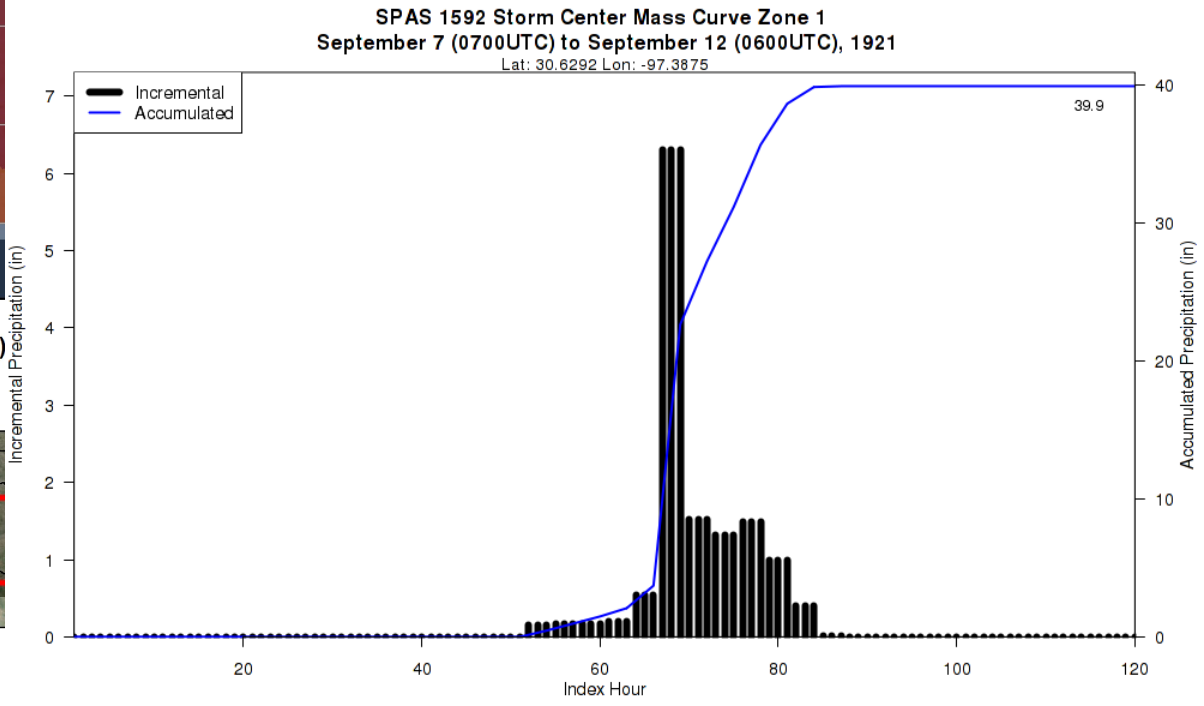


Total Storm (120-hours) Precipitation (inches)
September 7-11, 1921
SPAS 1592 - Thrall, TX

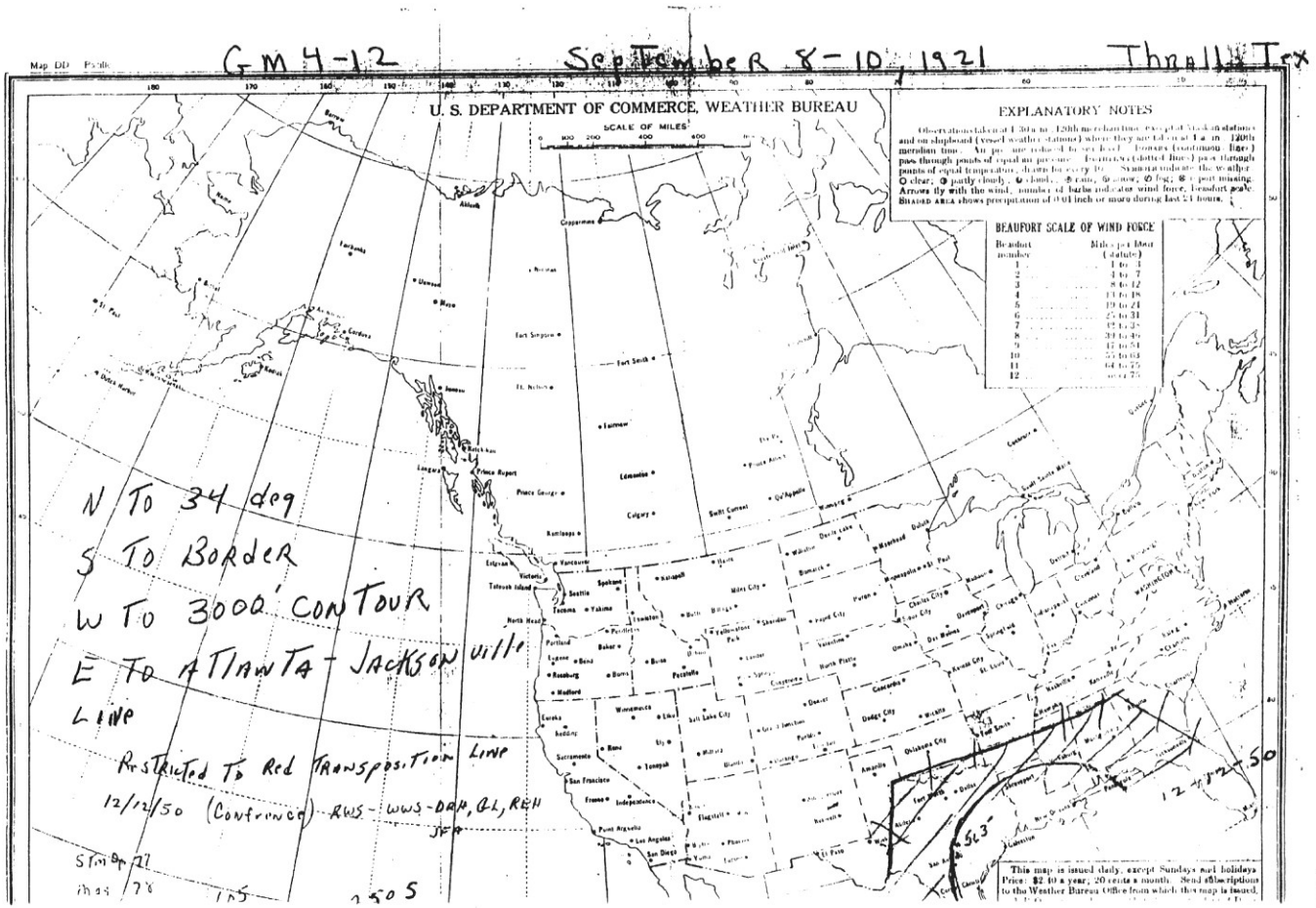
Gauges
- Daily
- Hourly
- HEP
- Hourly Pseudo
- Supplemental

Miles: 0 30 60 120
Kilometers: 0 65 130 260

Precipitation (inches)			
0.00 - 2.00	8.01 - 10.00	18.01 - 20.00	28.01 - 30.00
2.01 - 4.00	10.01 - 12.00	20.01 - 22.00	30.01 - 32.00
4.01 - 6.00	12.01 - 14.00	22.01 - 24.00	32.01 - 34.00
6.01 - 8.00	14.01 - 16.00	24.01 - 26.00	34.01 - 36.00
	16.01 - 18.00	26.01 - 28.00	36.01 - 38.00
			38.01 - 40.00



Thrall, TX Sept 1921



Gibson Dam, June 1964

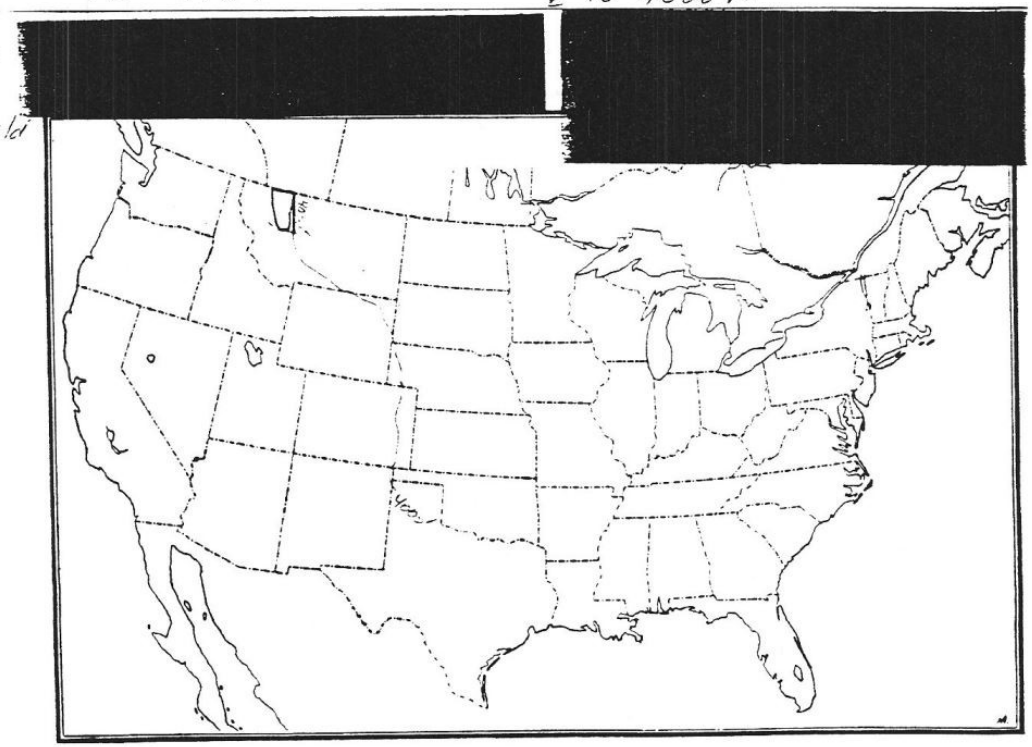
NP2-23 June 6-8, 1964
12 hr r Td = 64°F 310 ESE
72°F 148%

N to 49°
S to 47°
W to 5000 ft
E to 4000 ft

E hv 4700'

See Narrows Damsite and Chetlo Reports

Max obs at 48° 30' 113° 2'



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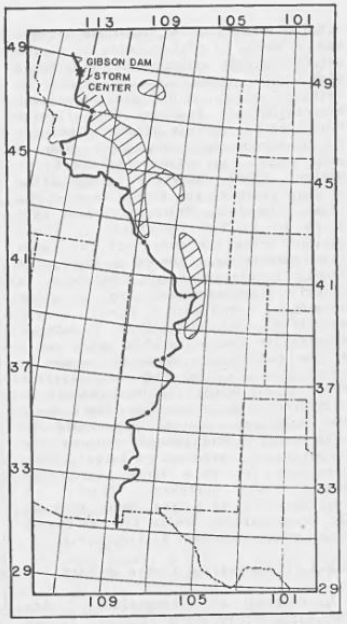
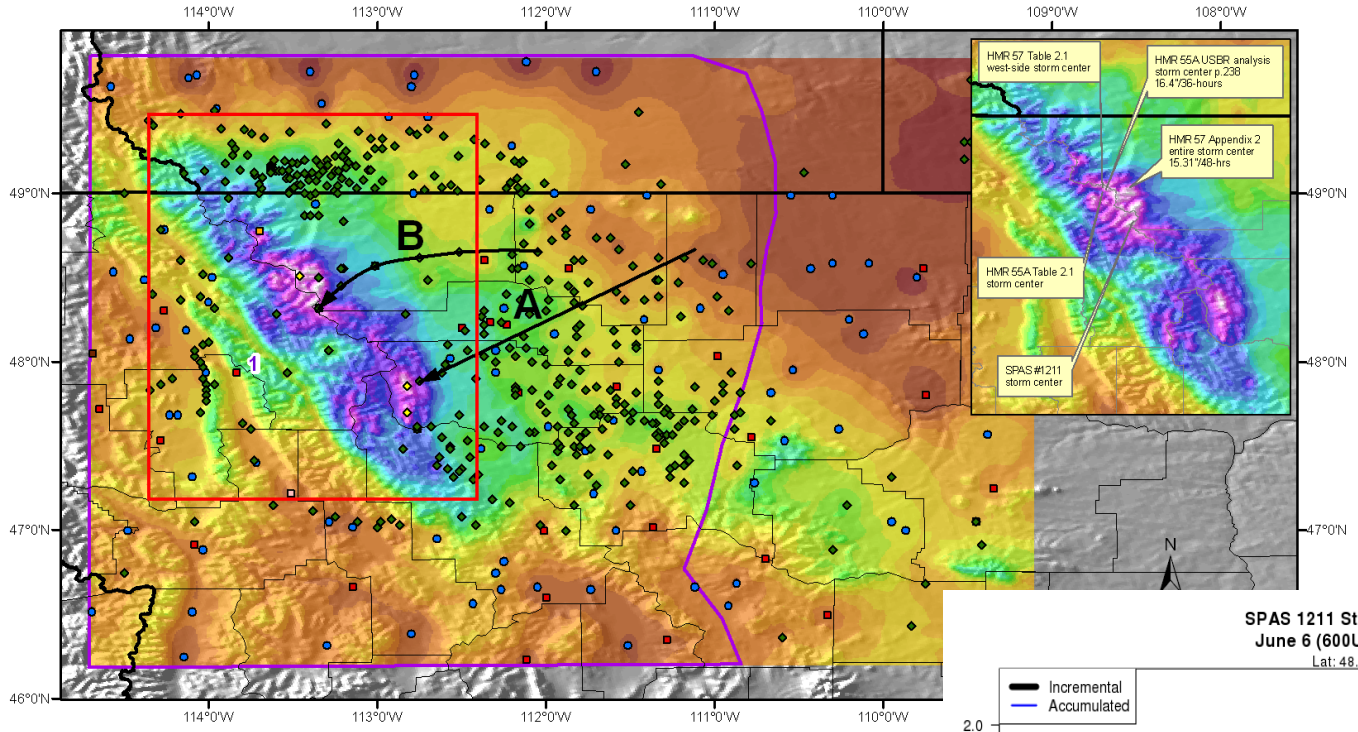


Figure 8.3.—Transposition limits for Gibson Dam, MT storm (75) of June 6–8, 1964.

The first limiting factor considered in this storm was topography. The primary rainfall center occurred along the ridge of the first upslopes. It was considered inappropriate to transpose the total precipitation from this storm to secondary upslopes. Second, the slopes in the vicinity of the major precipitation centers were examined. Though relatively steep, they were not within regions considered to be the steepest upslopes. This factor did not limit transposition within the first upslopes of the orographic regions.

Meteorological factors to be considered are moisture flow from the Gulf of Mexico, the formation of a well organized low pressure system, and a relatively stable air mass. These combined features can be found through the entire CD-103 region north of approximately 37°N. Figure 8.3 shows the transposition limits determined for the Gibson Dam storm.

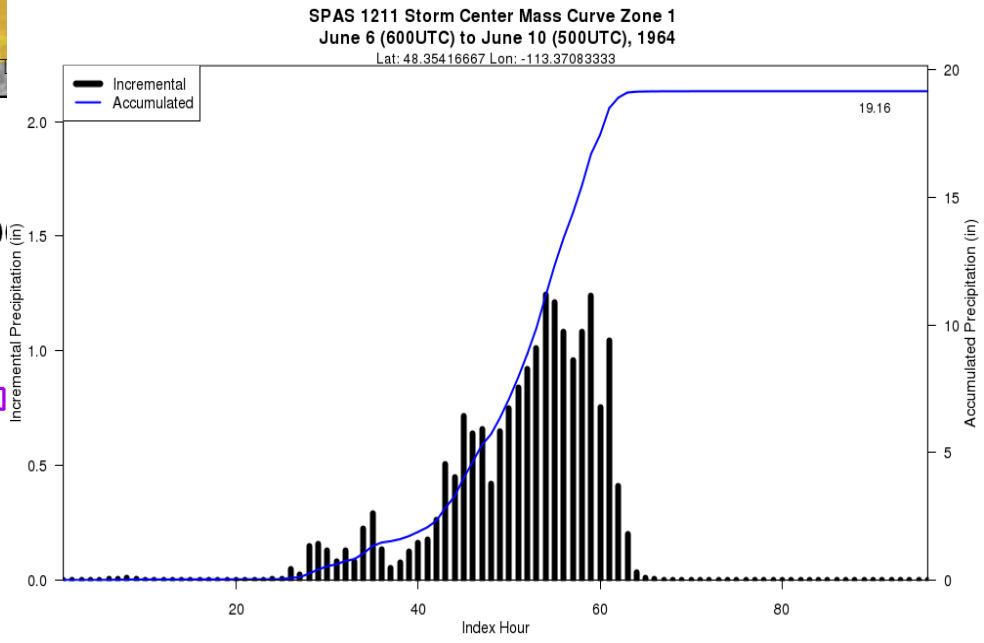
Gibson Dam, June 1964



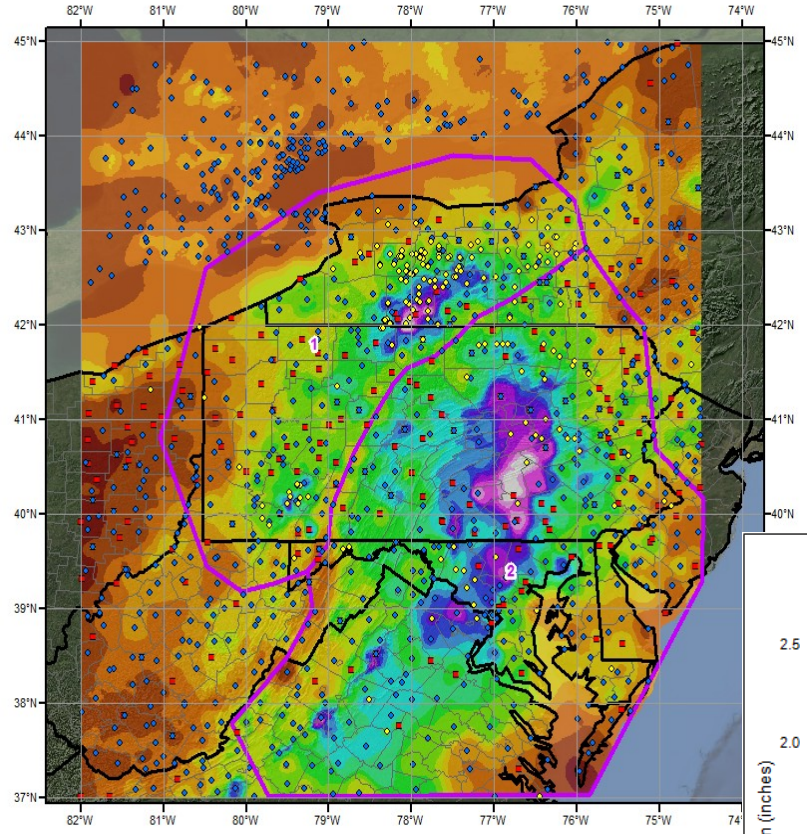
Total 96-hour Precipitation
SPAS #1211
June 6, 1964 0600 UTC - June 10, 1964 050

Precipitation (inches)

0.04 - 0.50	2.51 - 3.00	5.01 - 5.50	9.01 - 10.00	14.01 - 15.00	Daily	
0.51 - 1.00	3.01 - 3.50	5.51 - 6.00	10.01 - 11.00	15.01 - 16.00	Hourly	
1.01 - 1.50	3.51 - 4.00	6.01 - 7.00	11.01 - 12.00	16.01 - 17.00	Hourly Est.	
1.51 - 2.00	4.01 - 4.50	7.01 - 8.00	12.01 - 13.00	17.01 - 18.00	Hourly Est. Pseudo	
2.01 - 2.50	4.51 - 5.00	8.01 - 9.00	13.01 - 14.00	18.01 - 19.00		



Hurricane Agnes, June 1972



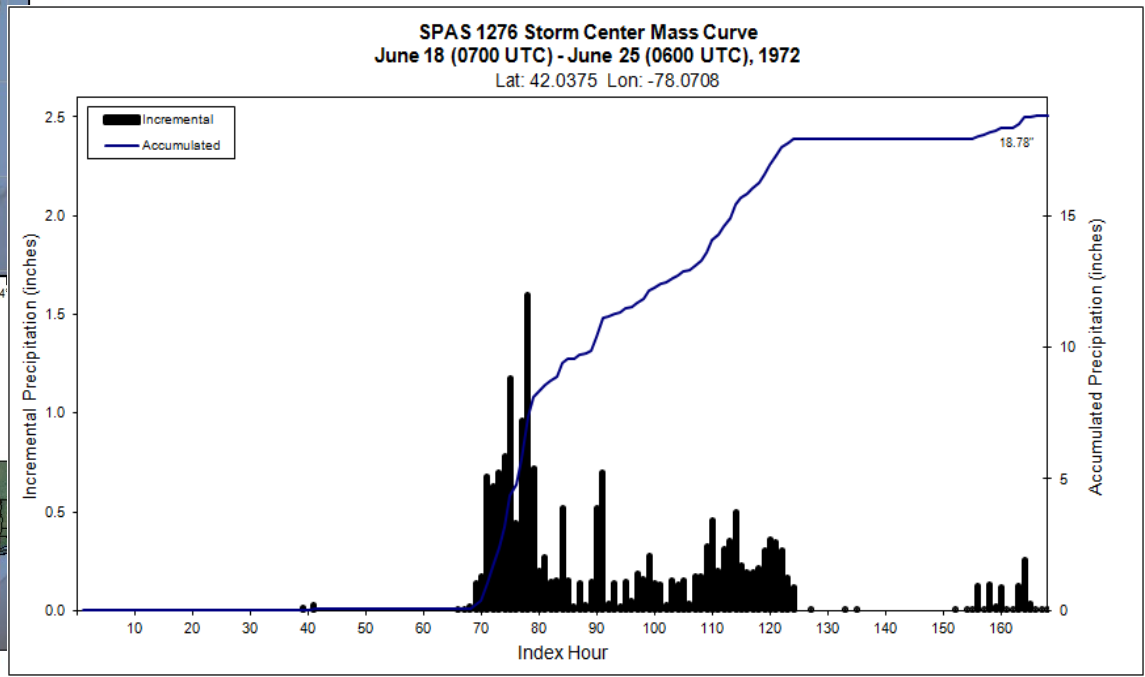
Total Storm (168-hr) Precipitation (inches)
June 18-24, 1972
SPAS 1276

Gauges
- Daily
- Hourly
- Hourly Pseudo
- Supplemental

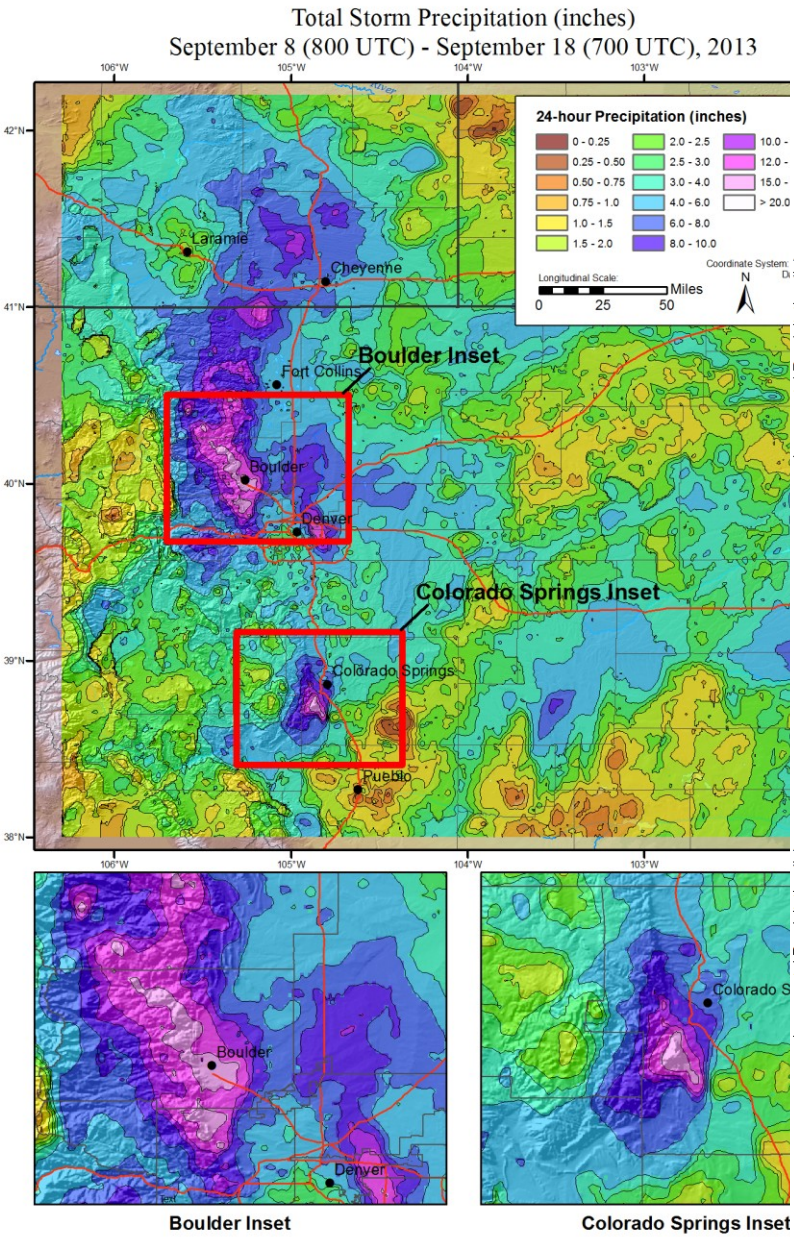
Miles: 0 40 80 160
Kilometers: 0 100 200 400

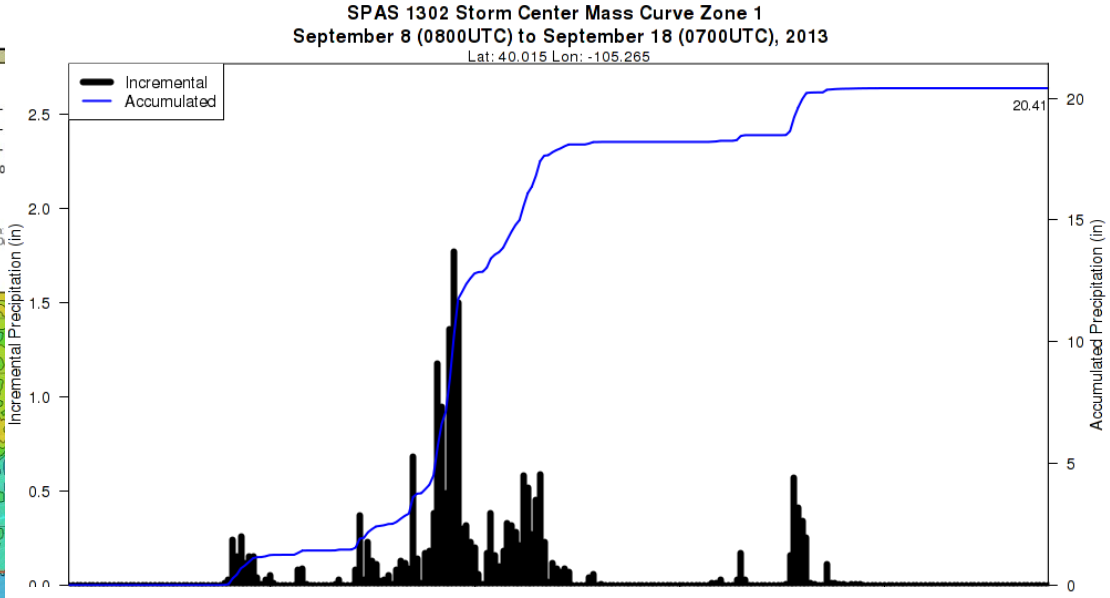
Precipitation (inches)

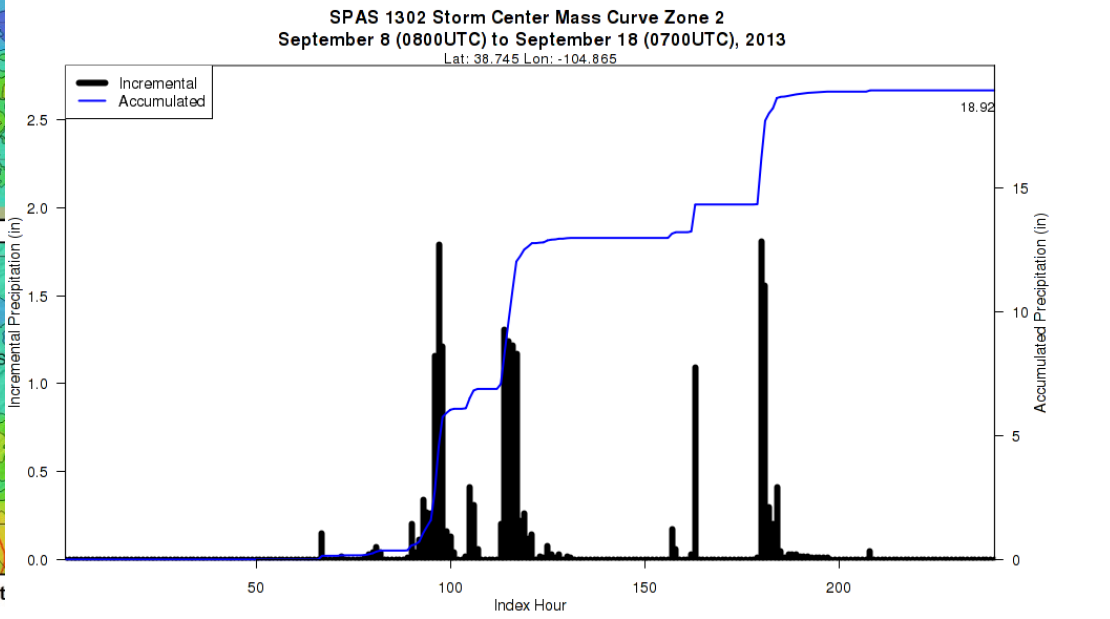
0.58 - 1.00	4.01 - 5.00	8.01 - 9.00	12.01 - 13.00	> 16.00
1.01 - 2.00	5.01 - 6.00	9.01 - 10.00	13.01 - 14.00	
2.01 - 3.00	6.01 - 7.00	10.01 - 11.00	14.01 - 15.00	
3.01 - 4.00	7.01 - 8.00	11.01 - 12.00	15.01 - 16.00	



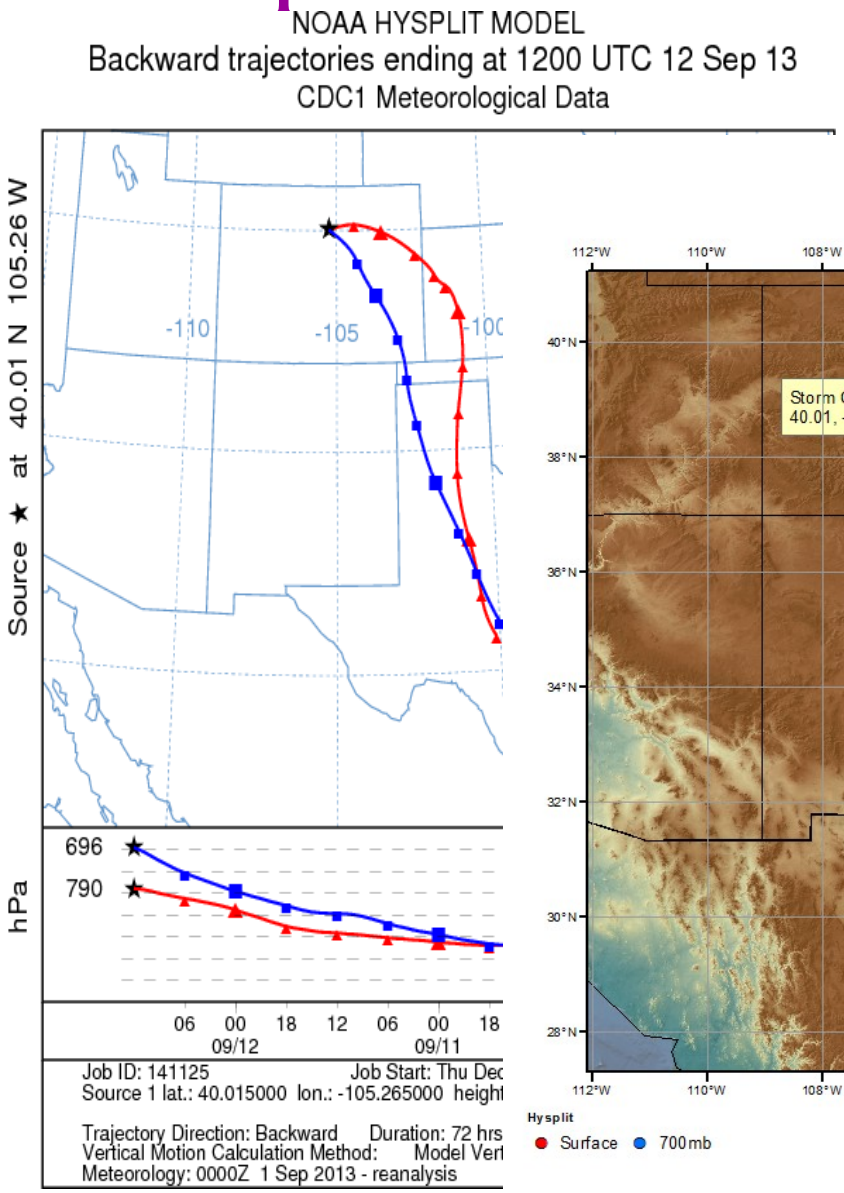
Colorado Front Range, Sept 2013

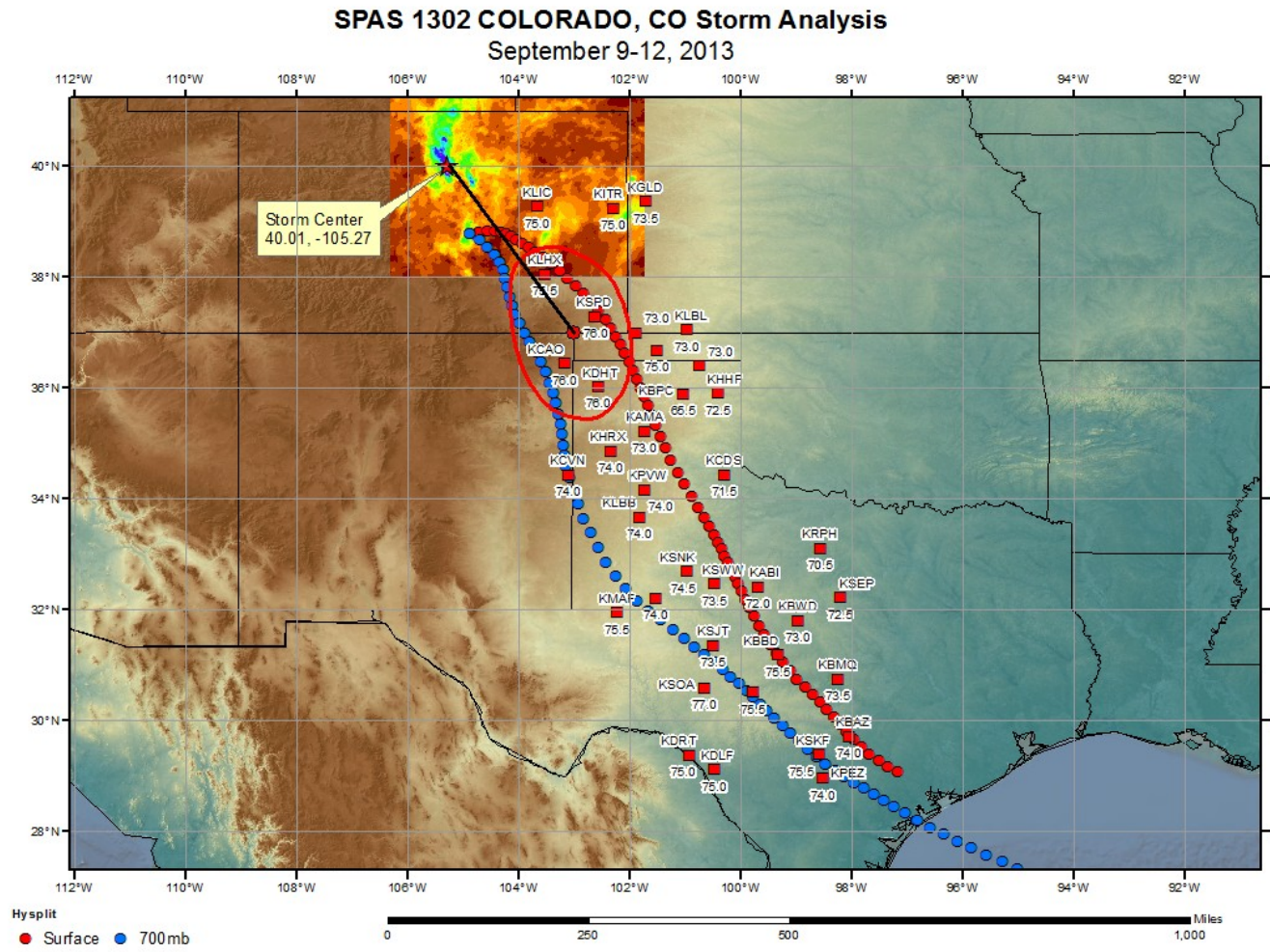






Sept 2013-In-Place Maximization





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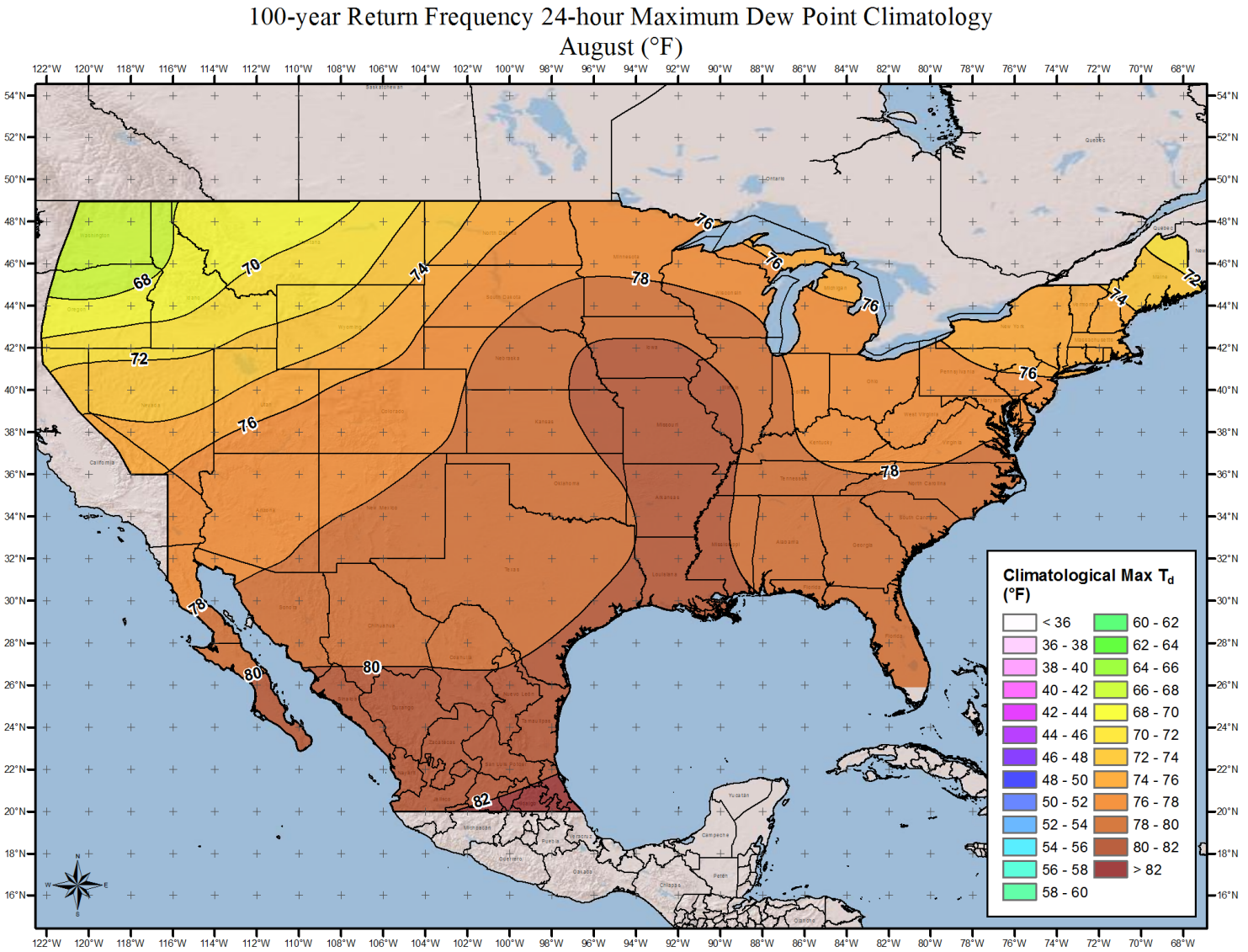
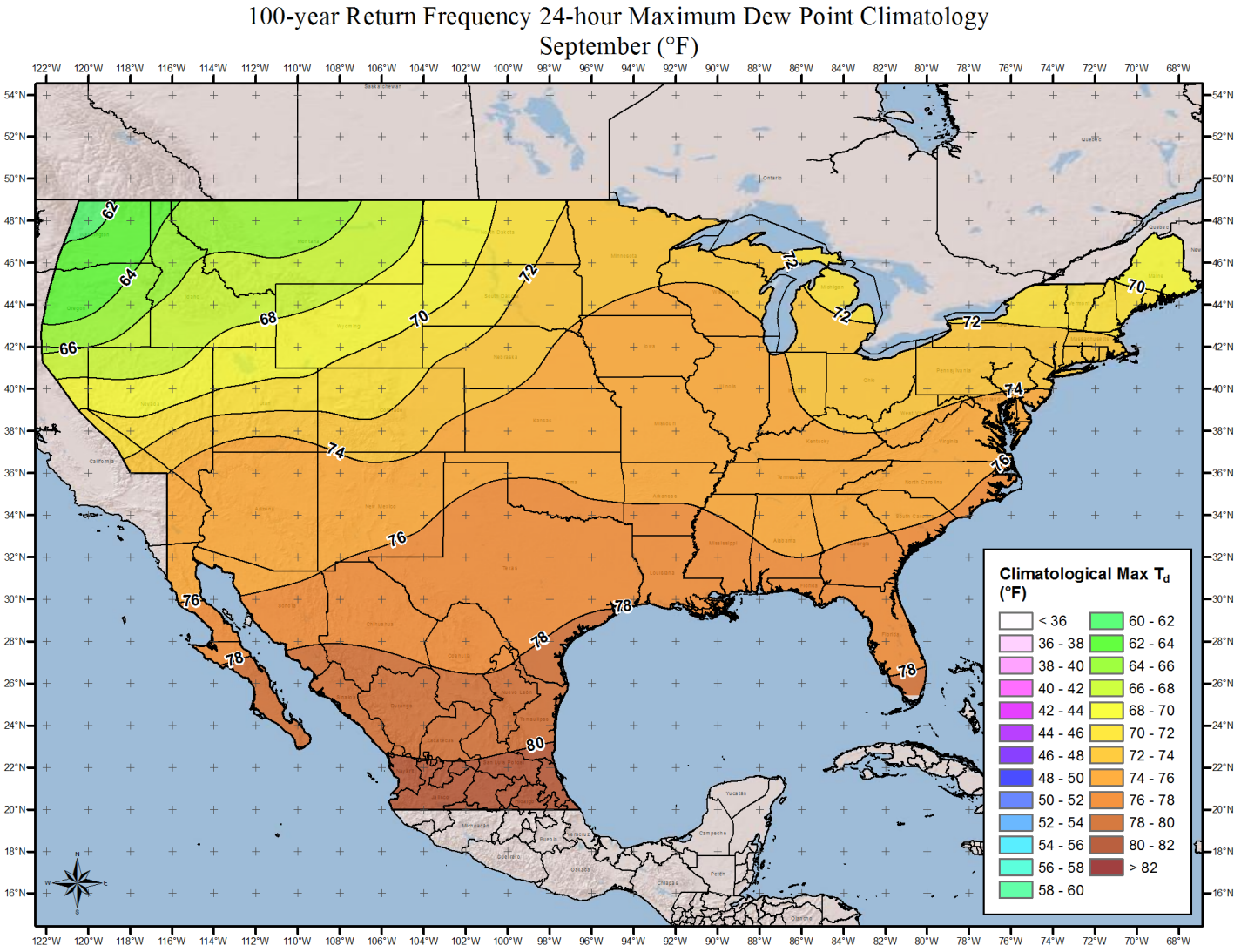
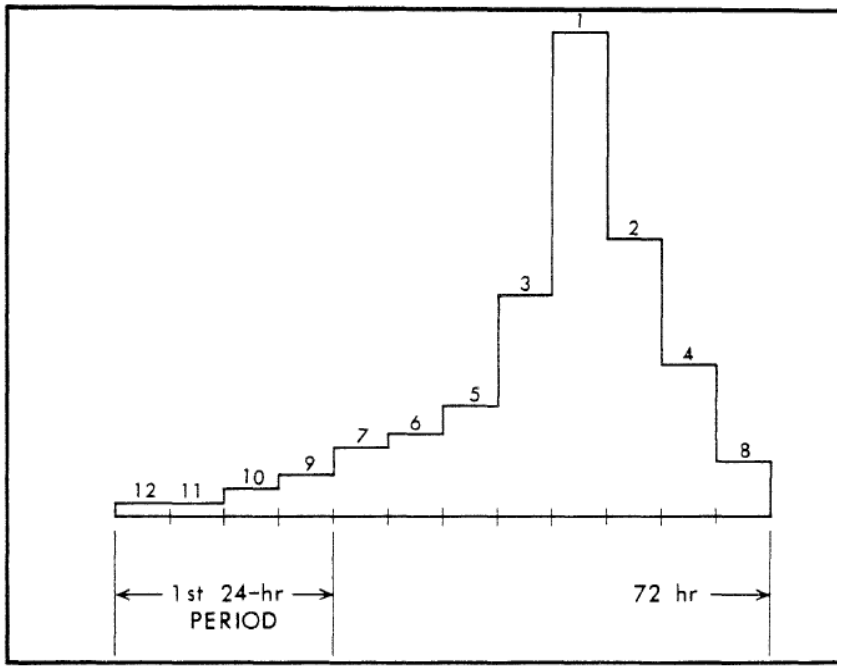
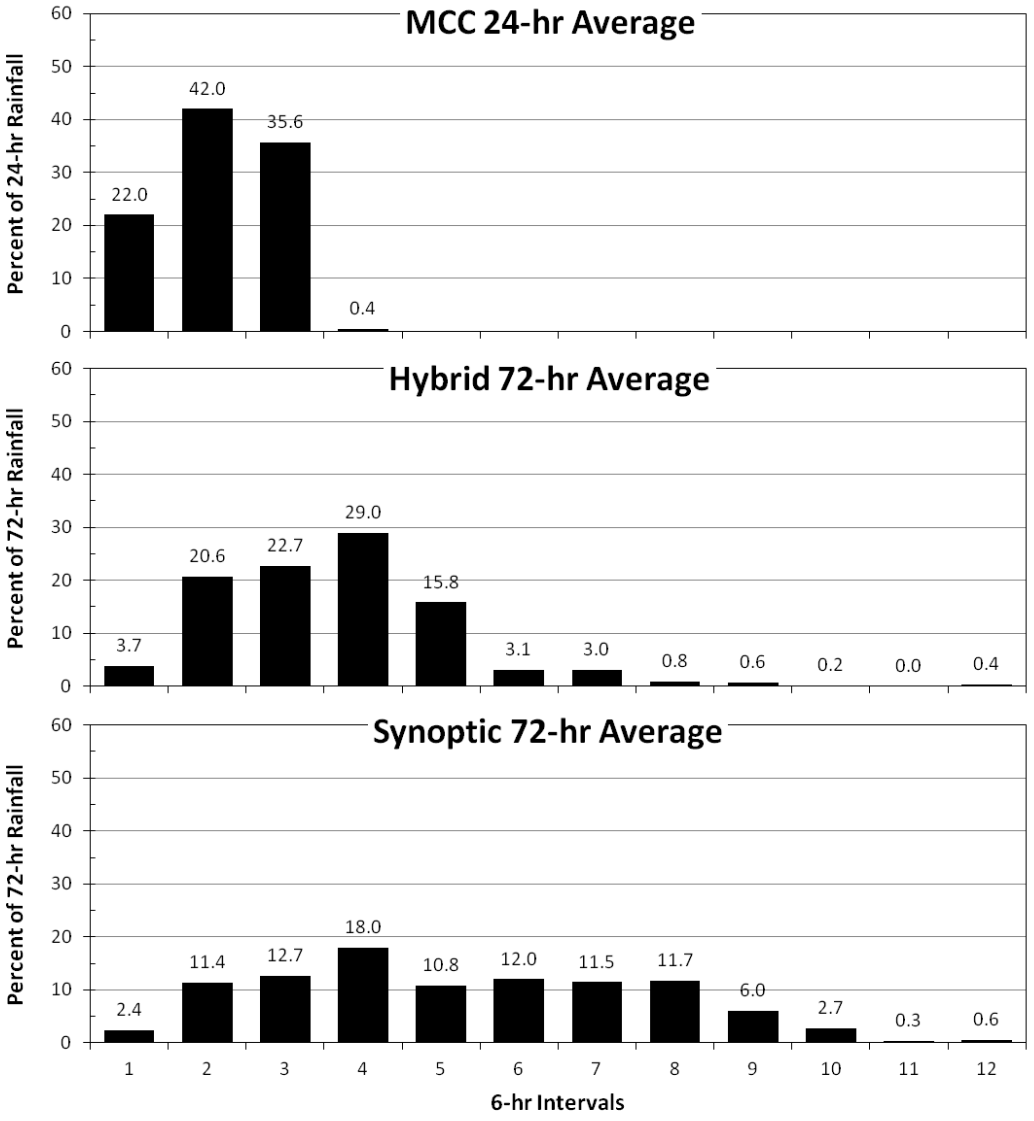


Sept 2013-In-Place Maximization



Temporal Distribution of PMP





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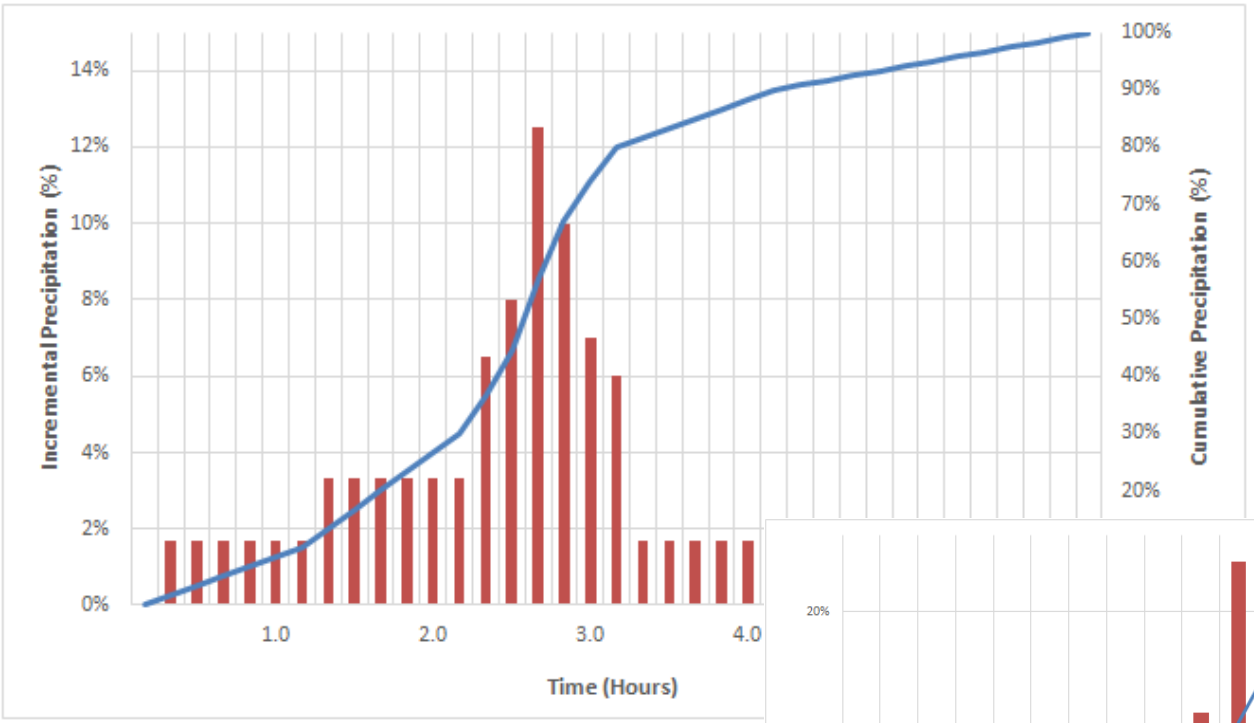
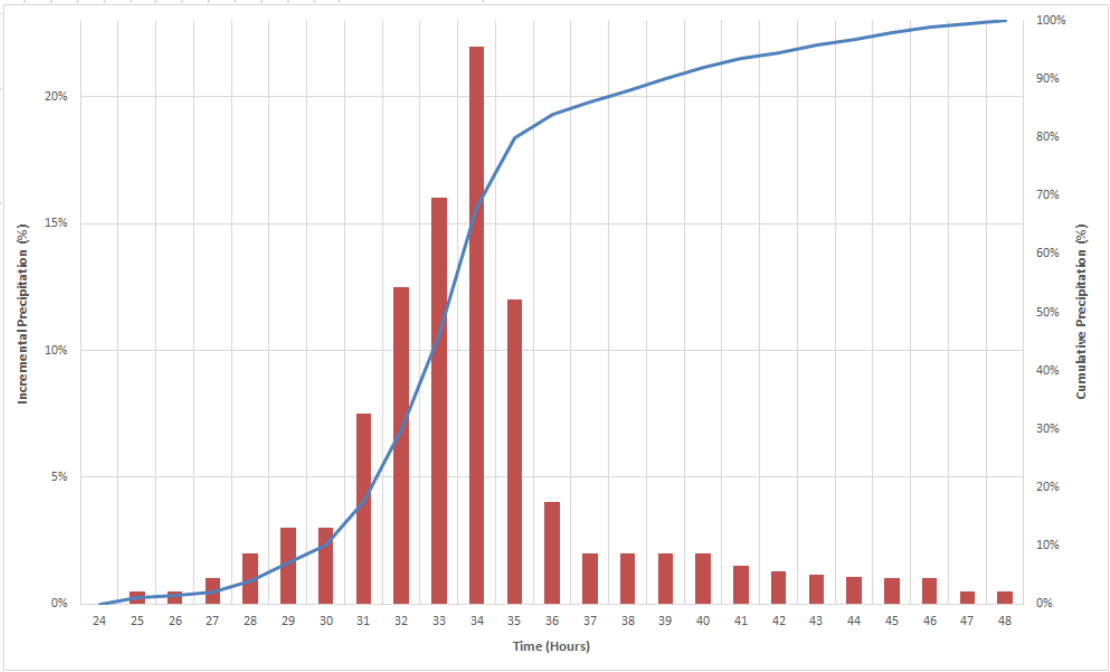
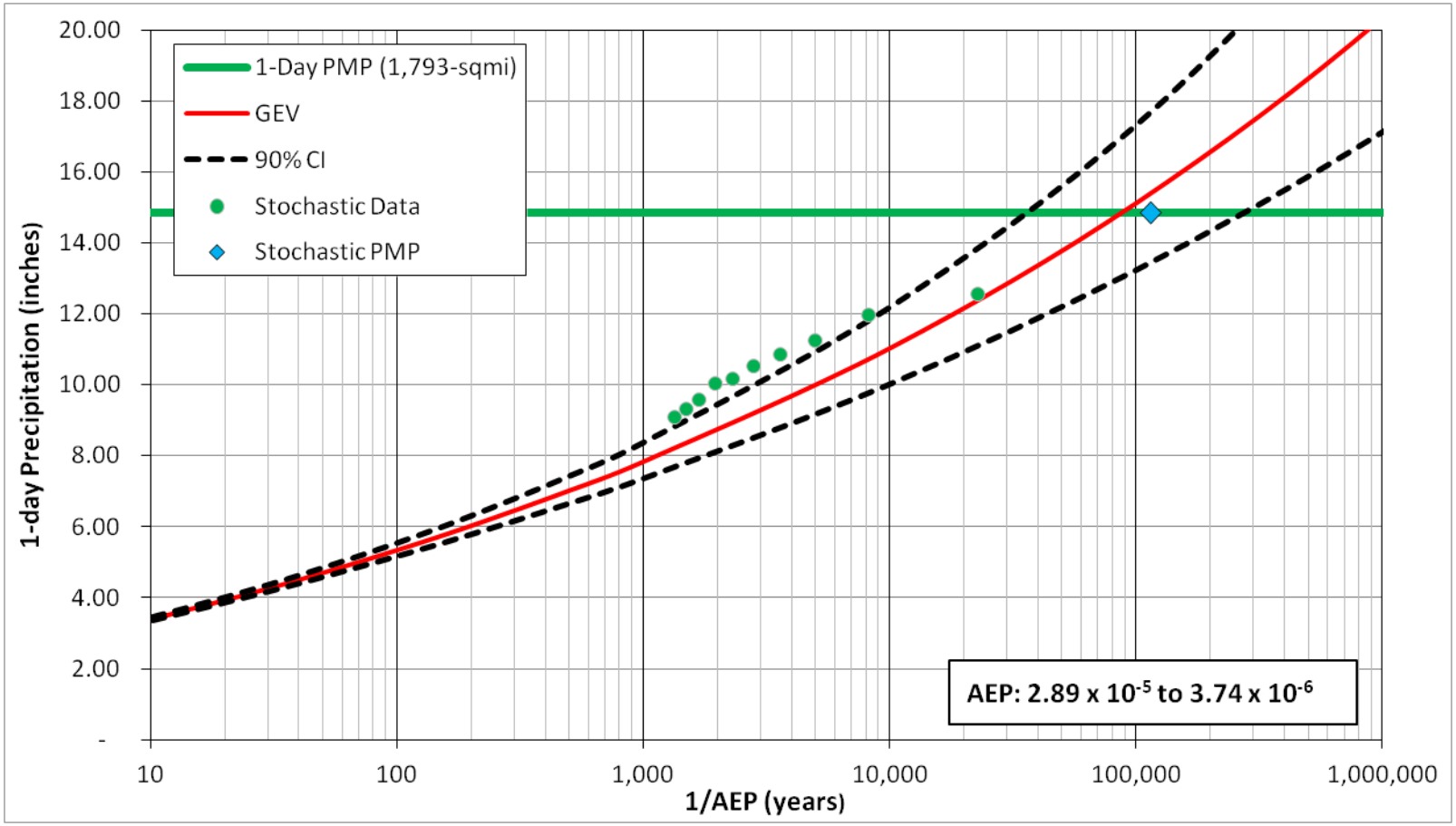




What's Next-Probability-RIDM

Regional L-moments Method

Stochastic Storm Transposition (SST) Method



INSERT SLIDES