Probable Maximum Precipitation Study for Virginia

Applied Weather Associates, LLC

Monument, Colorado

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Project Manager and Senior Meteorologist

Ed Tomlinson, PhD

Chief Meteorologist

First Virginia PMP Meeting

Richmond, Virginia

July 8, 2014

Applied Weather Associates, LLC

- Established 1996
- Bill Kappel
  - President and Senior Meteorologist
- Ed Tomlinson, PhD
  - Chief Meteorologist
- Hydrometeorologist
- GIS specialist
- Staff Meteorologists

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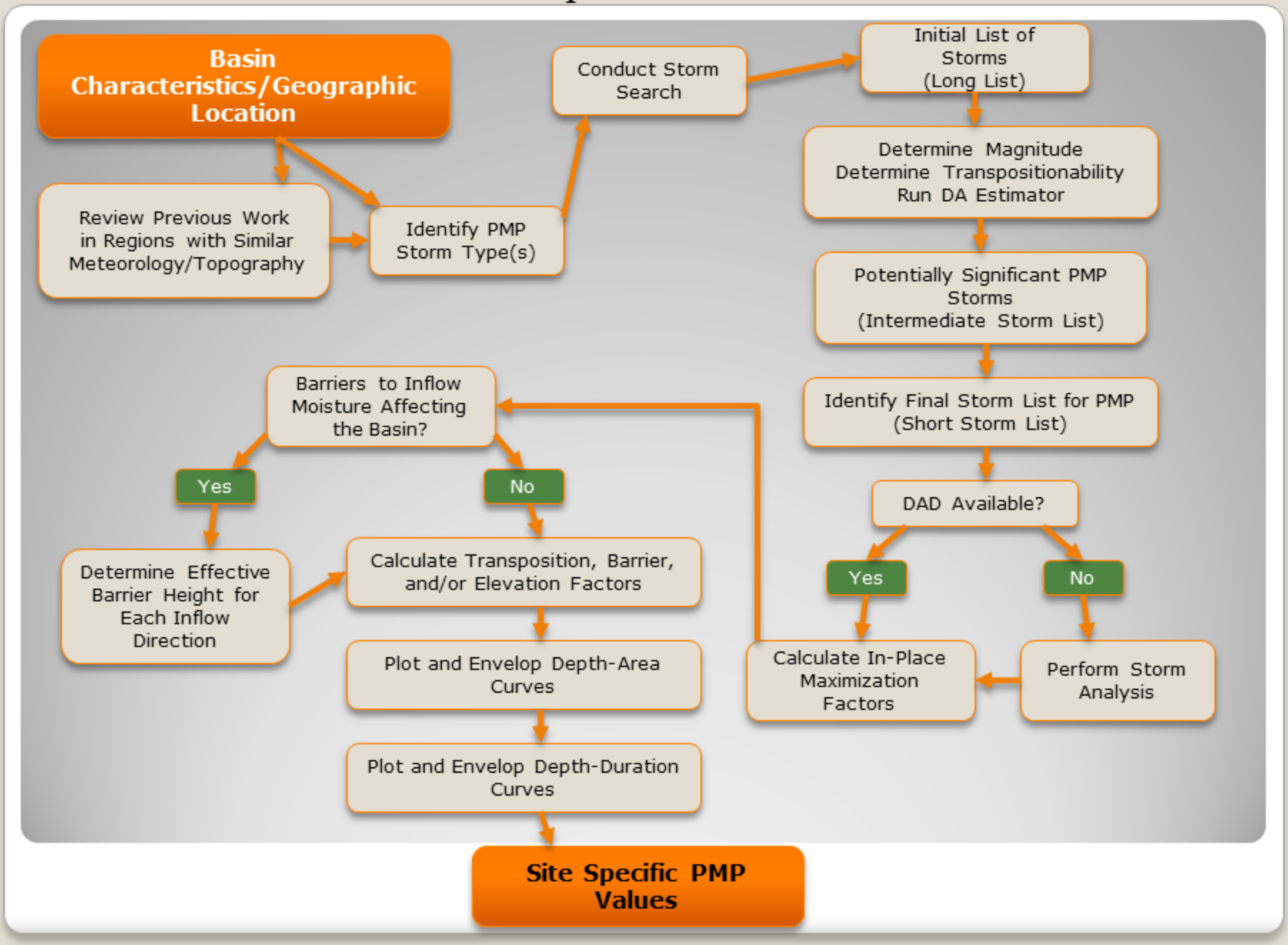
Applied Weather Associates, Personnel

- Project Manager and Senior Meteorologist
  - Bill Kappel
- Chief Meteorologist
  - Ed Tomlinson
- Senior Hydrometeorologist
  - Doug Hultstrand
- Senior GIS Specialist/Staff Scientist
  - Geoff Muhlestein
- Staff Meteorologists
  - Dana McGlone, Kristi Steinhilber, Bryon Lawrence, Steve Lovisone, Patrice Sutter

Probable Maximum Precipitation Determination Flowchart



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

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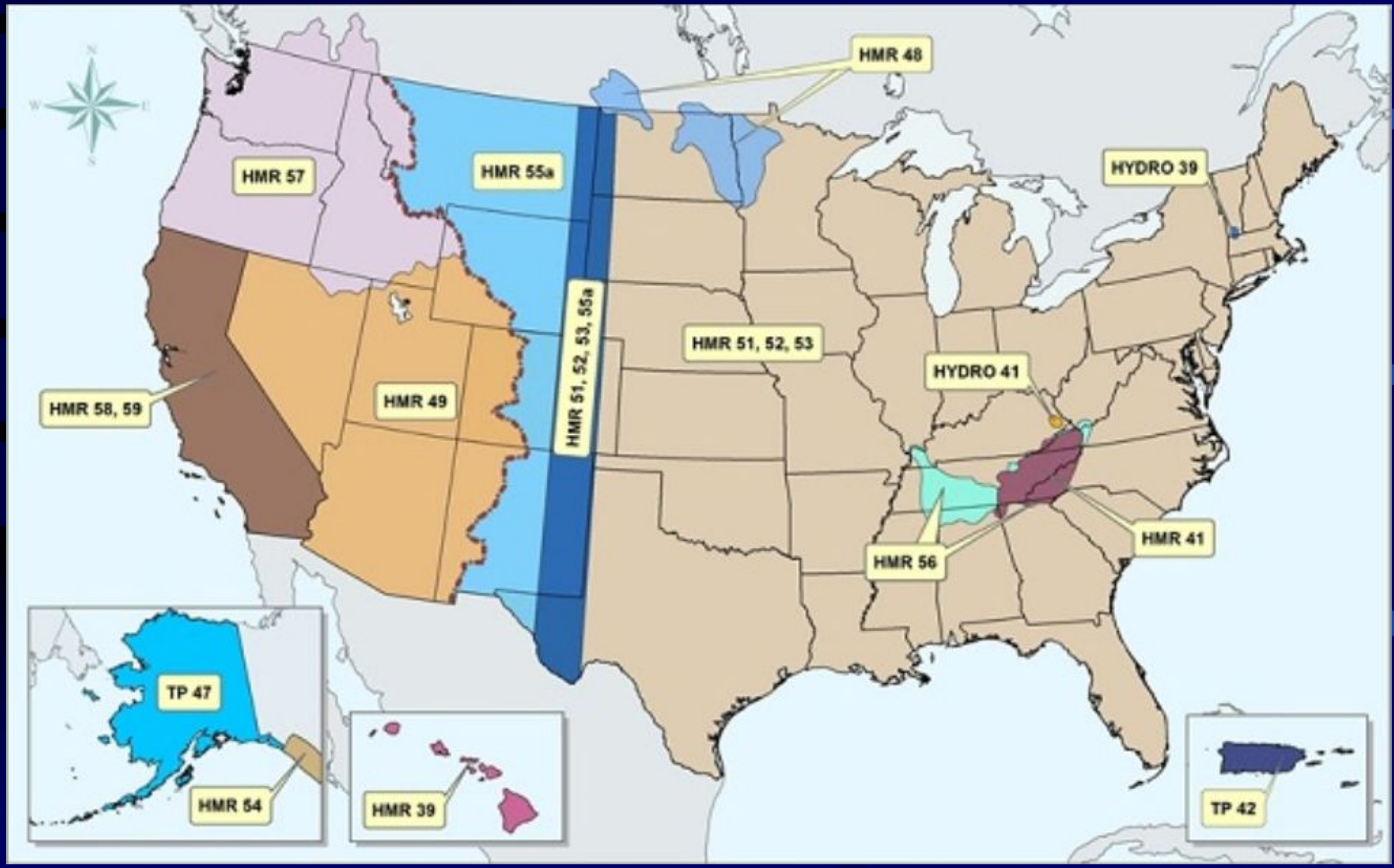
Coverage of HMRs



How Do Site-Specific, Statewide, Regional PMP Studies Provide Improved PMP Values?

- More storms considered
- New technologies used
- Problems/Unknowns in the HMRs corrected
- Topographic features addressed
- Updated climatologies used

Do These PMP Studies Provide Improved PMP Values?

- The accuracy of PMP estimates depends upon the quality or refinement of data and the technical knowledge and ability of the analyst.
- If any of these factors are improved, the PMP will become more reliably estimated.

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Method for Computing PMP Values

- **O**bserved extreme rainfall events are used
  - Storm based approach
- **I**dentify extreme storms in Virginia and regions that are considered transpositionable
  - **I**dentify recent extreme storms since publication of the appropriate HMRs
  - **R**eview older rainfall data records
- **I**dentify extreme storm types
  - **Local storms (thunderstorms/MCC)**
  - **General storms (frontal systems)**
  - **Hurricanes/Tropical Systems**

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Method for Computing PMP Values

- Identify unique topography
  - Precipitation enhancement/decrease
    - -orographics
  - Effects on rainfall center location
    - -physically possible storm centering/orientation
- Review HMR/Hydro/Tech Memo procedures
  - Identify inconsistent assumptions
  - Apply new technologies and data
  - Apply new/updated methods

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Probable Maximum Precipitation Study for Virginia

Project Overview

- Comprehensive evaluations of extreme rainfall storm events
  - Extreme rainfall storm identification
  - Storm analyses
  - Storm maximization
  - Storm transpositioning
- Synoptic extreme rainfall systems (General Storms)/Tropical Storms
- Thunderstorms and Mesoscale Convective System (MCS)

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Probable Maximum Precipitation Study for Virginia

Background

- **PMP values as provided in HMRs are over due for updating**
  - **Storm data base grossly out of date**
  - **Procedures used to analyze storms outdated**
  - **PMP values generally *unreasonably* conservative**
- **Provide greater confidence and more accurate/reliable values**
- **Apply updated meteorological understanding and techniques**

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Probable Maximum Precipitation Study for Virginia

Procedure

- **Update the storm database**
  - **Produce Depth-Area-Duration (DAD) analyses for all major storm events**
- **Use updated dew point analyses to maximize storms**
  - **Storm representative & maximum dew points**
- **Use of state-of-the-science procedures and tools**
  - **GIS & Orographic Transposition Factor**
- **Provide PMP values for all location within Virginia**
  - **All locations considered in this study**
  - **All durations and area sizes as required**
- **Utilize PMP Evaluation Tool to produce PMP on a gridded basis (~2.5sqmi grid)**

Probable Maximum Precipitation Study for Virginia

Procedure

- Follow the basic procedures used in previous AWA studies
  - Nebraska, Arizona, Ohio, Wyoming statewide PMP studies
  - Numerous individual basin PMP studies
  - Michigan and Wisconsin, Virginia regional PMP
- Incorporated storms through 2014
- Used GIS to provide efficient and effective distributions of PMP values across the Virginia
- PMP to provide continuity of PMP values across the region in space and time while taking into considerations differences in topography and climate

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Issues to Consider

- **Storm Search Processes**
  - **East/West of Appalachians**
  - **Seasonality**
  - **PMP storm type-General-Tropical-Local**
- **Hurricane landfalls**
- **Orographic vs Non-orographic**
- **Transposition limits**
  - **Similarity of meteorology, topography**
  - **Different parameters depending on**
    - **Storm type**
    - **Moisture source**
    - **Intervening barriers**
    - **Proximity to the coast**

Issues to Consider

- **Temporal distribution of PMP and Virginia precip**
  - **Not constrained to specific durations-can go longer than 72hrs if data supports**
  - **Use data to develop/confirm**
- **Gridded PMP depths provided, work with Virginia/users for application**

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Probable Maximum Precipitation Virginia

Transposition Limits

• Homogeneous meteorology and topography from original location to area of interest (HMR 51 Section 2.4)

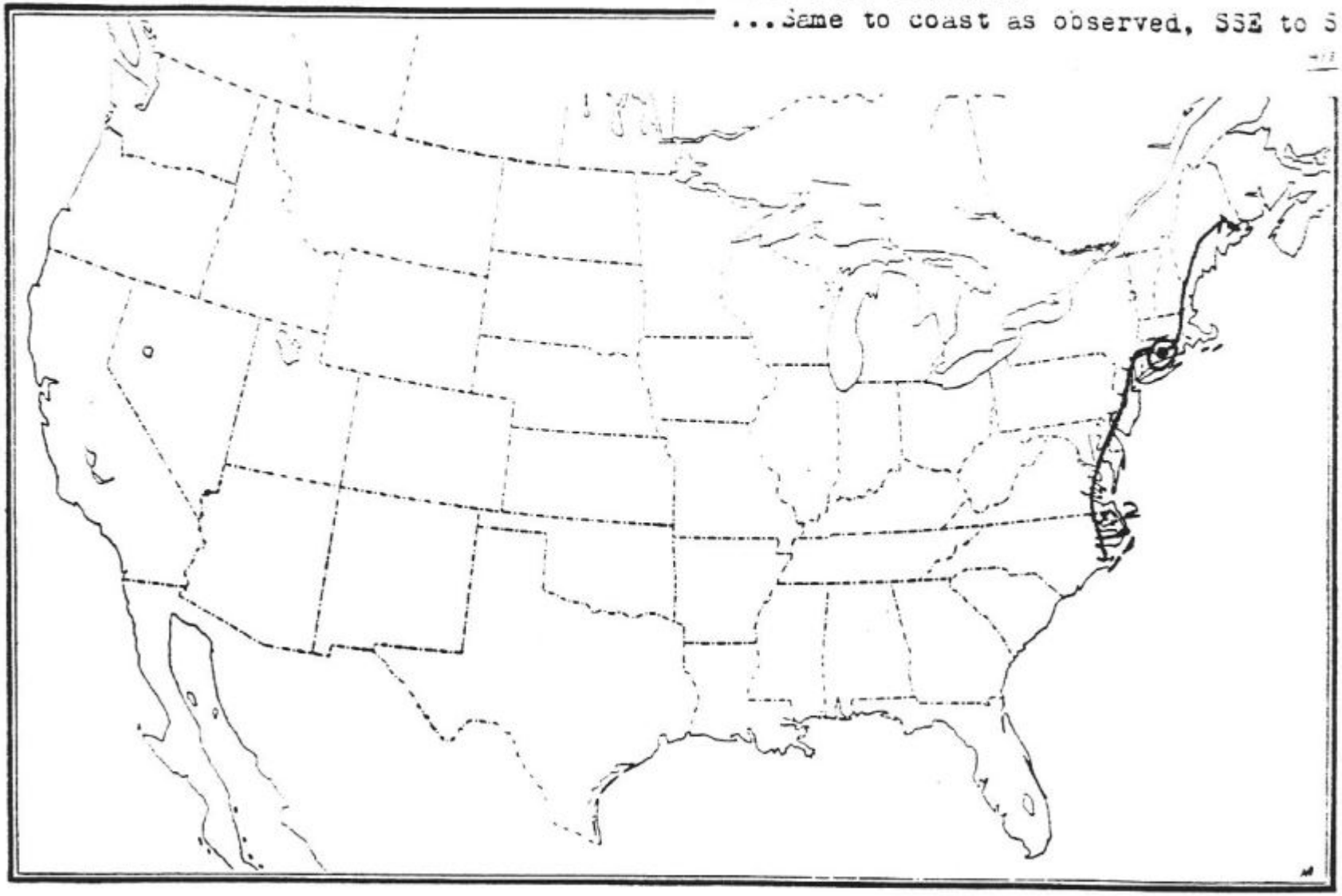
- Transposition not permitted across Appalachians
- Tropical storm rainfall not transposed w/out additional adjustment
- Region of large elevation difference, transposition restricted to narrow elevation band (usually 1000 feet of the elevation of the storm center)
- Eastward limits of Central US storms was first upslopes of Appalachians
- Southern limits to transposition not define since other storms produced higher values

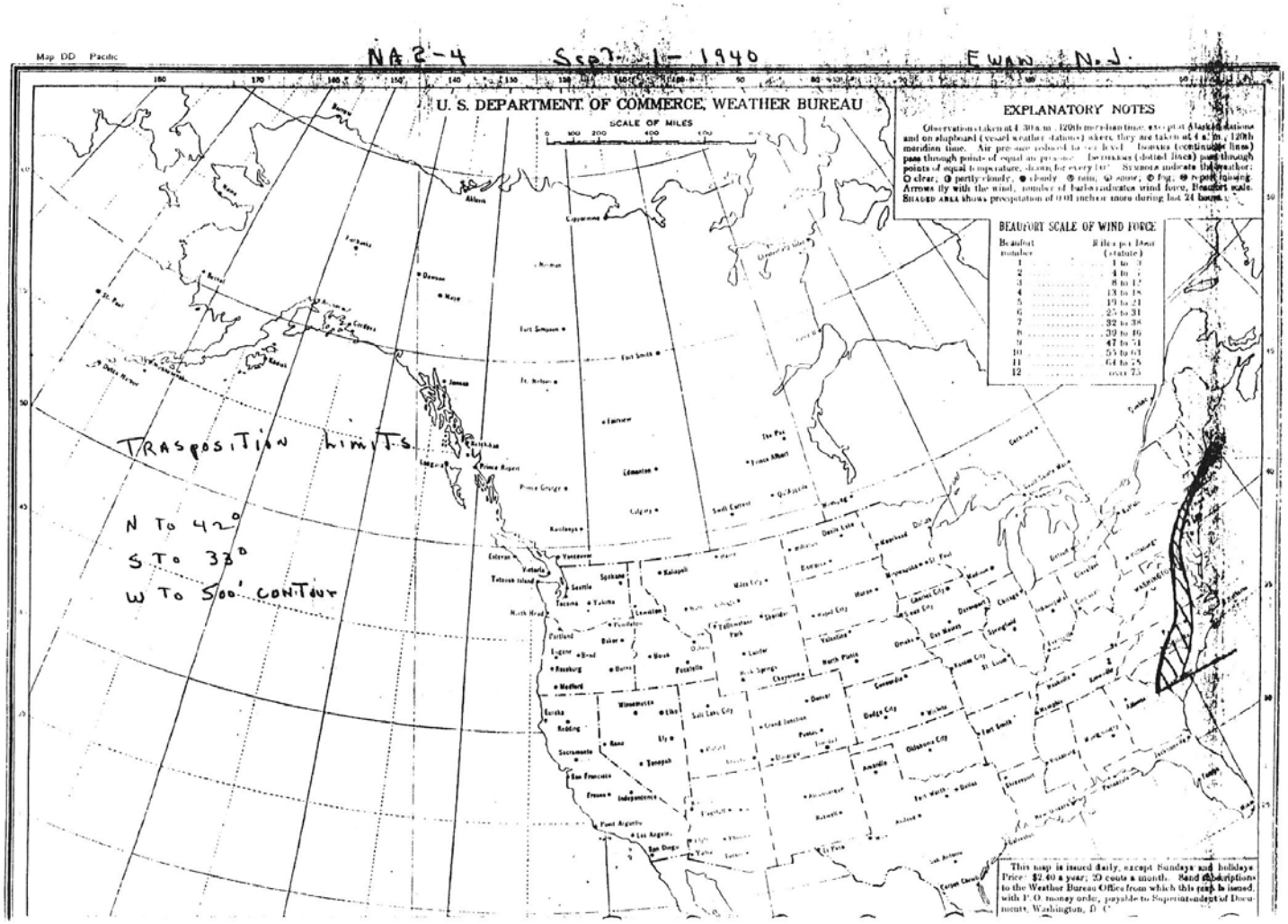
Probable Maximum Precipitation Virginia

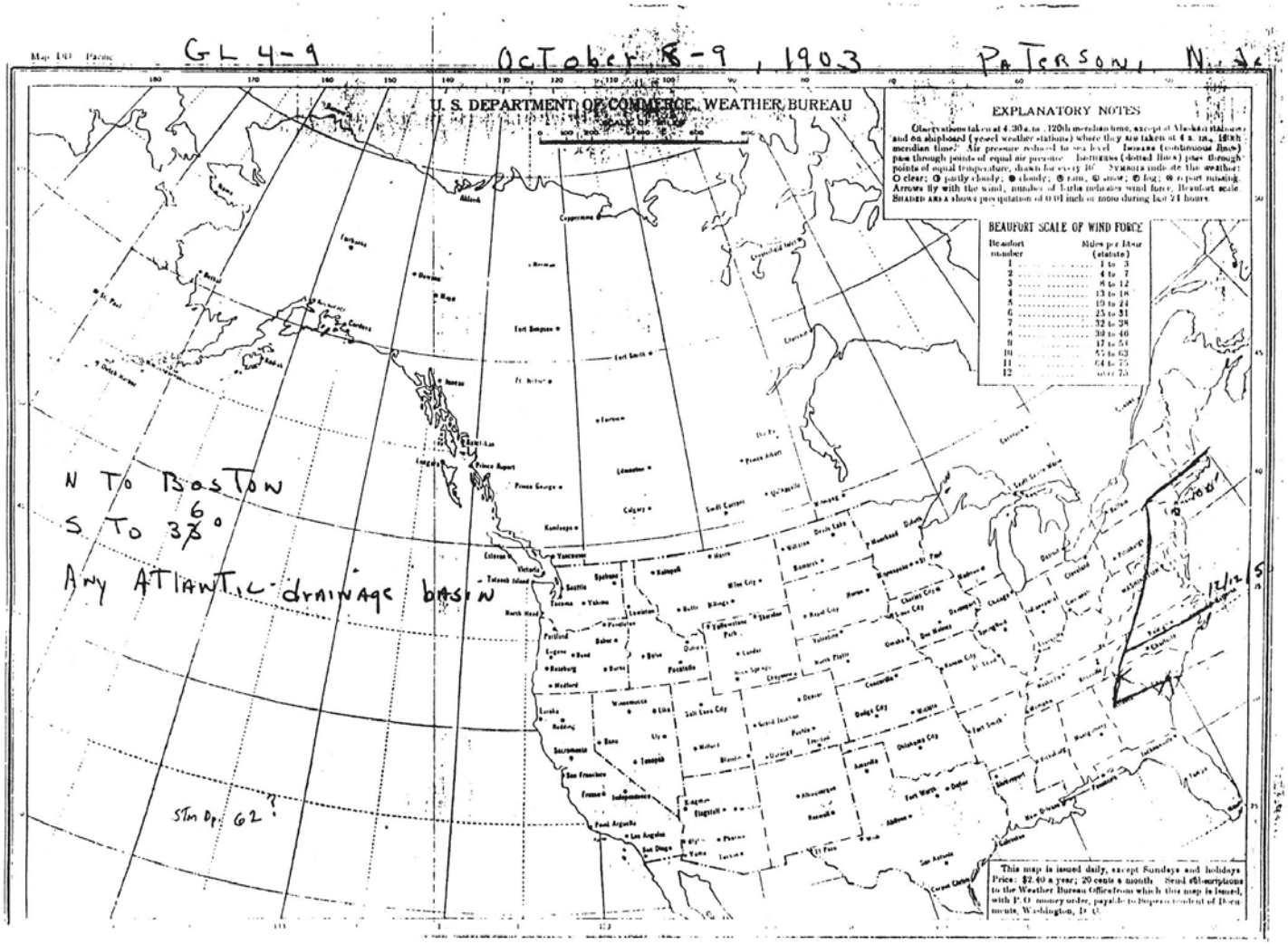
Transposition Limits

- **Subjective judgment is used**
- **Most choices obvious, it's the "gray" area that matter**
- **Let the data talk to us**
  - **OTF very helpful**

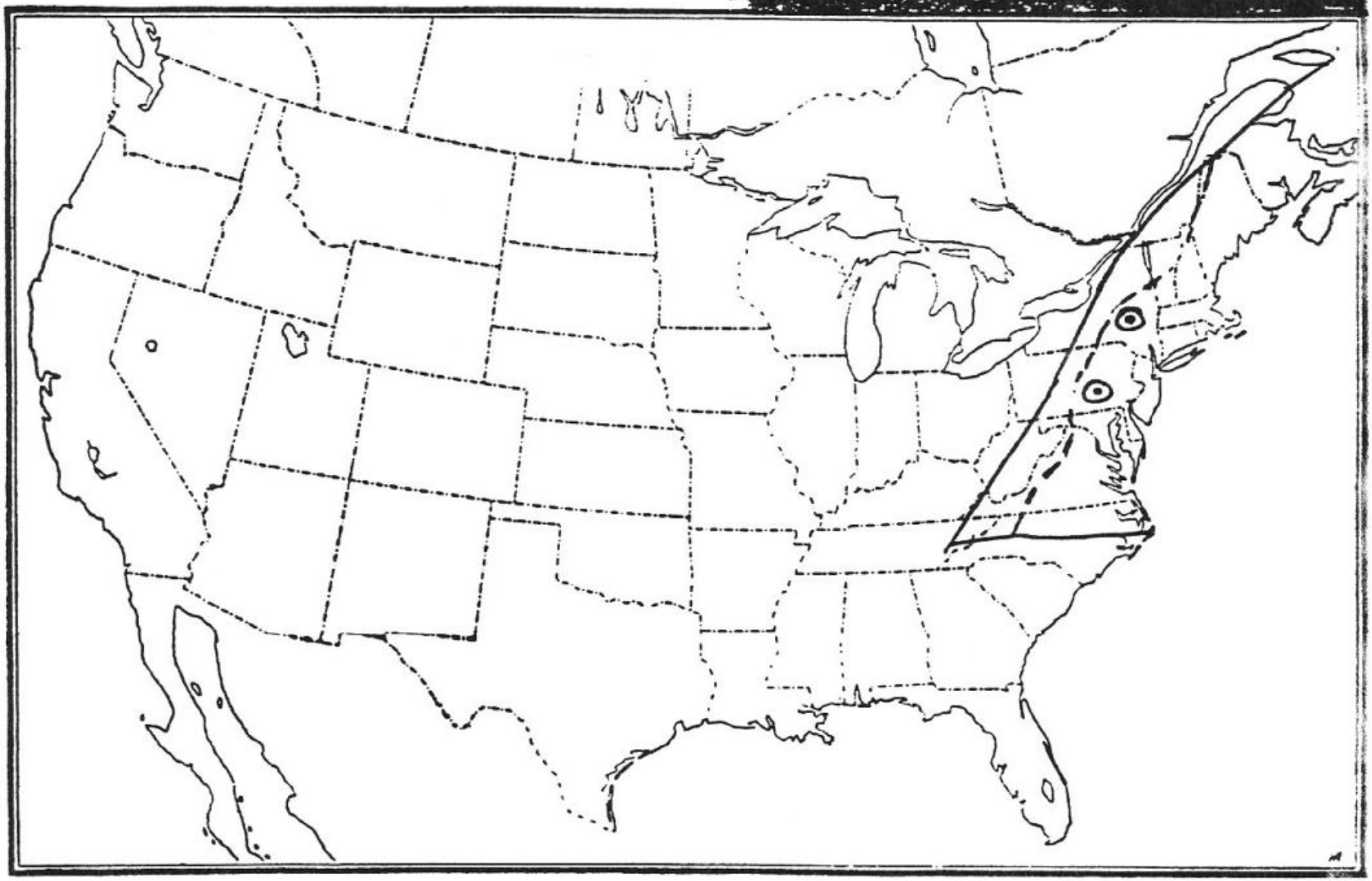
NA 2-2..Sept. 19-21, 1936..Buck, Conn.
12-hr. rTd 68(19th)..100 SW..to 75, 41
North to: border
South to: matteras
...Same to coast as observed, SSE to S

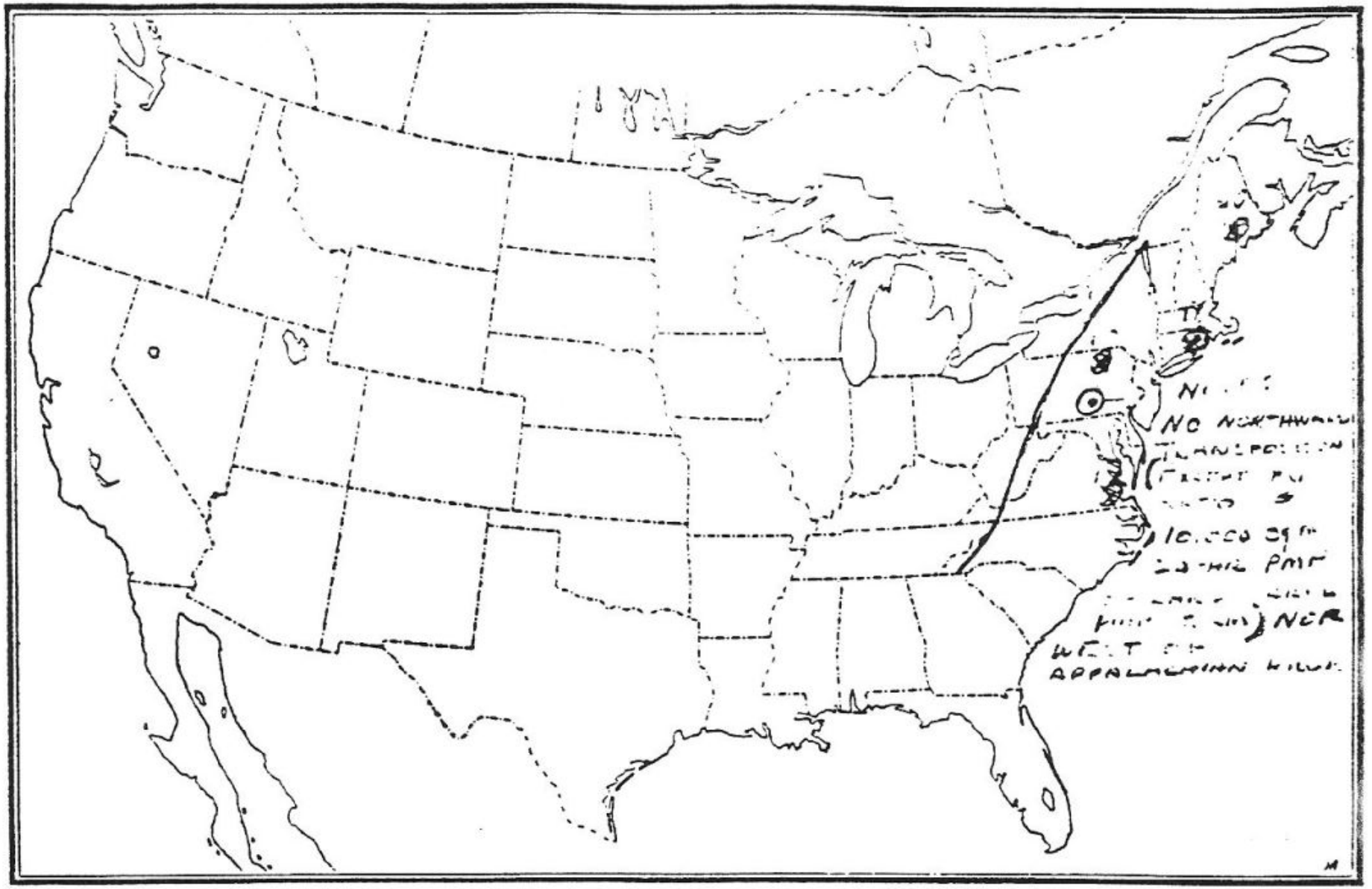



Map DD Pacific
NA 2-4 Sept. 1 1940 EWAN, N.J.
U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
SCALE OF MILES
EXPLANATORY NOTES
BEAUFORT SCALE OF WIND FORCE
TRASPOSITION LIMITS
N TO 42°
S TO 33°
W TO 500' CONTOUR
This map is issued daily, except Sundays and holidays
1940


GL 4-9
October 8-9, 1903
Paterson, N. J.
U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
EXPLANATORY NOTES
BEAUFORT SCALE OF WIND FORCE
Beaufort number
Miles per Hour (statute)
N To Boston
S To 38°
Any Atlantic drainage basin
Stm Dp 62°
This map is issued daily, except Sundays and holidays. Price: $2.40 a year; 20 cents a month. Send subscriptions to the Weather Bureau Office from which this map is issued, with P. O. money order, payable to Disbursing Clerk of Department, Washington, D. C.

NA 1-24a Aug 20-24, A33
Peekamoose NY
NA 1-246 York Pa




NO NORTHWARD
10,000 sq mi
WEST OF

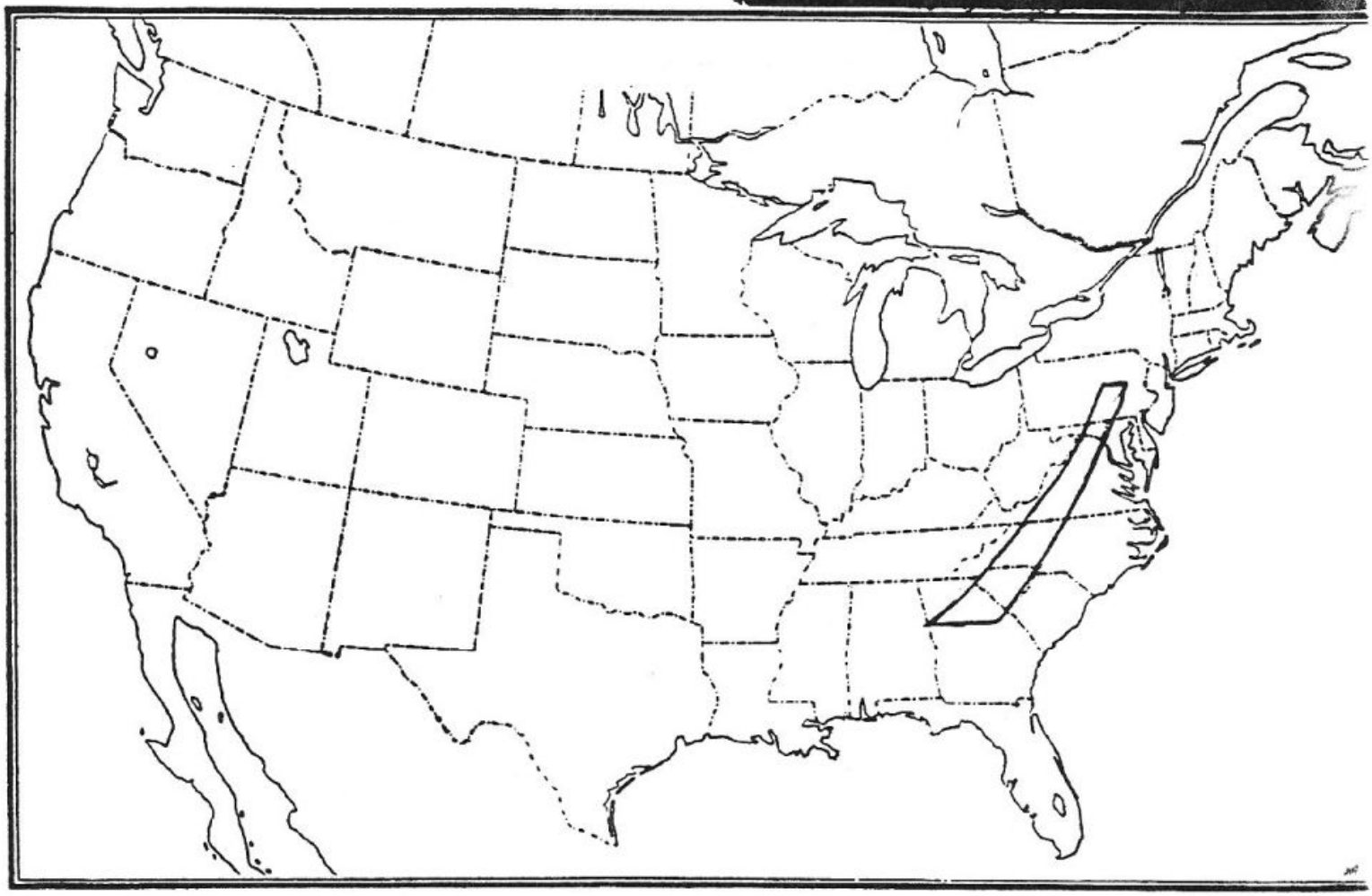
NA 2-23 Aug 19-20 1961 nr Tyro,
12 hr rTd = 76°F 1505 Max Td = 77°F
105°F Camille Elev 300 37°49' 79°00'

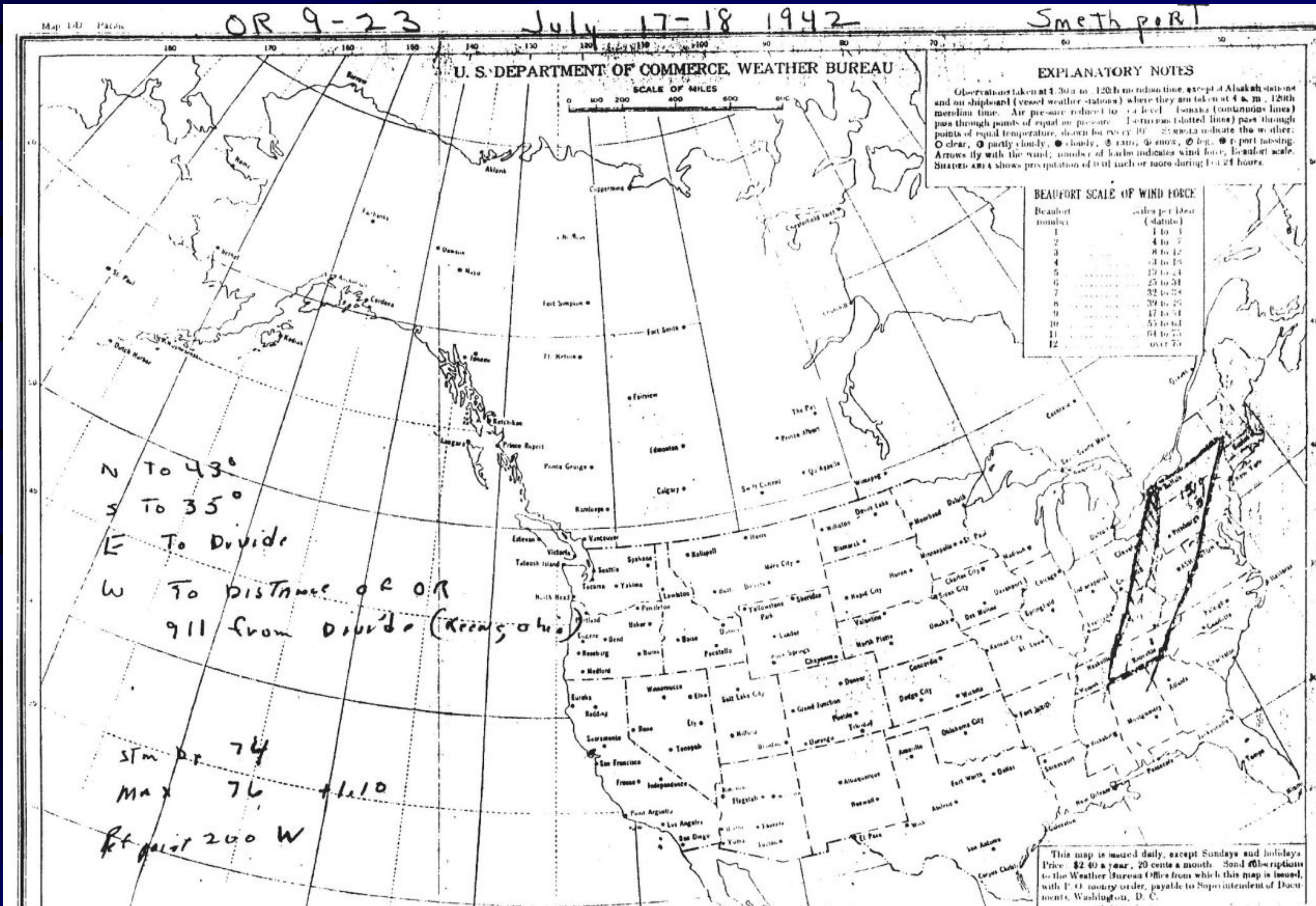
Tyro-VA Aug 1969.jpg
Type: JPG File
Size: 411 KB
Dimension: 1700 x 2800 pixels

[redacted]

[redacted]

N = 41°00'
S = 33°30'
W = 100°W
E = 300'




OR 9-23
July 17-18 1942
Smethport
U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
SCALE OF MILES
EXPLANATORY NOTES
BEAUFORT SCALE OF WIND FORCE
N To 43°
S To 35°
E To Divide
W To Distance of OR
Stm Dp 74
Max 76
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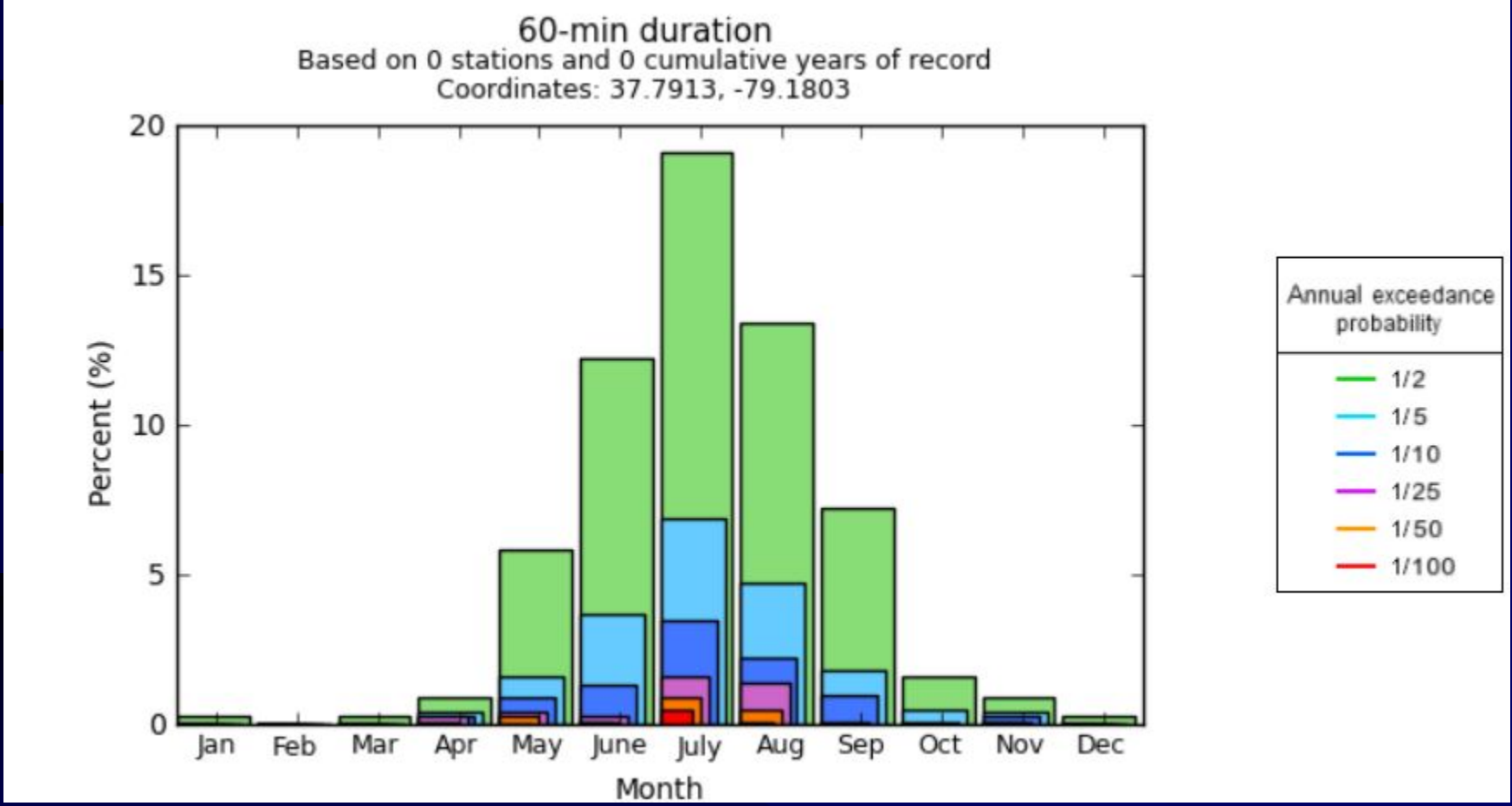
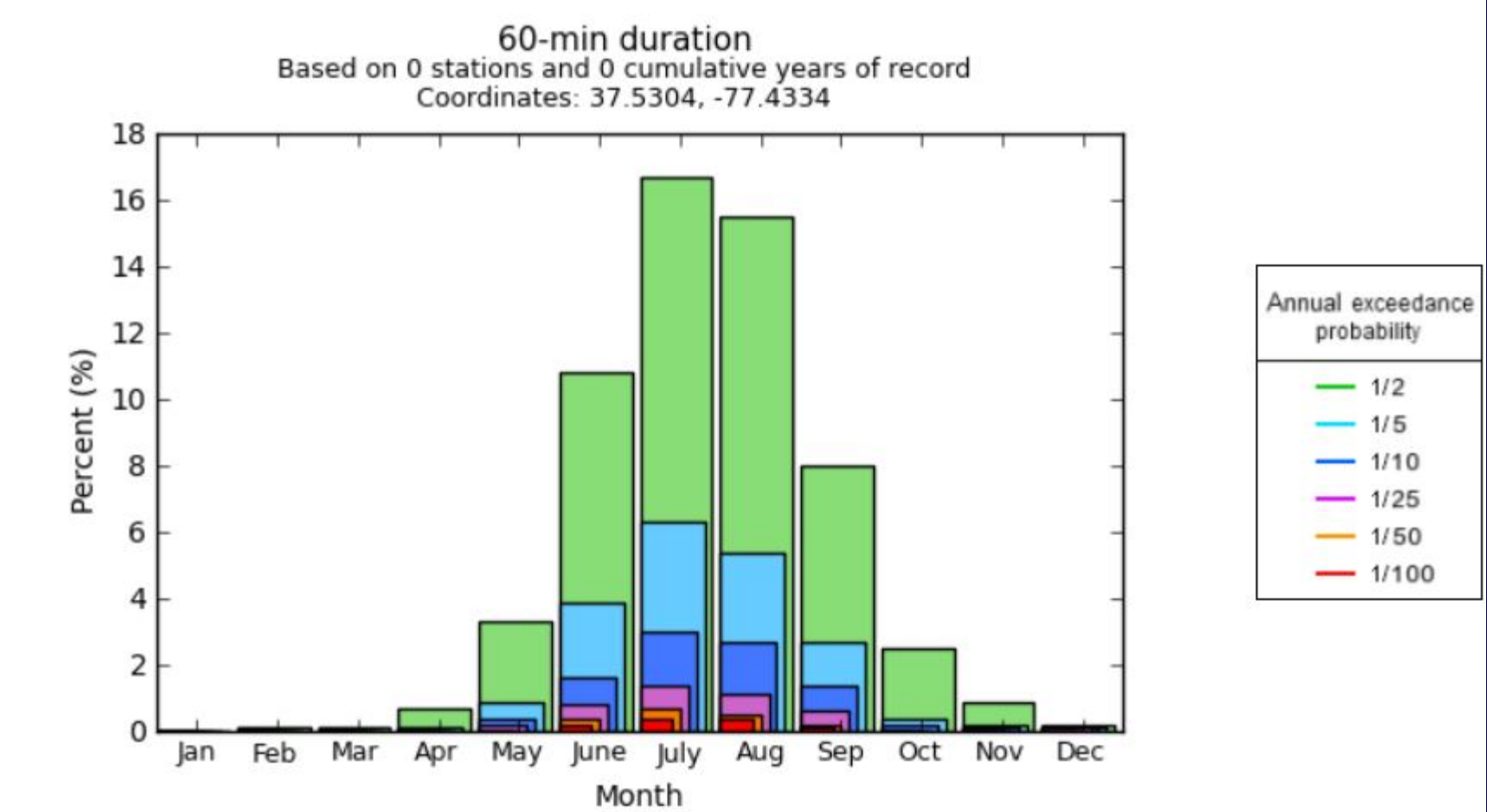
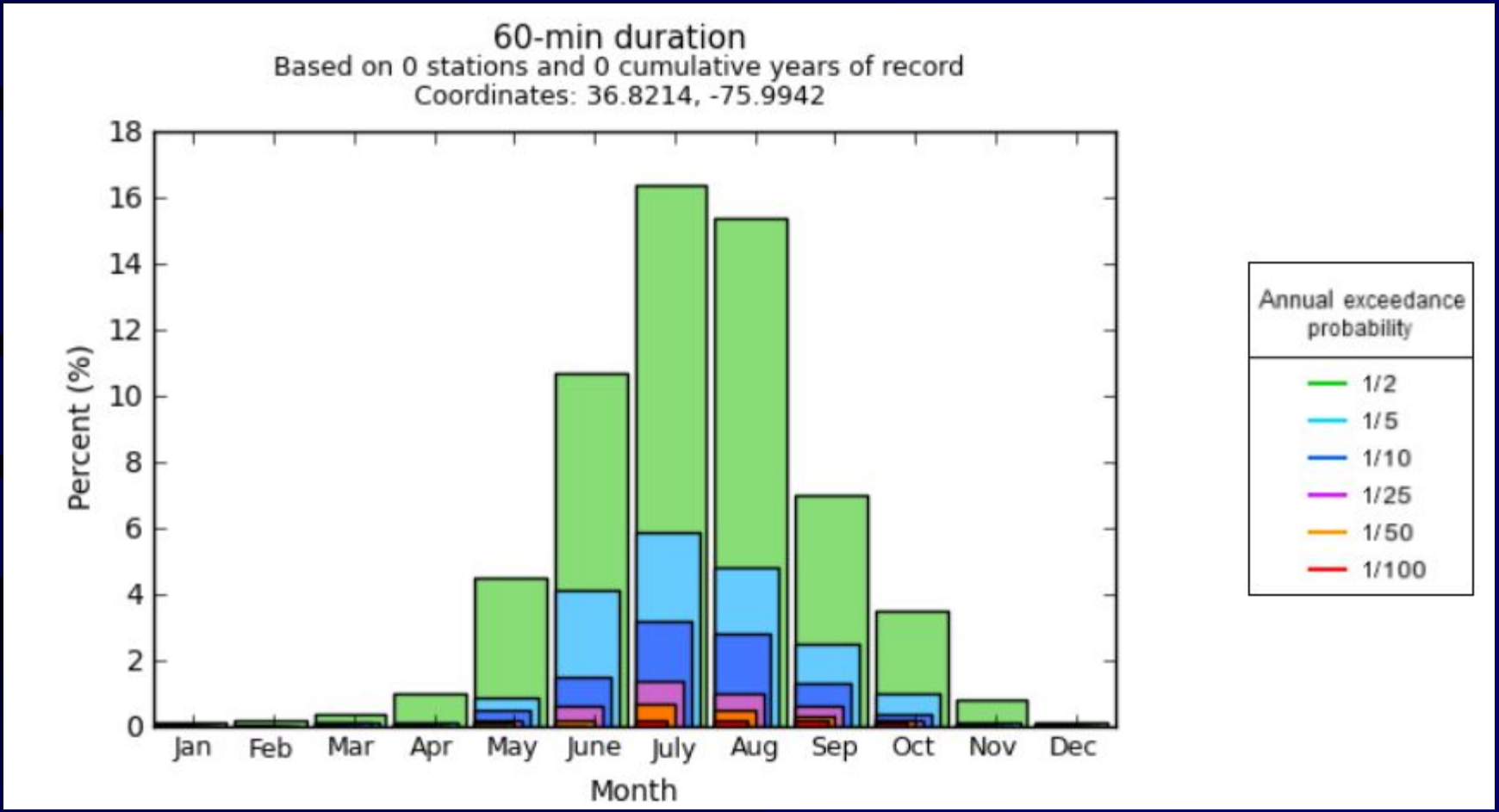
Seasonality Examples -60 minutes Mountains



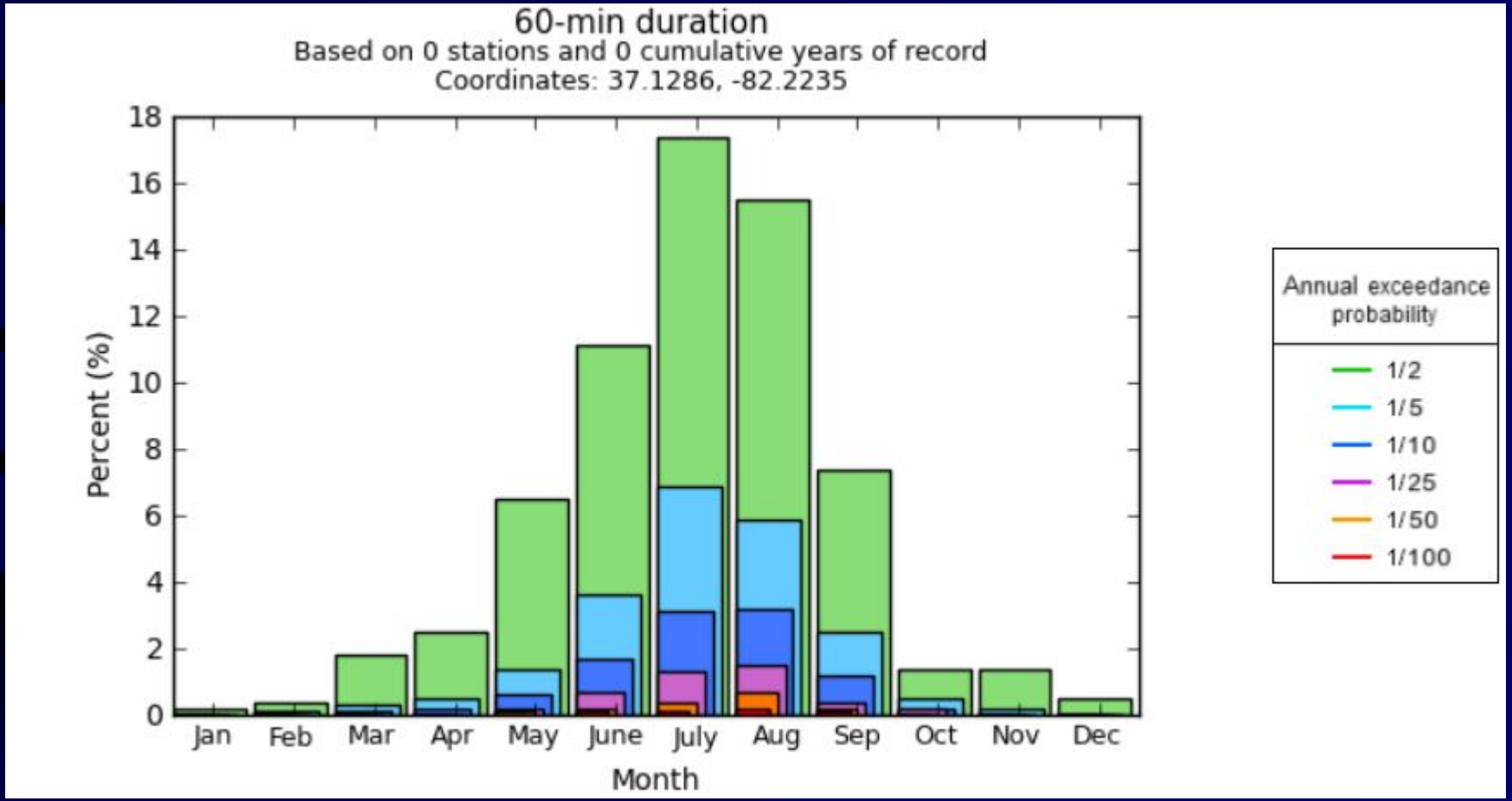
Seasonality Examples -60 minutes Richmond



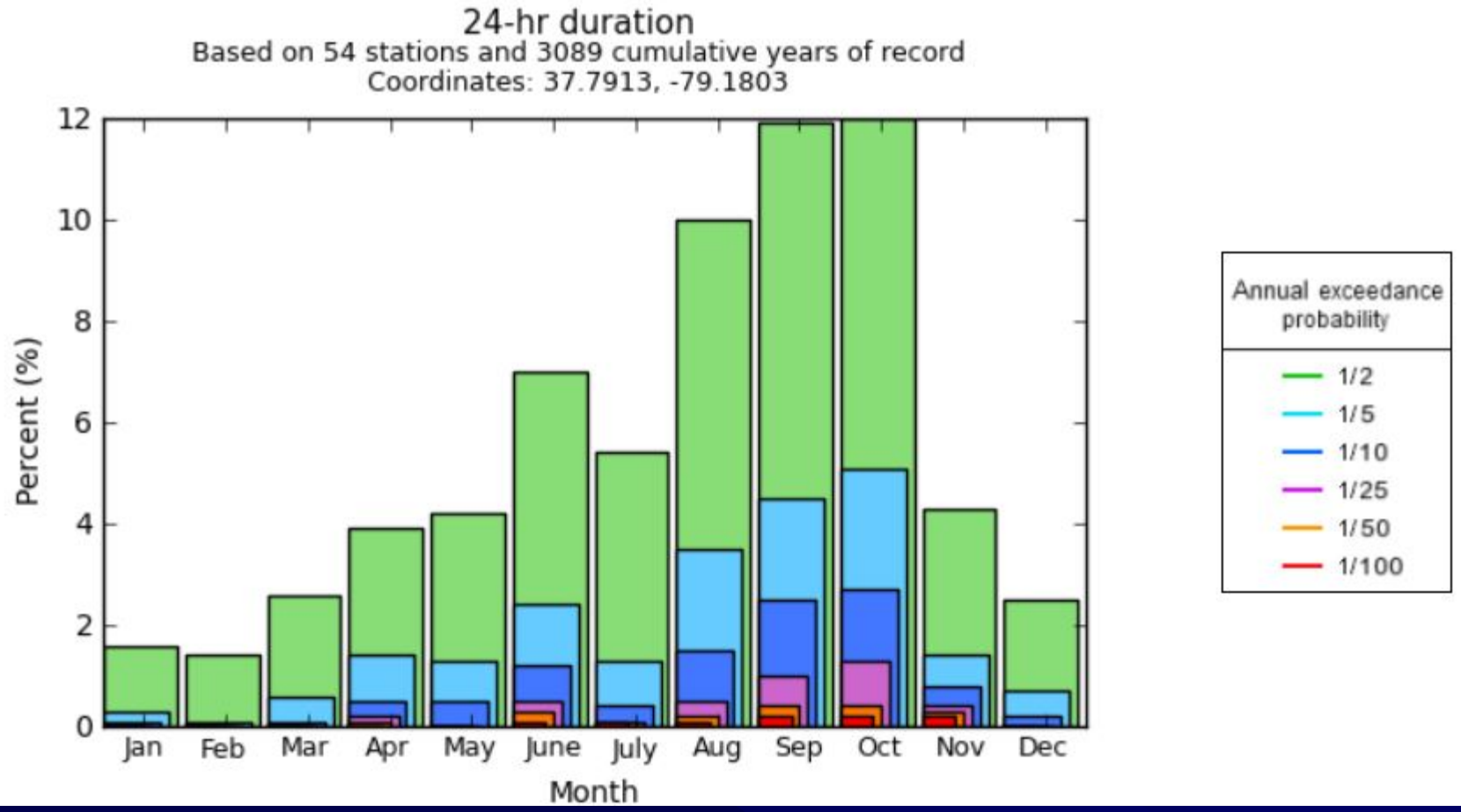
Seasonality Examples -60 minutes Virginia Beach



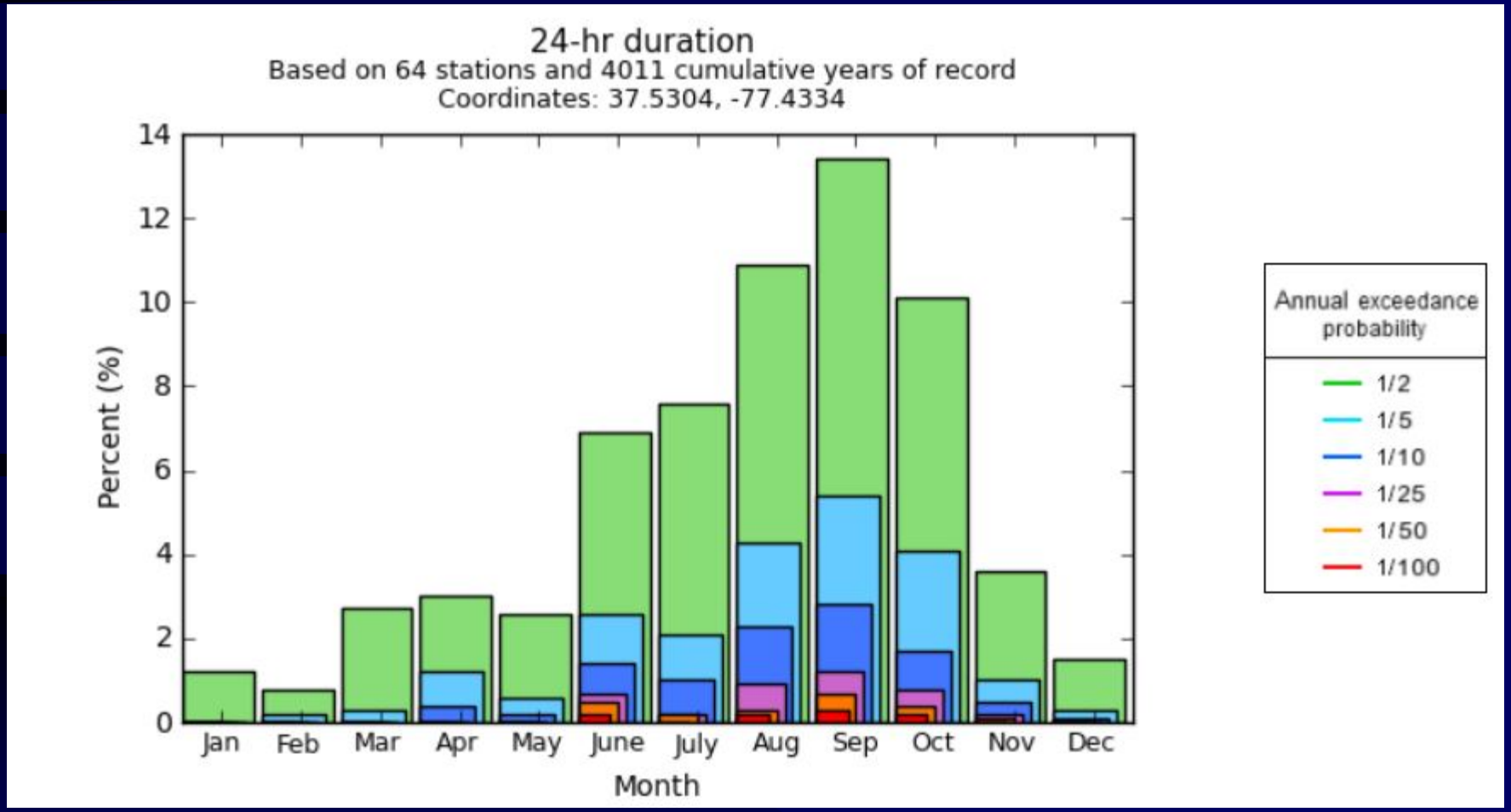
Seasonality Examples -60 minutes Far West



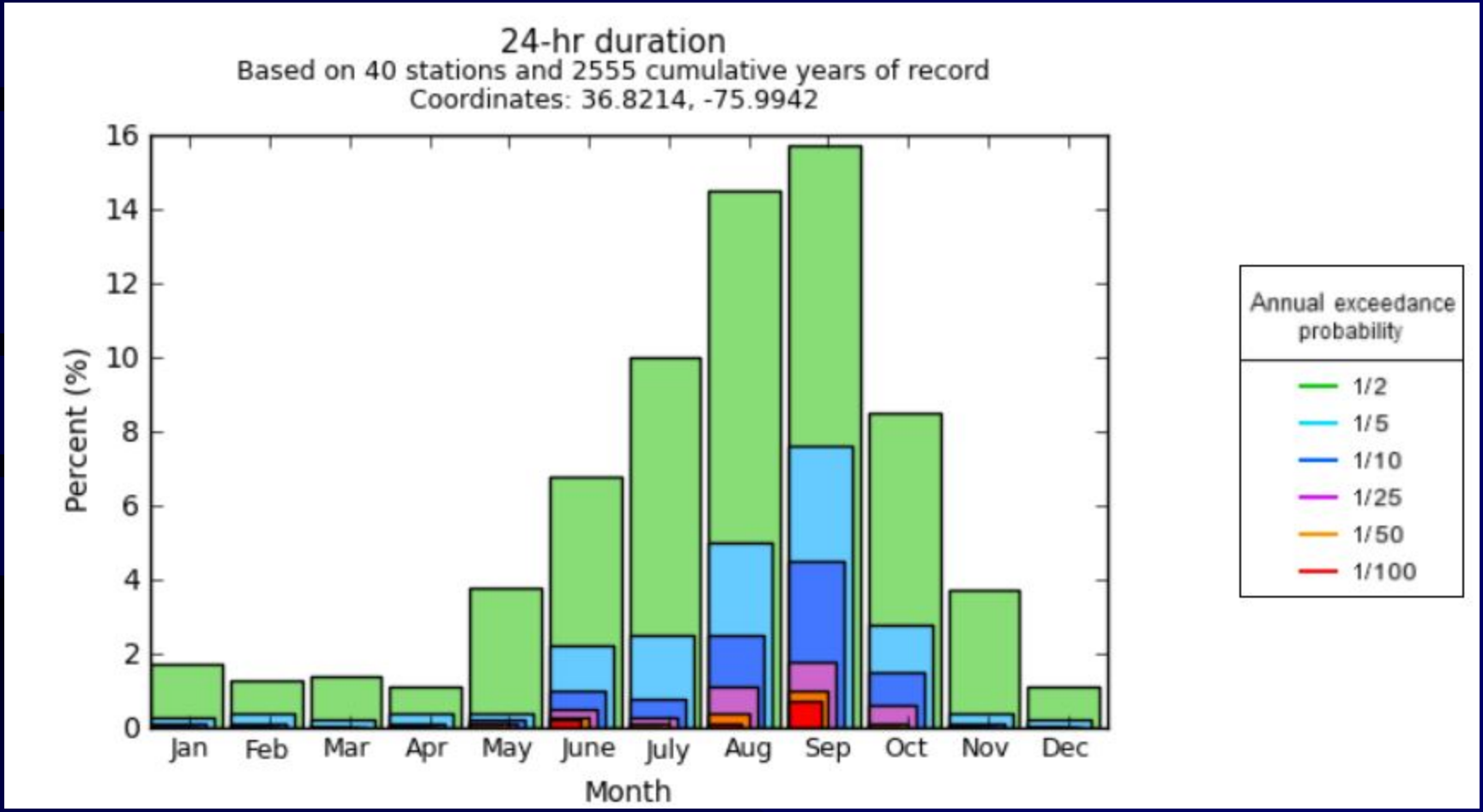
Seasonality Examples -24 hours Mountains



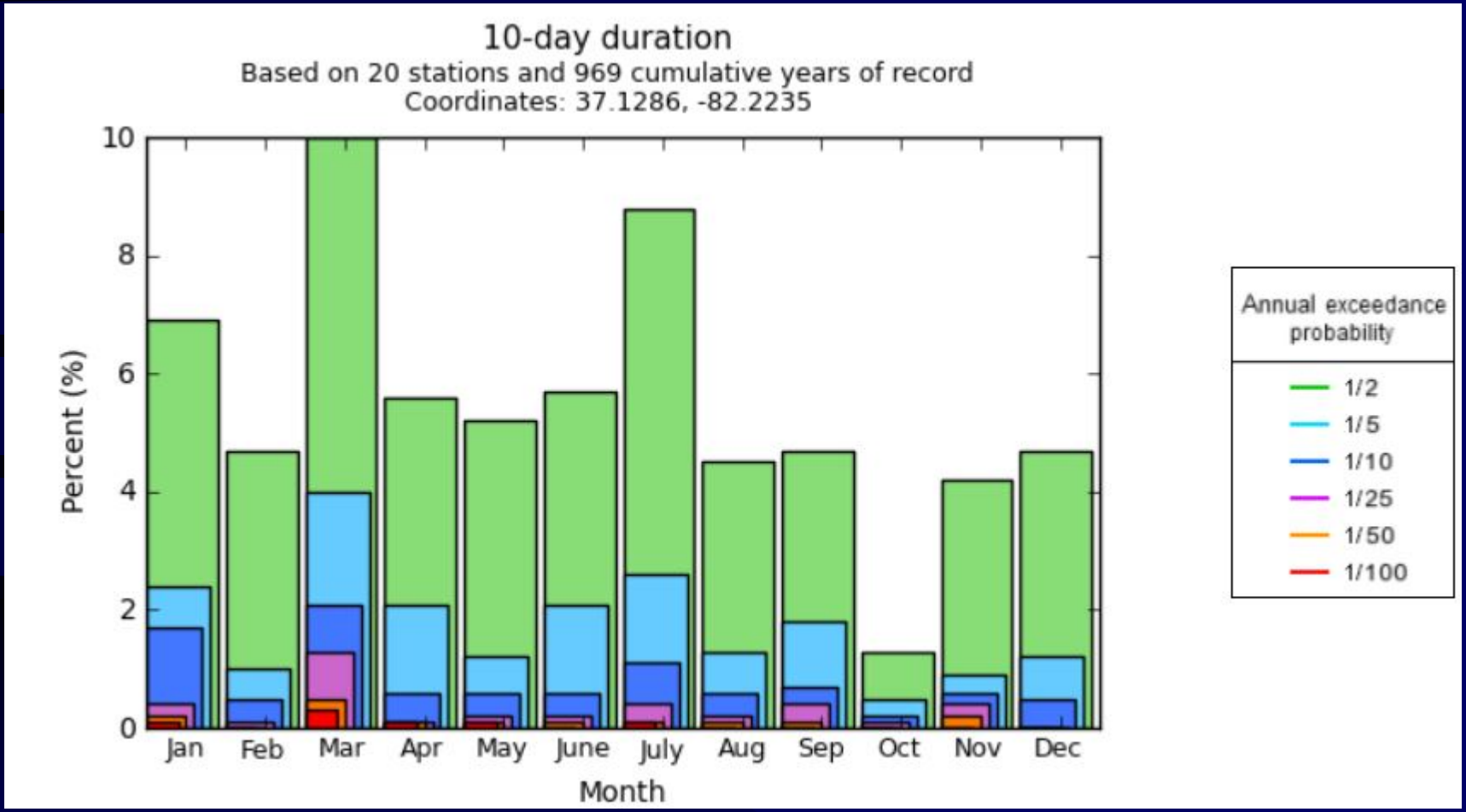
Seasonality Examples -24 hours Richmond



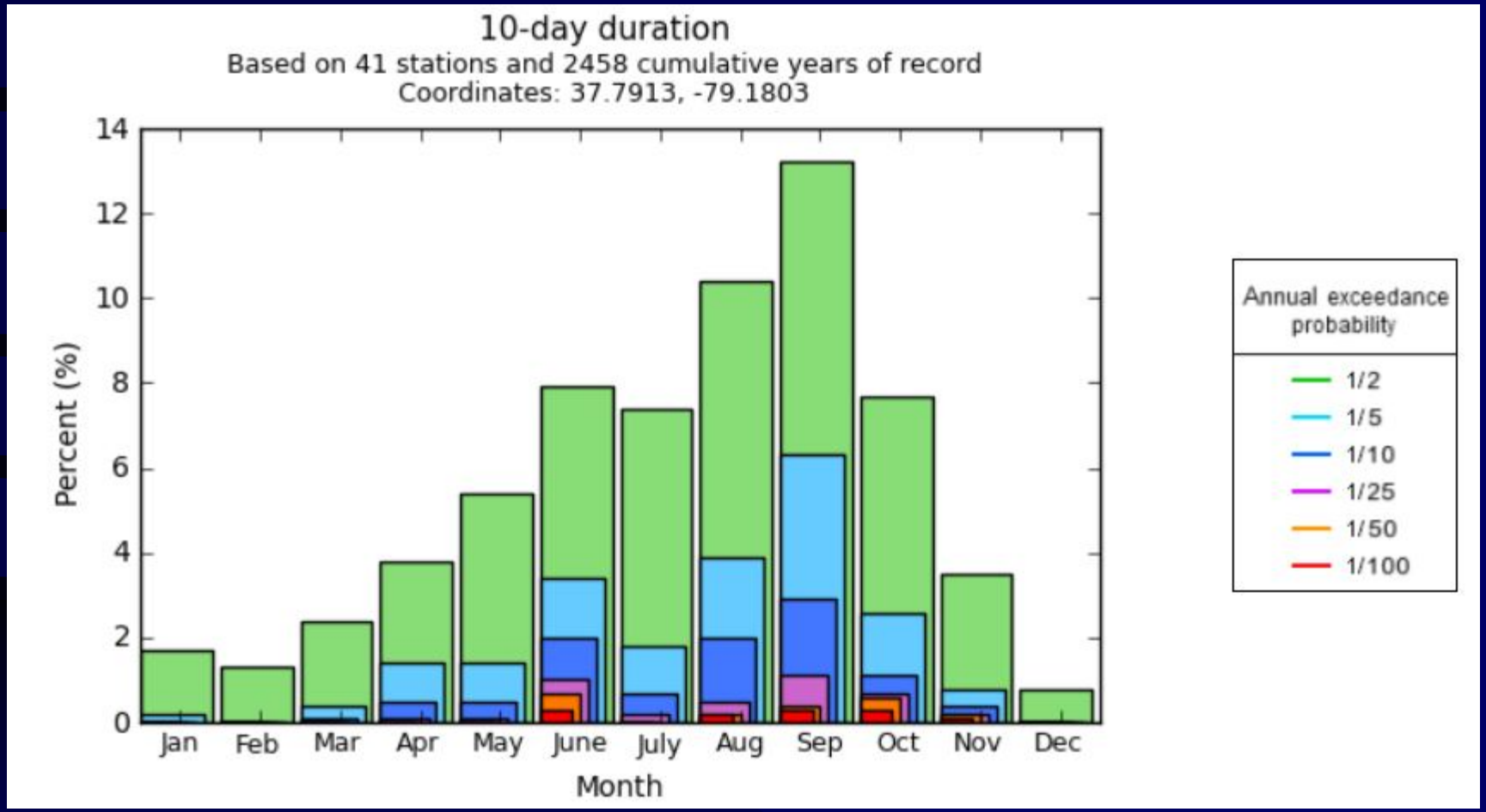
Seasonality Examples -24 hours Virginia Beach



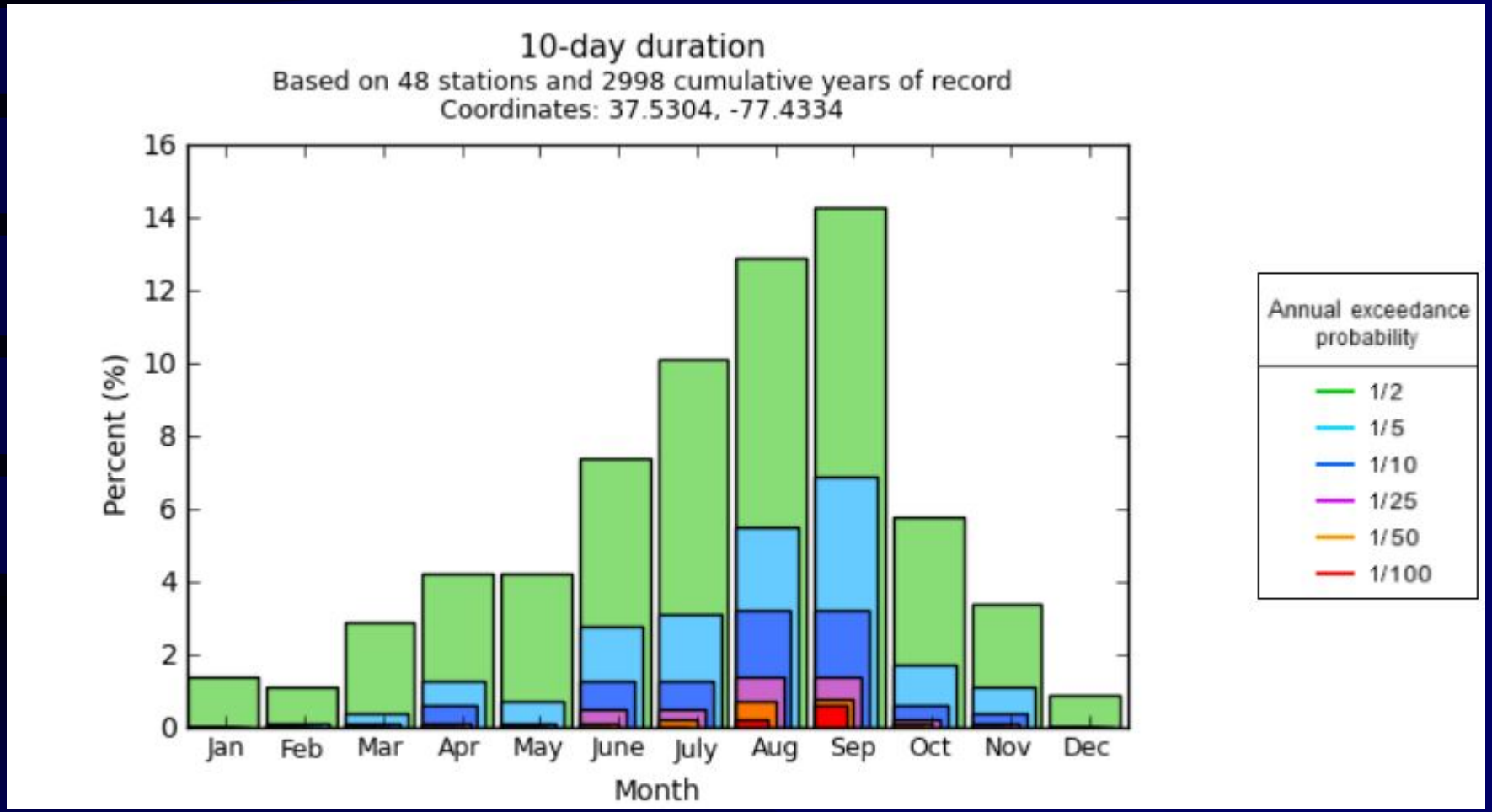
Seasonality Examples -24 hours Far West



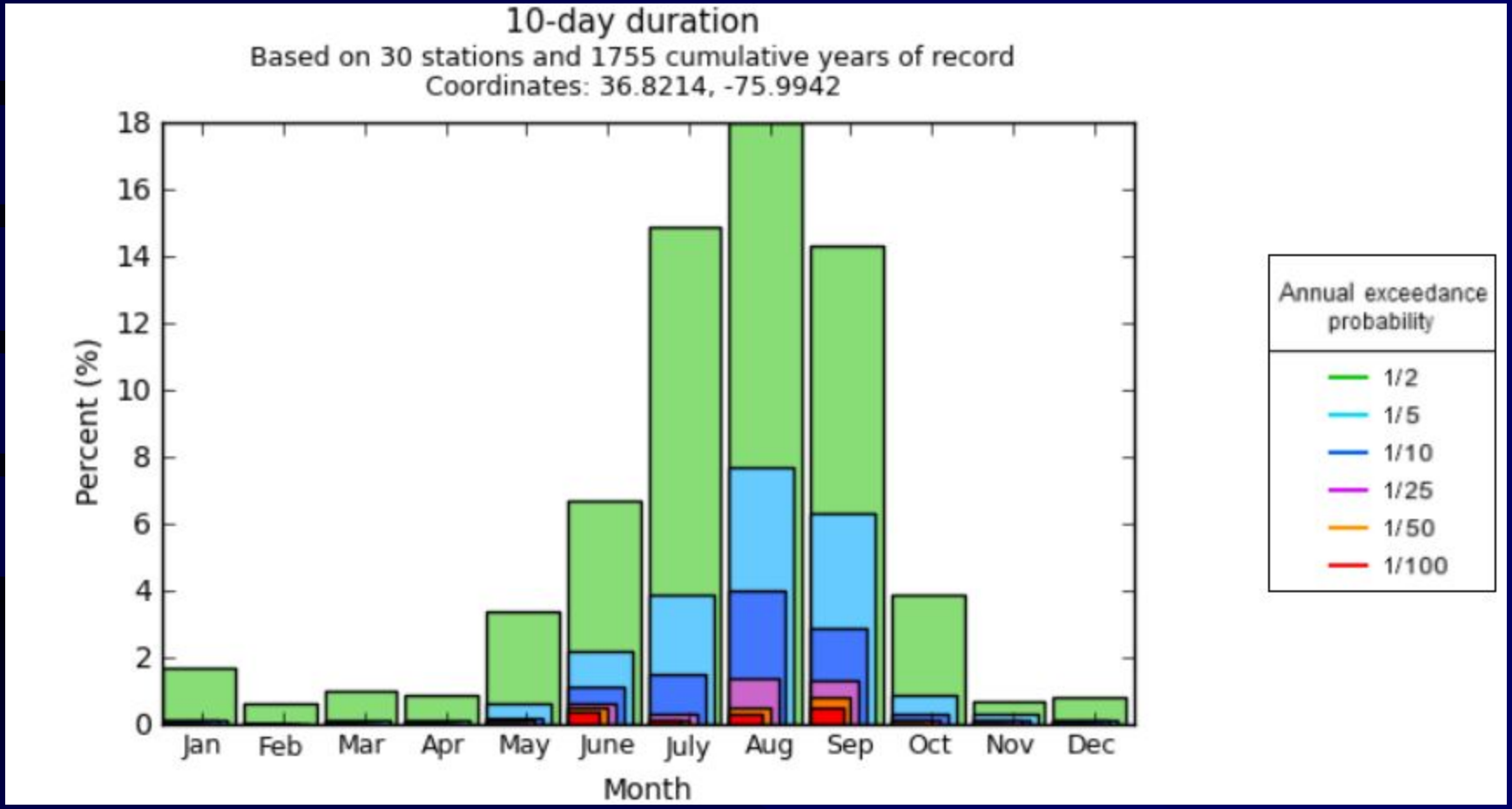
Seasonality Examples -10 Days Mountains



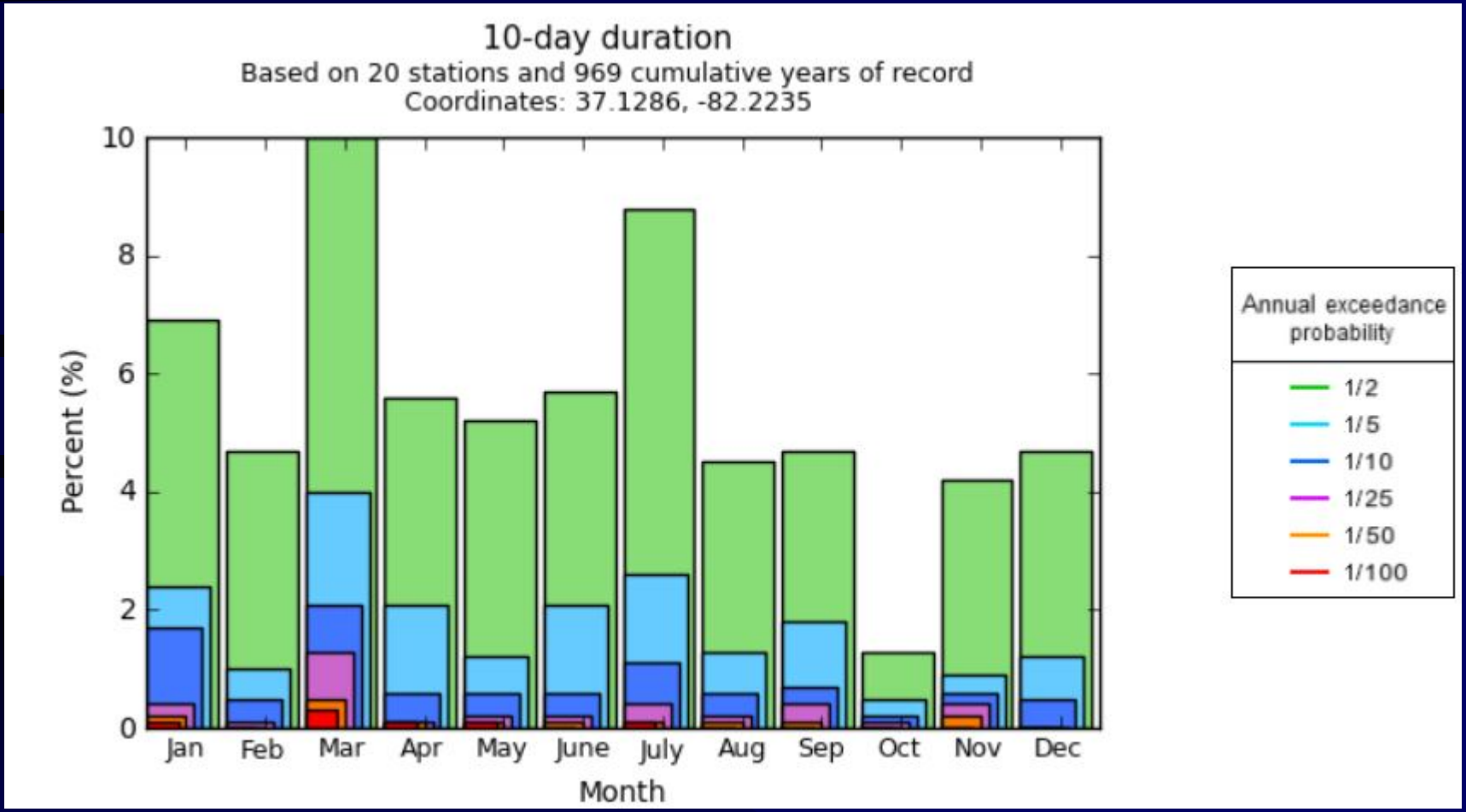
Seasonality Examples -10 Days Richmond



Seasonality Examples -10 Days Virginia Beach



Seasonality Examples -10 Days Far West



Probable Maximum Precipitation Study for Virginia

Task 1

Review of previous studies for applicability

1. AWA PMP studies (Virginia, Ohio, Tarrant, Quad Cities, etc)
2. HMRs 33, 51, 52, 53, etc
3. Virginia HMRs 41, 45, 47, 56
4. USACE and USGS storm and flood analyses

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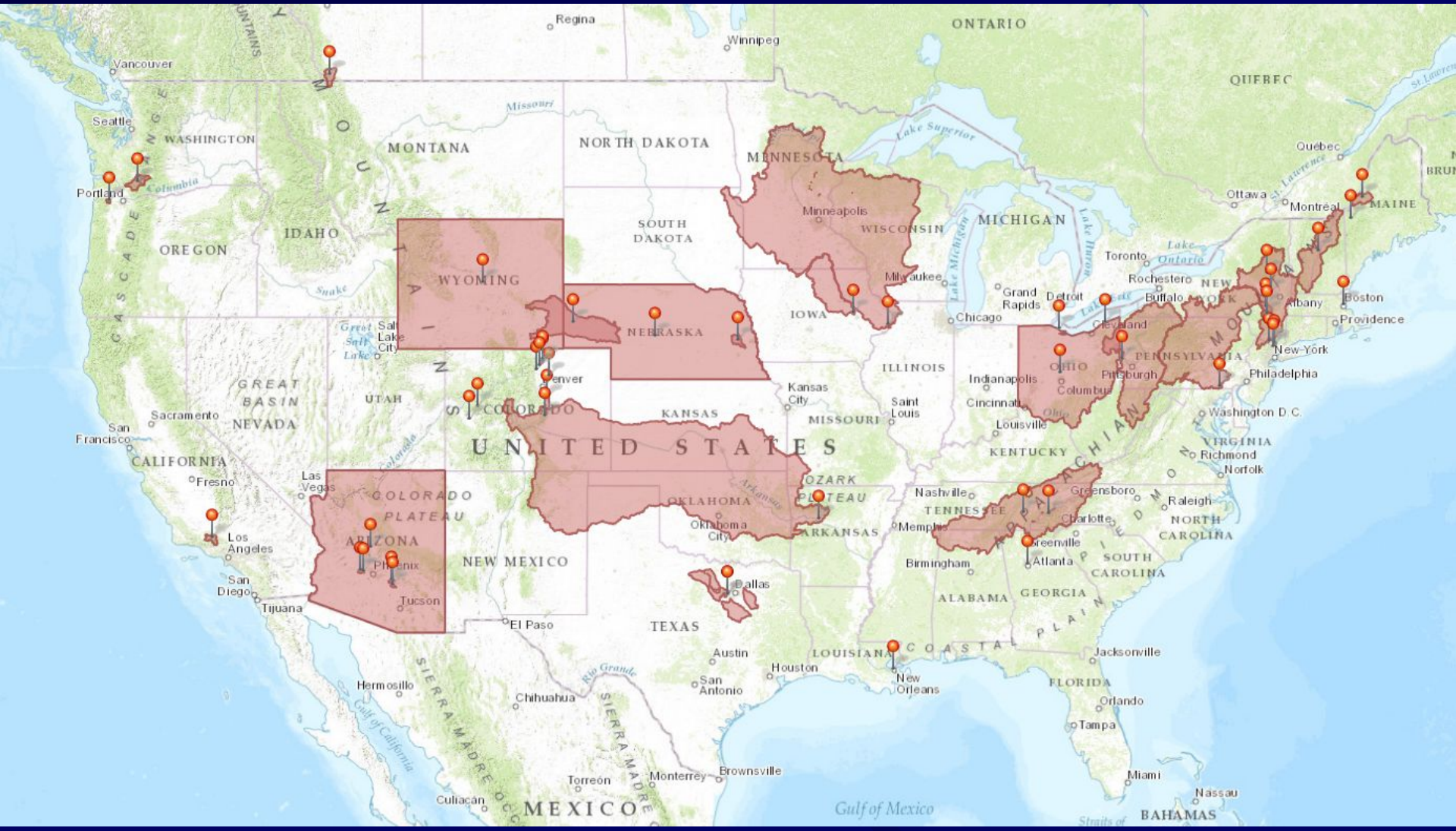
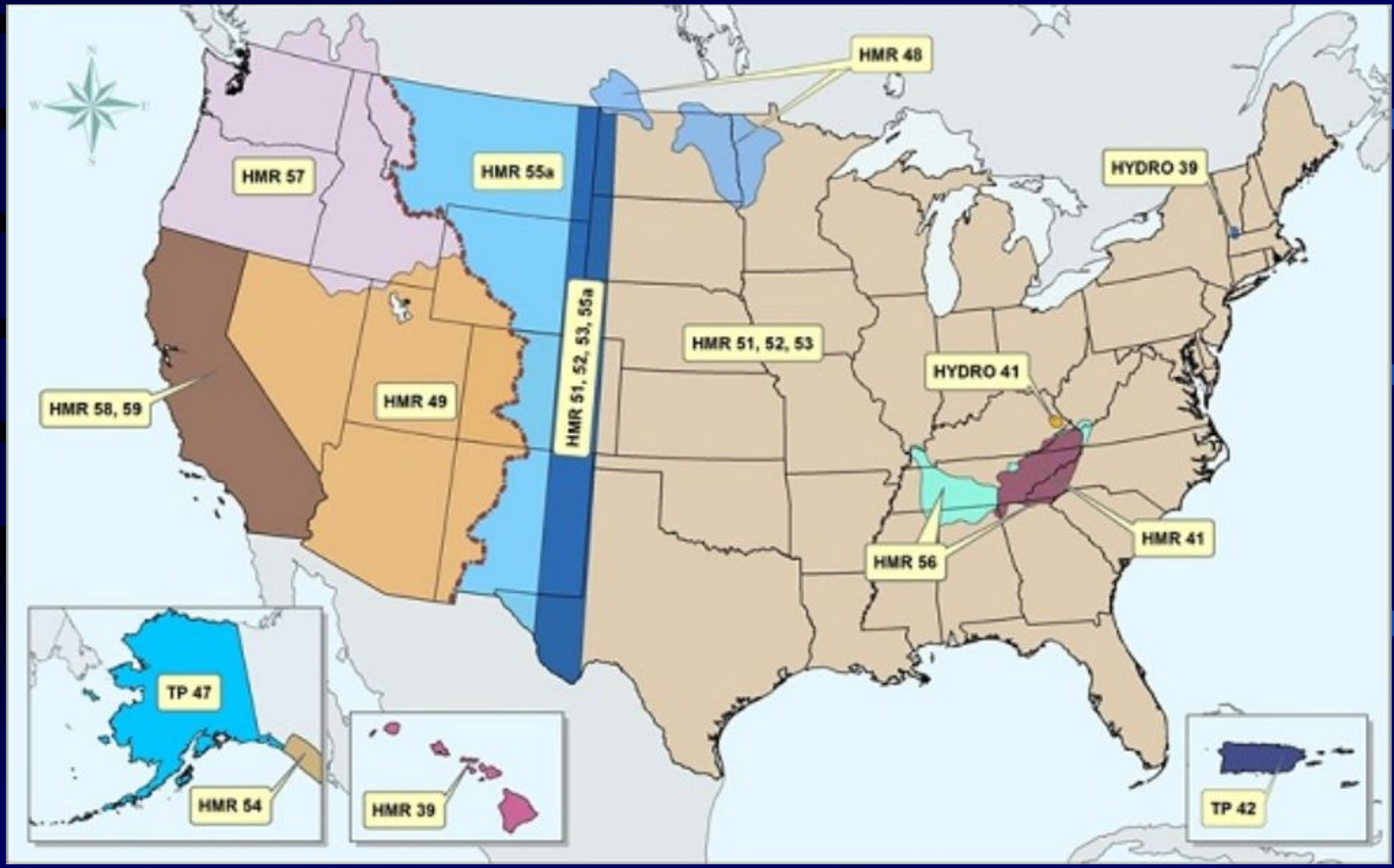
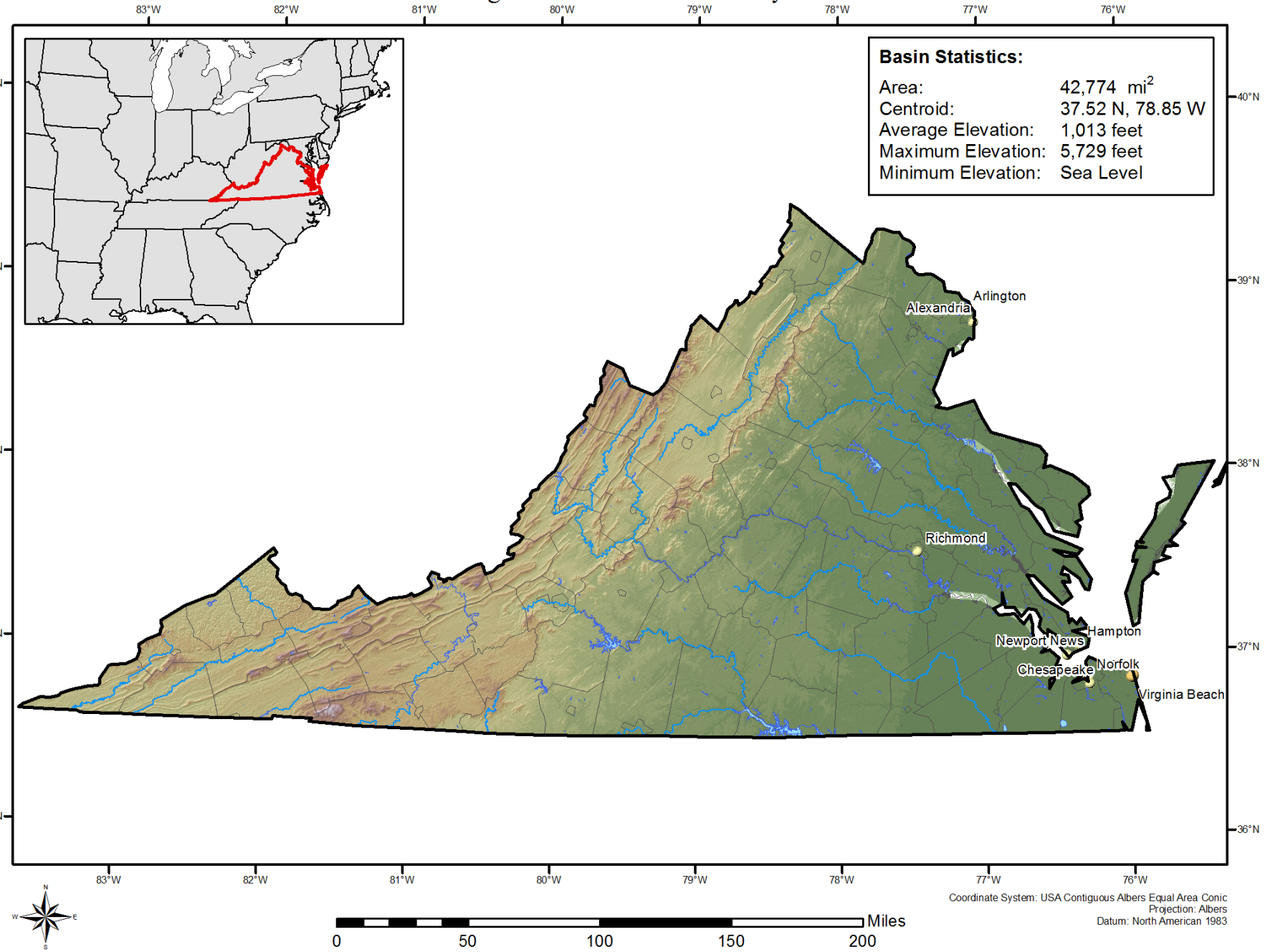
Probable Maximum Precipitation Study for Virginia



Coverage of HMRs



Elevation Statistics
Virginia Statewide PMP Study



Probable Maximum Precipitation Study for Virginia

Task 2

Storm Search and Short List Development

- Complete a storm search to identify the most significant storms that could have occurred over the region where storms are transpositionable to Virginia
- Identify storms used in HMRs and other PMP studies
- Identify the most significant flood events that have occurred in region
- Identify extreme rainfall-producing storm types and seasons associated with those storms
- Use SPAS to analyze extreme rainfall events that have not previously been analyzed
- Use SPAS to reanalyze extreme rainfall events

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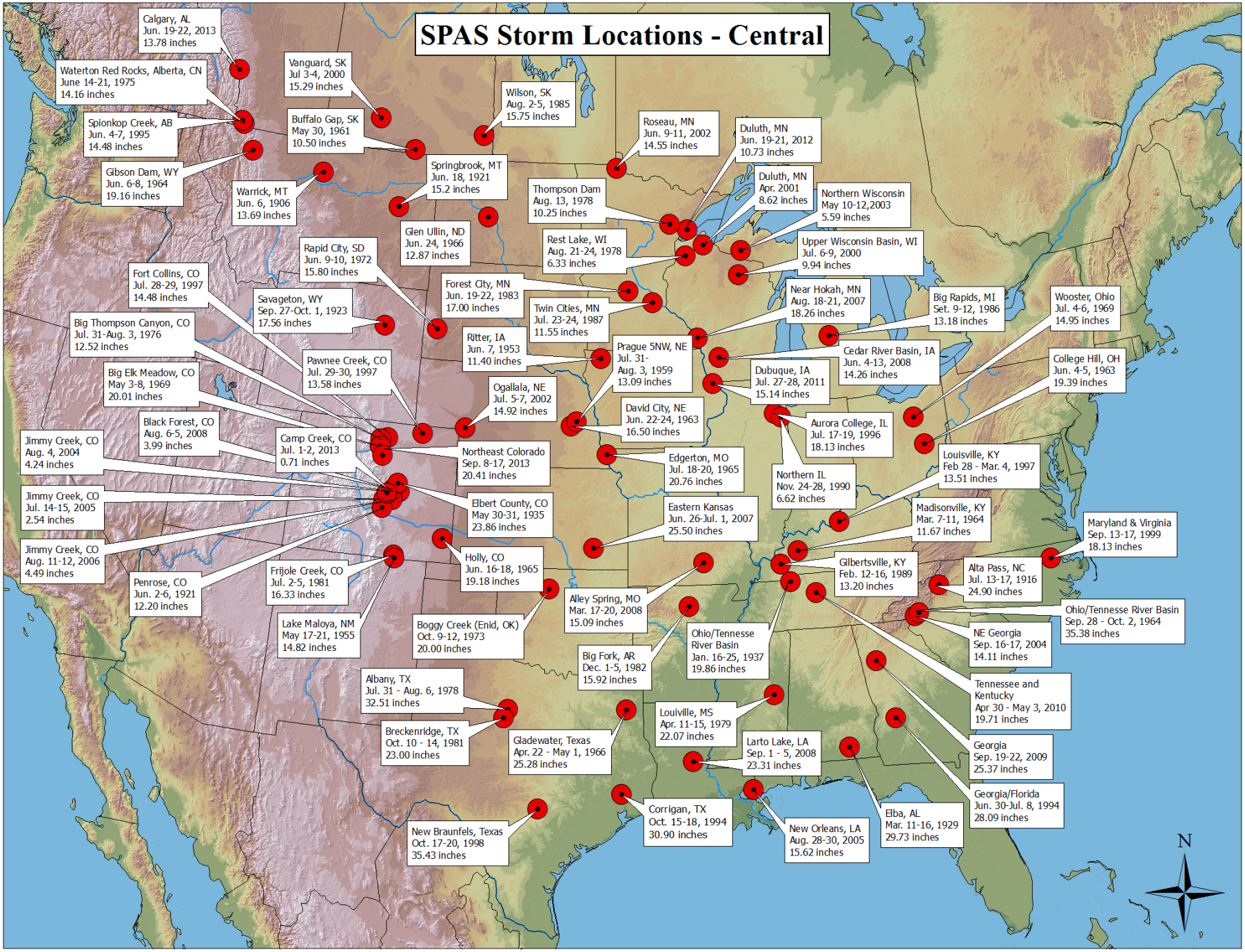
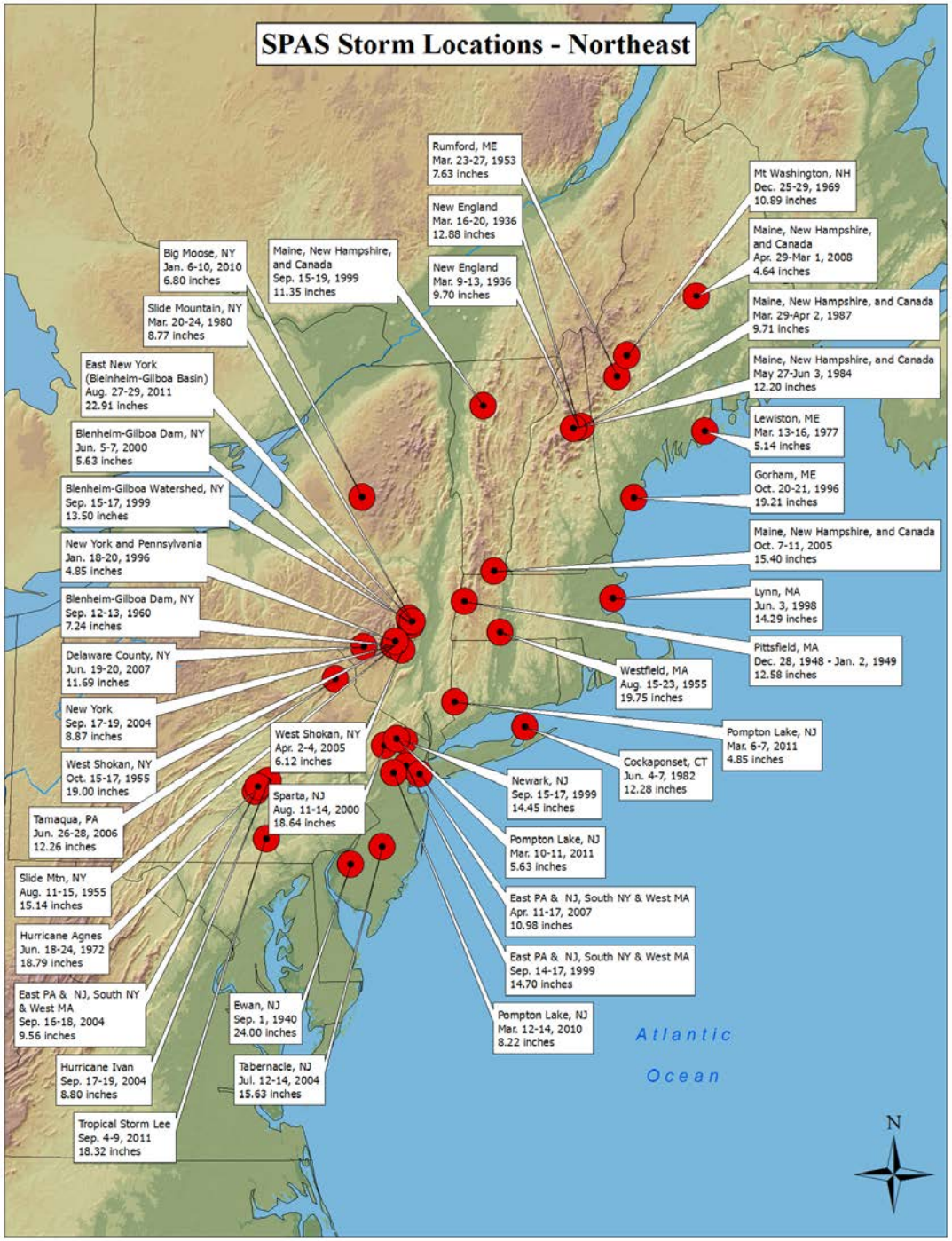

SPAS Storm Locations - Central
Calgary, AL
Jun. 19-22, 2013
13.78 inches
Waterton Red Rocks, Alberta, CN
June 14-21, 1975
14.16 inches
Spionkop Creek, AB
Jun. 4-7, 1995
14.48 inches
Gibson Dam, WY
Jun. 6-8, 1964
19.16 inches
Vanguard, SK
Jul 3-4, 2000
15.29 inches
Buffalo Gap, SK
May 30, 1961
10.50 inches
Warrick, MT
Jun. 6, 1906
13.69 inches
Springbrook, MT
Jun. 18, 1921
15.2 inches
Wilson, SK
Aug. 2-5, 1985
15.75 inches
Glen Ullin, ND
Jun. 24, 1966
12.87 inches
Rapid City, SD
Jun. 9-10, 1972
15.80 inches
Fort Collins, CO
Jul. 28-29, 1997
14.48 inches
Savageton, WY
Sep. 27-Oct. 1, 1923
17.56 inches
Big Thompson Canyon, CO
Jul. 31-Aug. 3, 1976
12.52 inches
Big Elk Meadow, CO
May 3-8, 1969
20.01 inches
Pawnee Creek, CO
Jul. 29-30, 1997
13.58 inches
Black Forest, CO
Aug. 6-5, 2008
3.99 inches
Camp Creek, CO
Jul. 1-2, 2013
0.71 inches
Jimmy Creek, CO
Aug. 4, 2004
4.24 inches
Jimmy Creek, CO
Jul. 14-15, 2005
2.54 inches
Jimmy Creek, CO
Aug. 11-12, 2006
4.49 inches
Penrose, CO
Jun. 2-6, 1921
12.20 inches
Frijole Creek, CO
Jul. 2-5, 1981
16.33 inches
Lake Maloya, NM
May 17-21, 1955
14.82 inches
Albany, TX
Jul. 31 - Aug. 6, 1978
32.51 inches
Breckenridge, TX
Oct. 10 - 14, 1981
23.00 inches
New Braunfels, Texas
Oct. 17-20, 1998
35.43 inches
Ogallala, NE
Jul. 5-7, 2002
14.92 inches
Northeast Colorado
Sep. 8-17, 2013
20.41 inches
Elbert County, CO
May 30-31, 1935
23.86 inches
Holly, CO
Jun. 16-18, 1965
19.18 inches
Boggy Creek (Enid, OK)
Oct. 9-12, 1973
20.00 inches
Gladewater, Texas
Apr. 22 - May 1, 1966
25.28 inches
Ritter, IA
Jun. 7, 1953
11.40 inches
Forest City, MN
Jun. 19-22, 1983
17.00 inches
Twin Cities, MN
Jul. 23-24, 1987
11.55 inches
Rest Lake, WI
Aug. 21-24, 1978
6.33 inches
Thompson Dam
Aug. 13, 1978
10.25 inches
Roseau, MN
Jun. 9-11, 2002
14.55 inches
Prague 5NW, NE
Jul. 31-
Aug. 3, 1959
13.09 inches
David City, NE
Jun. 22-24, 1963
16.50 inches
Edgerton, MO
Jul. 18-20, 1965
20.76 inches
Eastern Kansas
Jun. 26-Jul. 1, 2007
25.50 inches
Alley Spring, MO
Mar. 17-20, 2008
15.09 inches
Big Fork, AR
Dec. 1-5, 1982
15.92 inches
Louiville, MS
Apr. 11-15, 1979
22.07 inches
Corrigan, TX
Oct. 15-18, 1994
30.90 inches
Duluth, MN
Jun. 19-21, 2012
10.73 inches
Duluth, MN
Apr. 2001
8.62 inches
Northern Wisconsin
May 10-12,2003
5.59 inches
Upper Wisconsin Basin, WI
Jul. 6-9, 2000
9.94 inches
Near Hokah, MN
Aug. 18-21, 2007
18.26 inches
Dubuque, IA
Jul. 27-28, 2011
15.14 inches
Aurora College, IL
Jul. 17-19, 1996
18.13 inches
Northern IL
Nov. 24-28, 1990
6.62 inches
Ohio/Tennesse
River Basin
Jan. 16-25, 1937
19.86 inches
Larto Lake, LA
Sep. 1 - 5, 2008
23.31 inches
New Orleans, LA
Aug. 28-30, 2005
15.62 inches
Big Rapids, MI
Set. 9-12, 1986
13.18 inches
Cedar River Basin, IA
Jun. 4-13, 2008
14.26 inches
Wooster, Ohio
Jul. 4-6, 1969
14.95 inches
College Hill, OH
Jun. 4-5, 1963
19.39 inches
Louisville, KY
Feb 28 - Mar. 4, 1997
13.51 inches
Madisonville, KY
Mar. 7-11, 1964
11.67 inches
Gilbertsville, KY
Feb. 12-16, 1989
13.20 inches
Maryland & Virginia
Sep. 13-17, 1999
18.13 inches
Alta Pass, NC
Jul. 13-17, 1916
24.90 inches
Ohio/Tennesse River Basin
Sep. 28 - Oct. 2, 1964
35.38 inches
NE Georgia
Sep. 16-17, 2004
14.11 inches
Tennessee and
Kentucky
Apr 30 - May 3, 2010
19.71 inches
Georgia
Sep. 19-22, 2009
25.37 inches
Georgia/Florida
Jun. 30-Jul. 8, 1994
28.09 inches
Elba, AL
Mar. 11-16, 1929
29.73 inches
N


SPAS Storm Locations - Northeast
Rumford, ME
Mar. 23-27, 1953
7.63 inches
New England
Mar. 16-20, 1936
12.88 inches
New England
Mar. 9-13, 1936
9.70 inches
Maine, New Hampshire, and Canada
Sep. 15-19, 1999
11.35 inches
Big Moose, NY
Jan. 6-10, 2010
6.80 inches
Slide Mountain, NY
Mar. 20-24, 1980
8.77 inches
East New York (Bleinheim-Gilboa Basin)
Aug. 27-29, 2011
22.91 inches
Blenheim-Gilboa Dam, NY
Jun. 5-7, 2000
5.63 inches
Blenheim-Gilboa Watershed, NY
Sep. 15-17, 1999
13.50 inches
New York and Pennsylvania
Jan. 18-20, 1996
4.85 inches
Blenheim-Gilboa Dam, NY
Sep. 12-13, 1960
7.24 inches
Delaware County, NY
Jun. 19-20, 2007
11.69 inches
New York
Sep. 17-19, 2004
8.87 inches
West Shokan, NY
Oct. 15-17, 1955
19.00 inches
Tamaqua, PA
Jun. 26-28, 2006
12.26 inches
Slide Mtn, NY
Aug. 11-15, 1955
15.14 inches
Hurricane Agnes
Jun. 18-24, 1972
18.79 inches
East PA & NJ, South NY & West MA
Sep. 16-18, 2004
9.56 inches
Hurricane Ivan
Sep. 17-19, 2004
8.80 inches
Tropical Storm Lee
Sep. 4-9, 2011
18.32 inches
West Shokan, NY
Apr. 2-4, 2005
6.12 inches
Sparta, NJ
Aug. 11-14, 2000
18.64 inches
Ewan, NJ
Sep. 1, 1940
24.00 inches
Tabernacle, NJ
Jul. 12-14, 2004
15.63 inches
Mt Washington, NH
Dec. 25-29, 1969
10.89 inches
Maine, New Hampshire, and Canada
Apr. 29-Mar 1, 2008
4.64 inches
Maine, New Hampshire, and Canada
Mar. 29-Apr 2, 1987
9.71 inches
Maine, New Hampshire, and Canada
May 27-Jun 3, 1984
12.20 inches
Lewiston, ME
Mar. 13-16, 1977
5.14 inches
Gorham, ME
Oct. 20-21, 1996
19.21 inches
Maine, New Hampshire, and Canada
Oct. 7-11, 2005
15.40 inches
Lynn, MA
Jun. 3, 1998
14.29 inches
Pittsfield, MA
Dec. 28, 1948 - Jan. 2, 1949
12.58 inches
Westfield, MA
Aug. 15-23, 1955
19.75 inches
Pompton Lake, NJ
Mar. 6-7, 2011
4.85 inches
Cockaponset, CT
Jun. 4-7, 1982
12.28 inches
Newark, NJ
Sep. 15-17, 1999
14.45 inches
Pompton Lake, NJ
Mar. 10-11, 2011
5.63 inches
East PA & NJ, South NY & West MA
Apr. 11-17, 2007
10.98 inches
East PA & NJ, South NY & West MA
Sep. 14-17, 1999
14.70 inches
Pompton Lake, NJ
Mar. 12-14, 2010
8.22 inches
Atlantic
Ocean
N

Probable Maximum Precipitation Study for Virginia

Task 2

Current Storm List

Probable Maximum Precipitation Study for Virginia

Task 3

SPAS Storm Analysis

All storms used for PMP develop analyzed with SPAS

SPAS produces gridded rainfall analysis and required data sets

USACE storms will need to be re-analyzed

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Probable Maximum Precipitation Study for Virginia

Task 4

Storm Maximizations/Transpositioning/Orographics

- Utilize the updated maximum dew point climatology for use in storm maximization and transpositioning
- Maximum average dew point values
  - 6-hour
  - 12-hour
  - 24-hour
- SST climatology for some events

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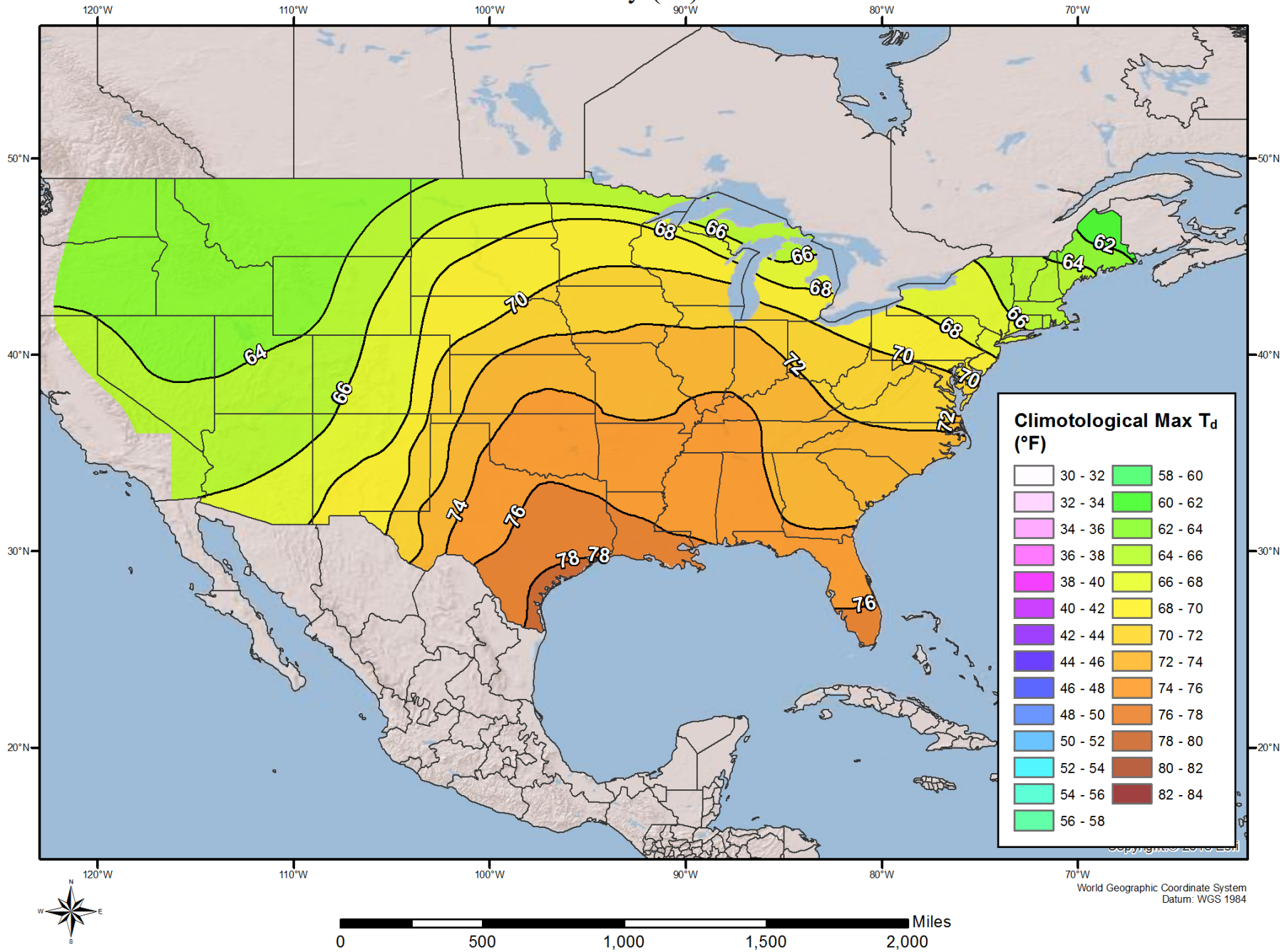
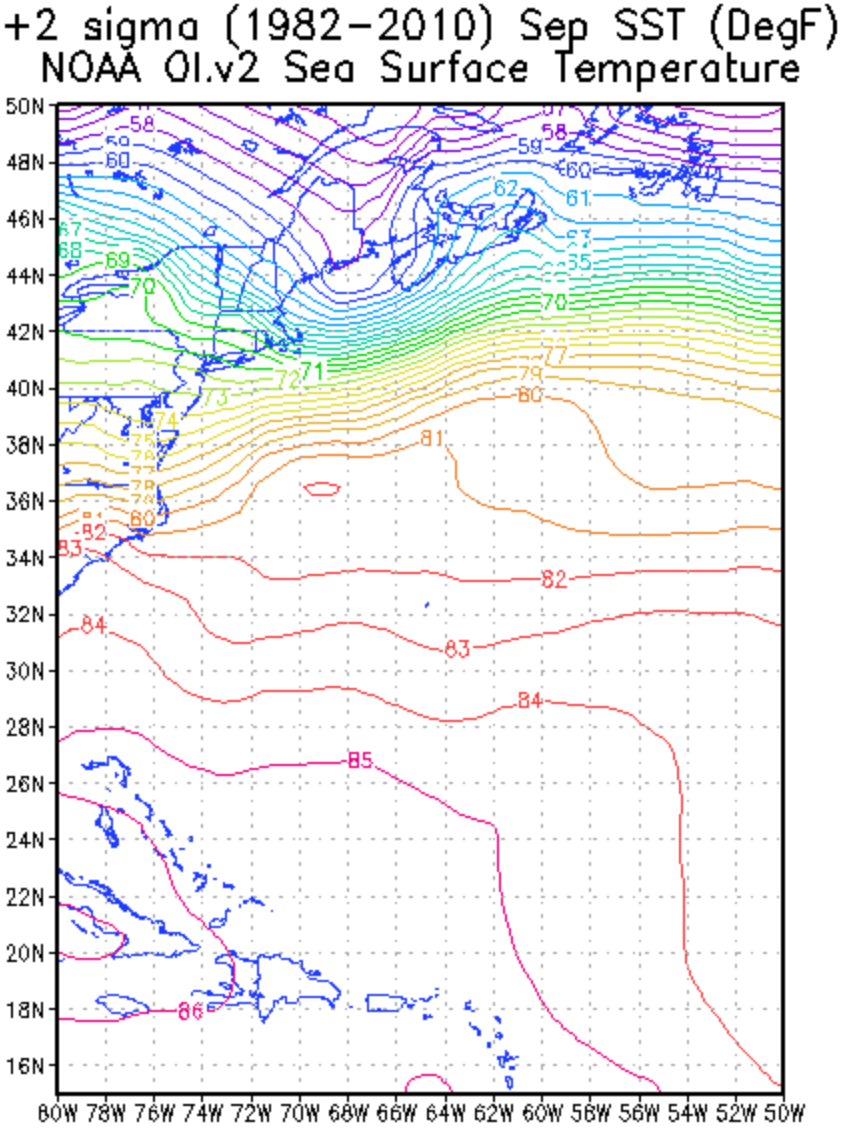
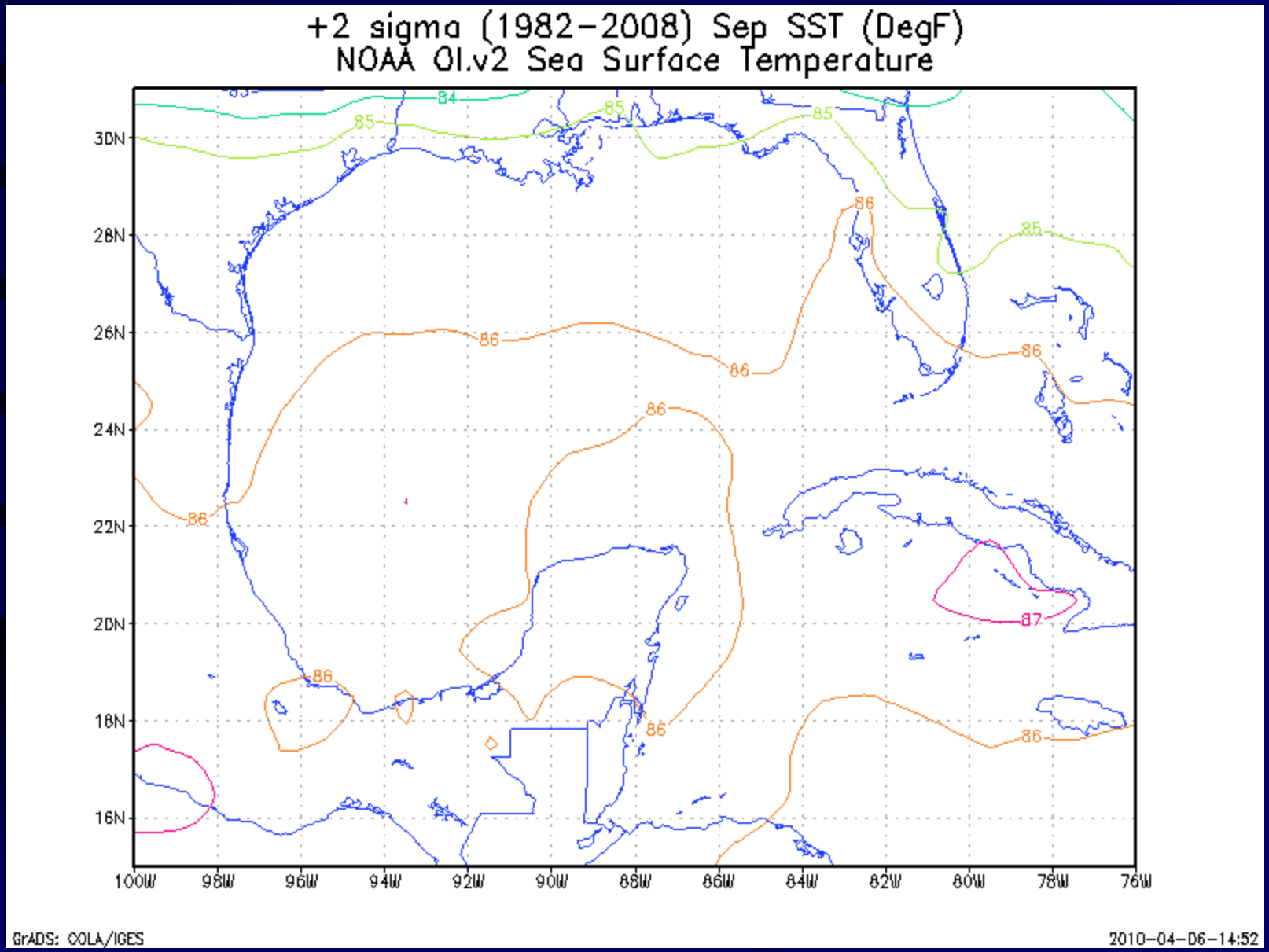
100-year Return Frequency 24-hour Maximum Dew Point Climatology
May (°F)



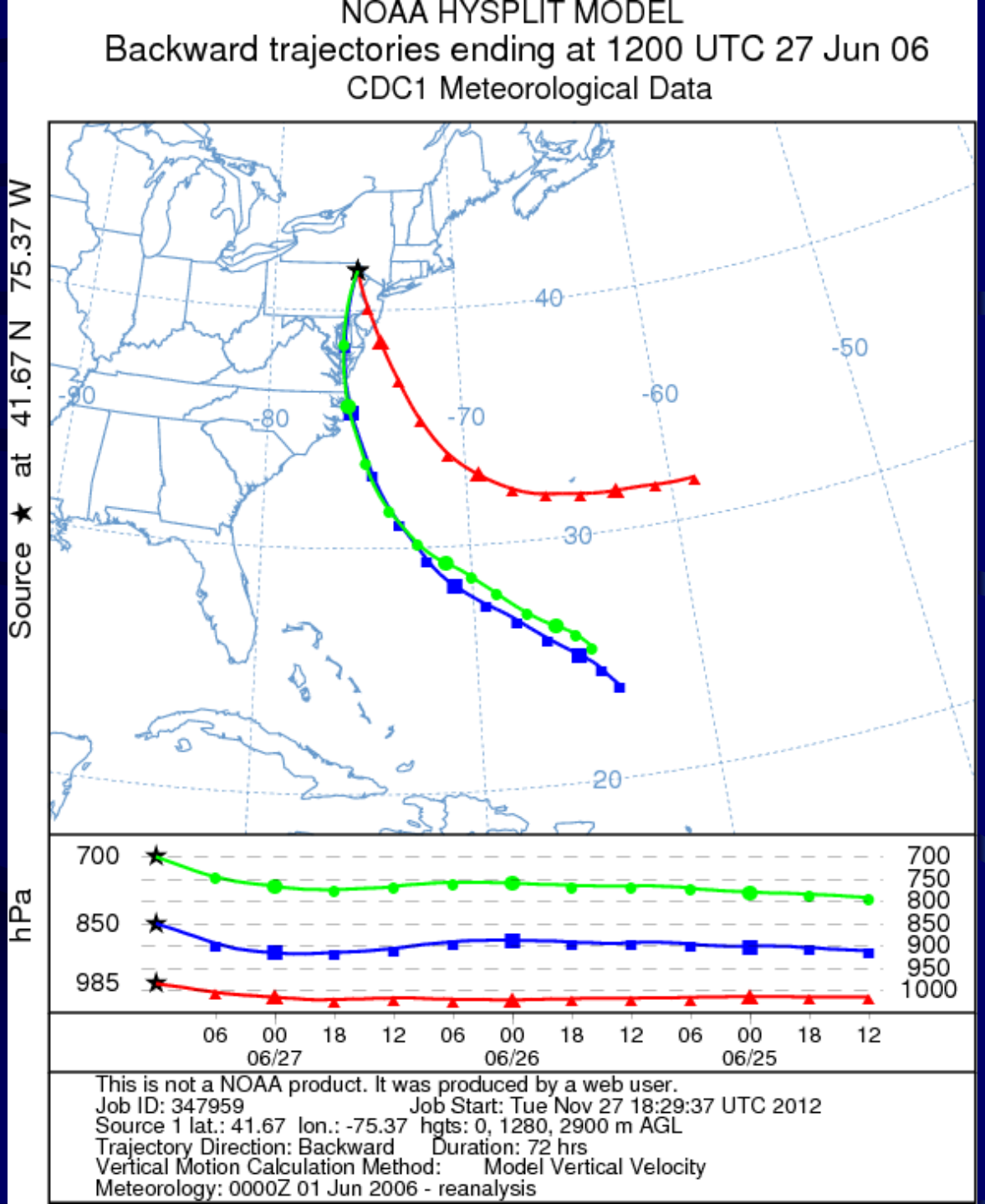
Probable Maximum Precipitation

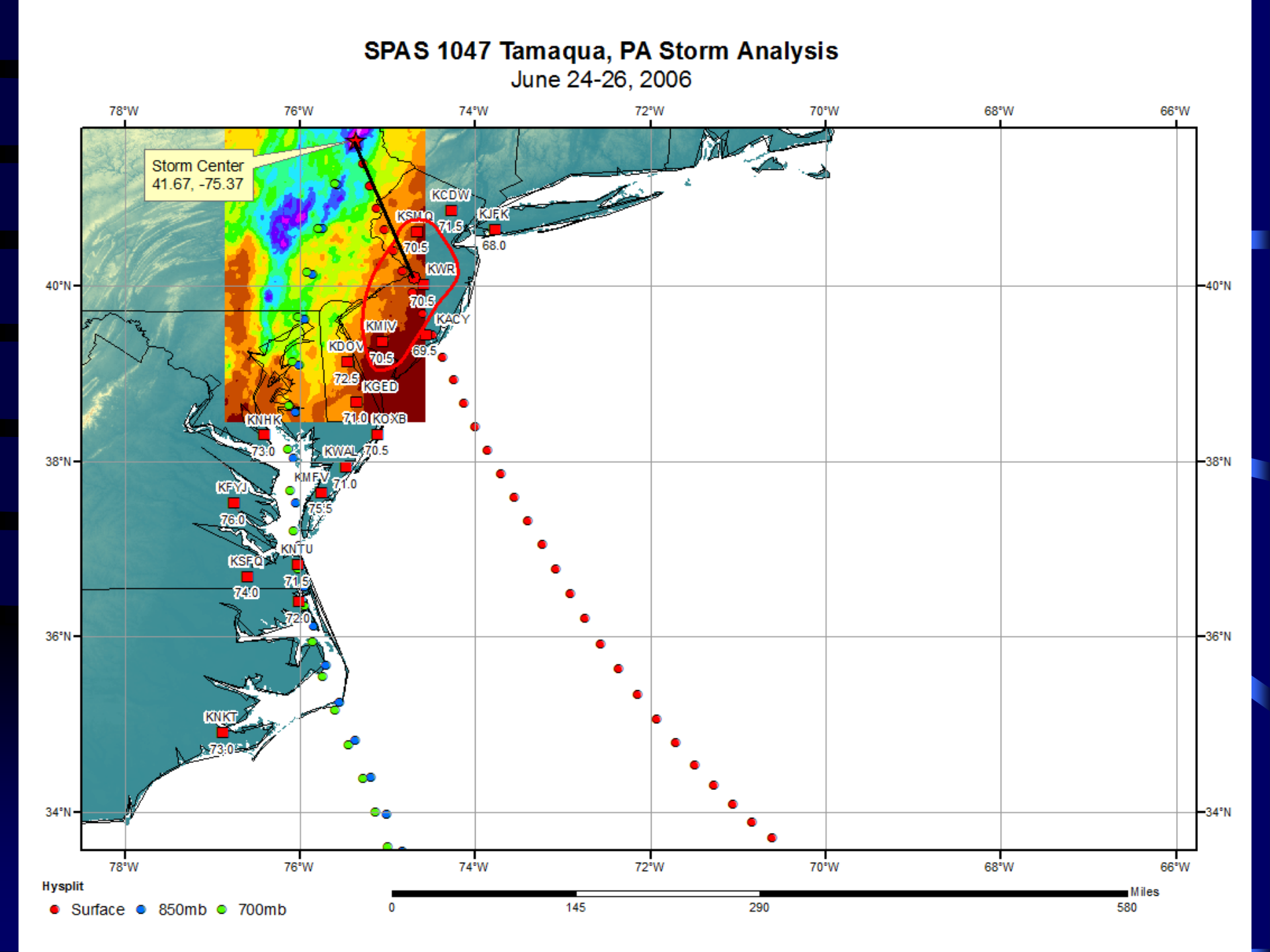


Probable Maximum Precipitation

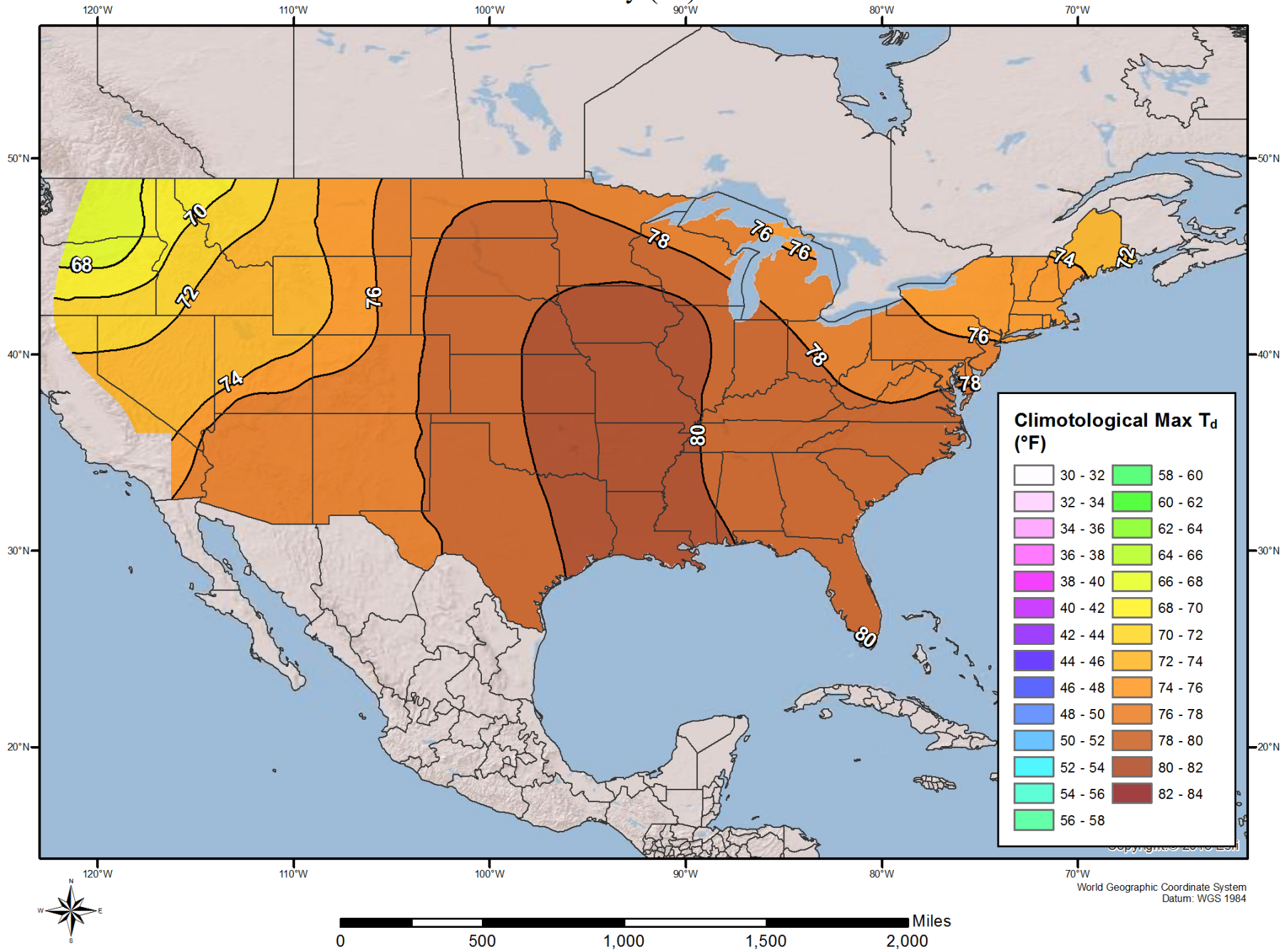


HYSPLIT Trajectory used for Tamaqua June 2006




SPAS 1047 Tamaqua, PA Storm Analysis
June 24-26, 2006
Storm Center
41.67, -75.37
KCDW
KSMQ
KJFK
KWR
KACY
KMIV
KDOV
KGED
KOXB
KWAL
KMFV
KFYJ
KNTU
KSFQ
KNKT
KNHK
71.5
68.0
70.5
70.5
70.5
69.5
72.5
71.0
70.5
71.0
75.5
76.0
71.5
74.0
72.0
73.0
73.0
78°W
76°W
74°W
72°W
70°W
68°W
66°W
40°N
38°N
36°N
34°N
Hysplit
Surface
850mb
700mb
0
145
290
580
Miles

100-year Return Frequency 24-hour Maximum Dew Point Climatology
July (°F)



Storm Spreadsheet for Tamaqua June 2006

Storm Name:	SPAS 1047-Tamaqua, PA
Storm Date:	June 26-28, 2006
AWA Analysis Date:	12/7/2013

Storm Adjustment for PBAPS Basin Centroid

Temporal Transposition Date: 10-Jul

	Lat	Lon
Storm Center Location	41.68 N	75.38 W
Storm Rep Dew Point Location	40.10 N	74.70 W
Transposition Dew Point Location	39.68 N	76.21 W
Basin Location	41.26 N	76.90 W

Moisture Inflow Direction	SSE @ 115	miles
Basin Average Elevation	1,300	feet
Storm Center Elevation	1,250	feet
Storm Analysis Duration	24	hours
Effective Barrier Height	N/A	feet

The storm representative Td is	71.0 F	with total precipitable water above sea level of				2.36	inches.
The in-place maximum Td is	76.0 F	with total precipitable water above sea level of				2.99	inches.
The transpositioned maximum Td is	76.5 F	with total precipitable water above sea level of				3.07	inches.
The in-place storm elevation is	1,250	feet which subtracts	0.27	inches of precipitable water at	71.0 F		
The in-place storm elevation is	1,250	feet which subtracts	0.32	inches of precipitable water at	76.0 F		
The transposition basin elevation at	1,300	feet which subtracts	0.34	inches of precipitable water at	76.5 F		
The inflow barrier/basin elevation height is	N/A	feet which subtracts	0.34	inches of precipitable water at	76.5 F		

The in-place maximization factor is	1.28
The transposition factor is	1.02
The barrier adjustment factor is	1.00
The total adjustment factor is	1.30

Notes: DAD values taken from SPAS 1047. Storm representative dew point value was based on average 24-hr Td values for June 26-27, 2006 at KSMQ, KMIV, and KWRI.

Observed Storm Depth-Area-Duration

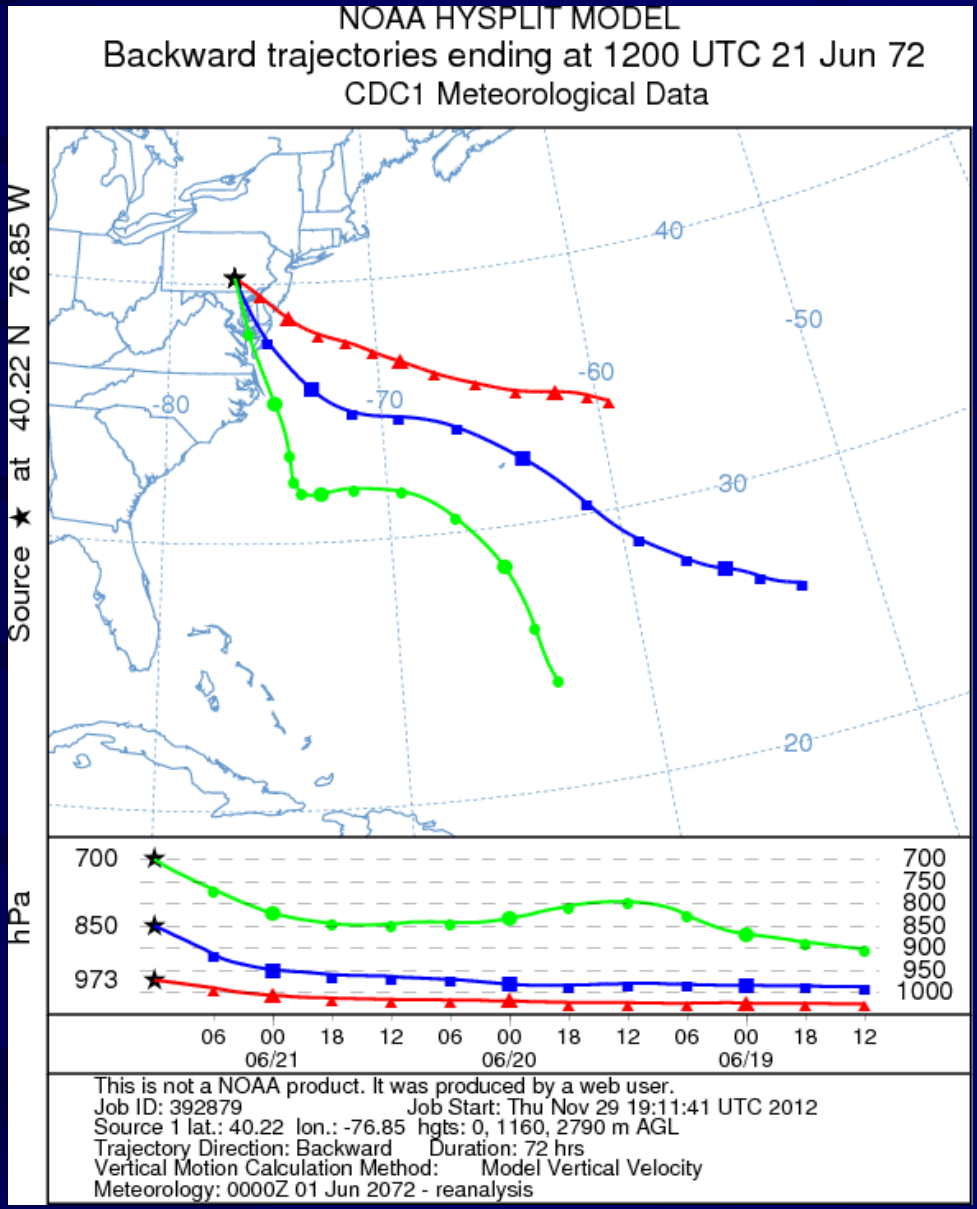
	6 Hours	12 Hours	18 Hours	24 Hours	30 Hours	36 Hours	48 Hours	60 Hours	72 Hours
1 sq miles	4.1	5.1	6.4	9.5	-	10.4	10.9	-	12.2
10 sq miles	4.0	5.1	6.3	9.2	-	10.1	10.8	-	11.9
100 sq miles	3.6	4.9	5.7	8.1	-	9.1	10.3	-	11.1
200 sq miles	3.3	4.7	5.4	7.8	-	8.8	10.0	-	10.8
500 sq miles	2.9	4.3	5.1	7.1	-	8.3	9.6	-	10.3
1000 sq miles	2.6	4.0	4.8	6.6	-	7.8	9.1	-	9.7
5000 sq miles	1.9	3.1	3.9	5.1	-	6.4	7.3	-	7.9
10000 sq miles	1.6	2.7	3.3	4.3	-	5.5	6.4	-	7.0
20000 sq miles	1.3	2.1	2.6	3.1	-	4.1	5.1	-	5.6
50000 sq miles	-	-	-	-	-	-	-	-	-

Adjusted Storm Depth-Area-Duration

	6 Hours	12 Hours	18 Hours	24 Hours	30 Hours	36 Hours	48 Hours	60 Hours	72 Hours
1 sq miles	5.3	6.6	8.3	12.4	-	13.6	14.2	-	15.9
10 sq miles	5.2	6.6	8.1	12.0	-	13.2	14.1	-	15.5
100 sq miles	4.7	6.3	7.4	10.6	-	11.8	13.4	-	14.5
200 sq miles	4.3	6.1	7.1	10.1	-	11.4	13.1	-	14.0
500 sq miles	3.8	5.6	6.7	9.3	-	10.8	12.5	-	13.4
1000 sq miles	3.4	5.2	6.2	8.6	-	10.2	11.8	-	12.6
5000 sq miles	2.5	4.1	5.1	6.7	-	8.3	9.6	-	10.3
10000 sq miles	2.1	3.5	4.3	5.6	-	7.1	8.3	-	9.1
20000 sq miles	1.7	2.8	3.4	4.0	-	5.3	6.6	-	7.3
50000 sq miles	-	-	-	-	-	-	-	-	-

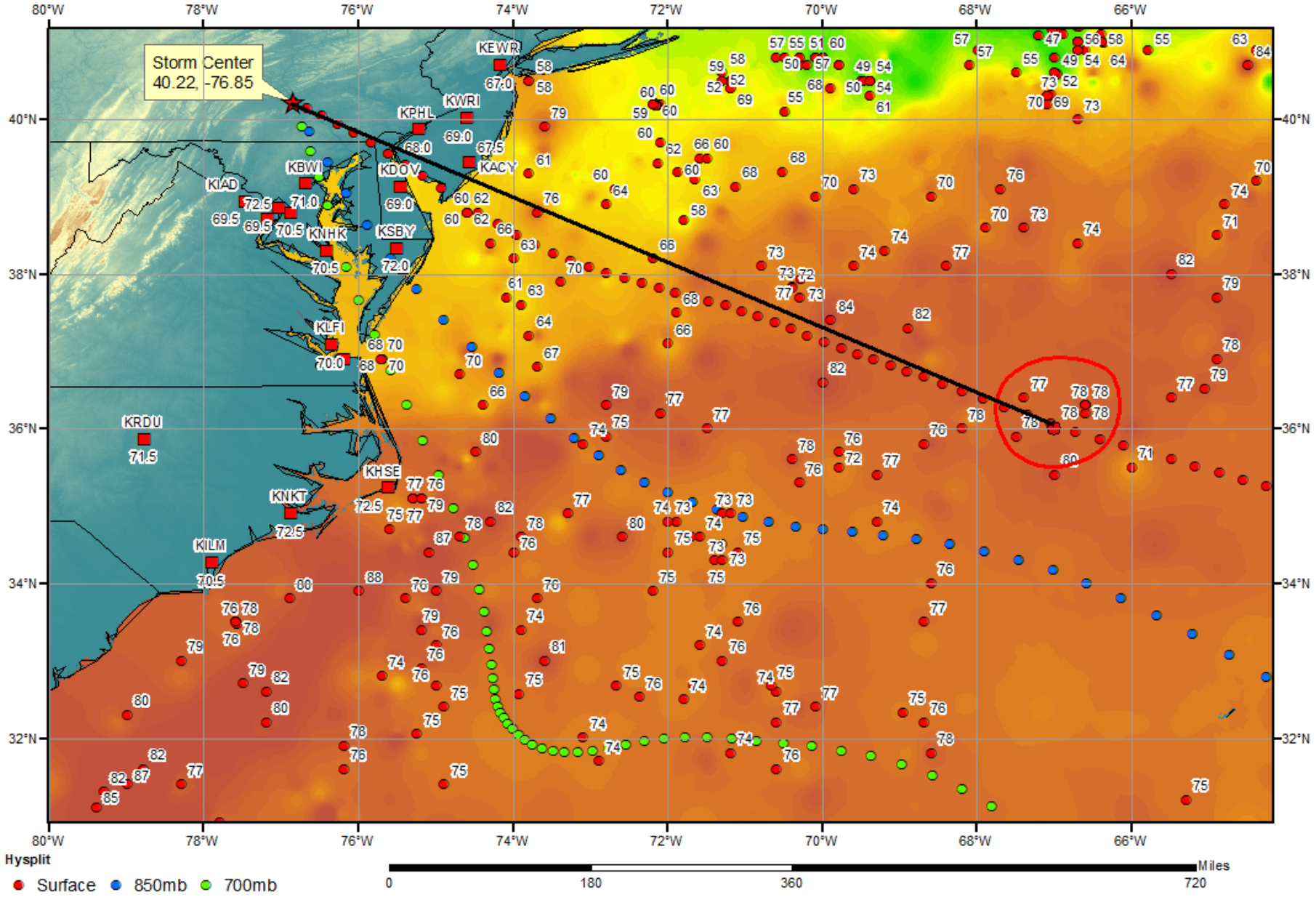
Storm or Storm Center Name	SPAS 1047-Tamaqua, PA			
Storm Date(s)	June 26-28, 2006			
Storm Type	General Storm			
Storm Location	41.68 N	75.38 W		
Storm Center Elevation	1,250			
Precipitation Total & Duration	12.26 Inches; 72 Hrs SPAS 1047			
Storm Representative Dew Point	71.0 F	24hr		
Storm Representative Dew Point Location	40.10 N	74.70 W	Jun	Jul
Maximum Dew Point	76.0 F		74	76.5
Moisture Inflow Vector	SSE @ 115	Miles		
In-place Maximization Factor	1.28			
Temporal Transposition Date	10-Jul			
Transposition Dew Point Location	39.68 N	76.21 W	Jun	Jul
Transposition Maximum Dew Point	76.5 F		74.5	77
Transposition Adjustment Factor	1.02			
Average Basin Elevation	1,300			
Highest Elevation in Basin	3,120			
Inflow Barrier Height	N/A			
Elevation Adjustment Factor	1.00			
Total Adjustment Factor	1.30			

HYSPLIT Trajectory used for Zerbe (Agnes) Storm Rep Analysis



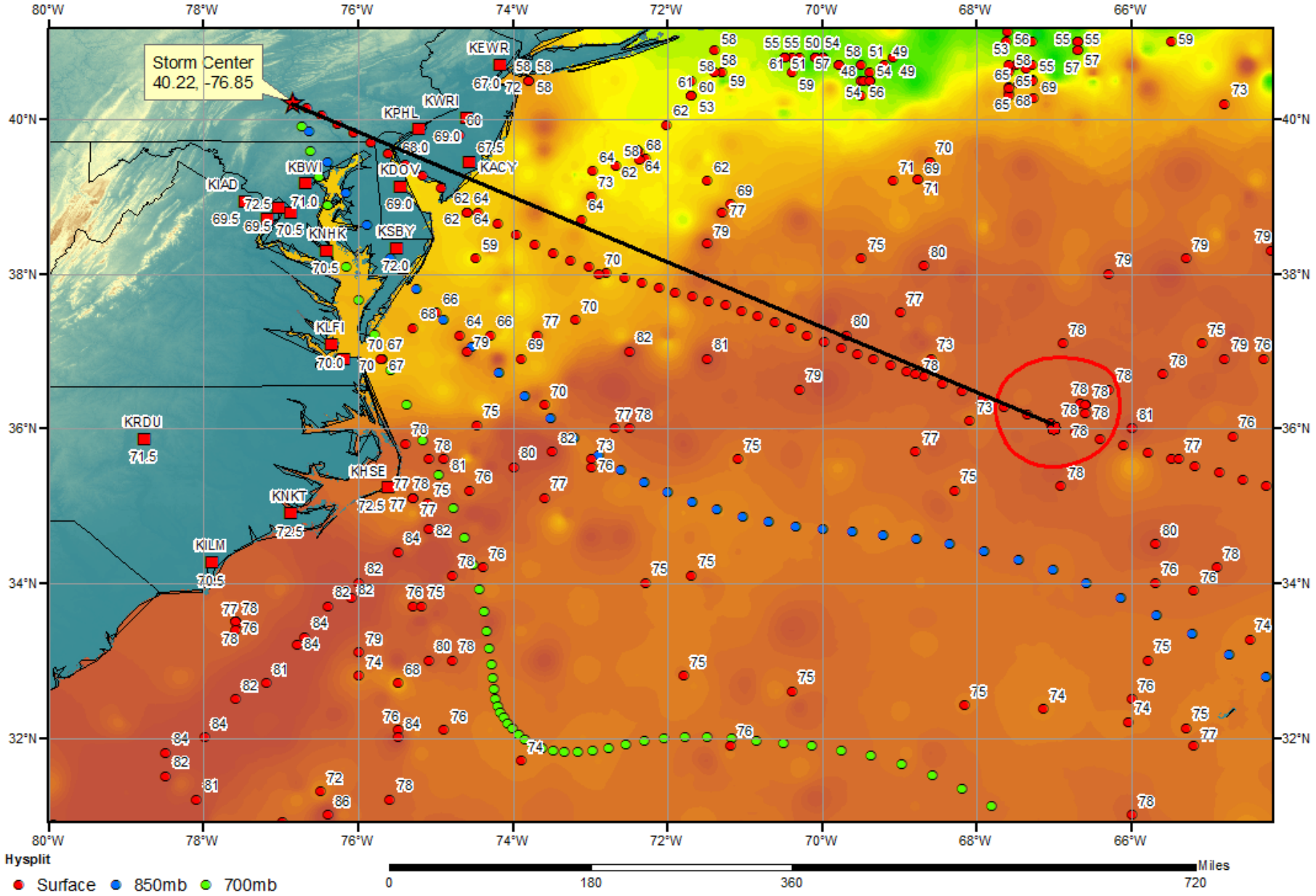
USACE NA 2-24A Zerbe, PA Storm Analysis

June 18, 1972



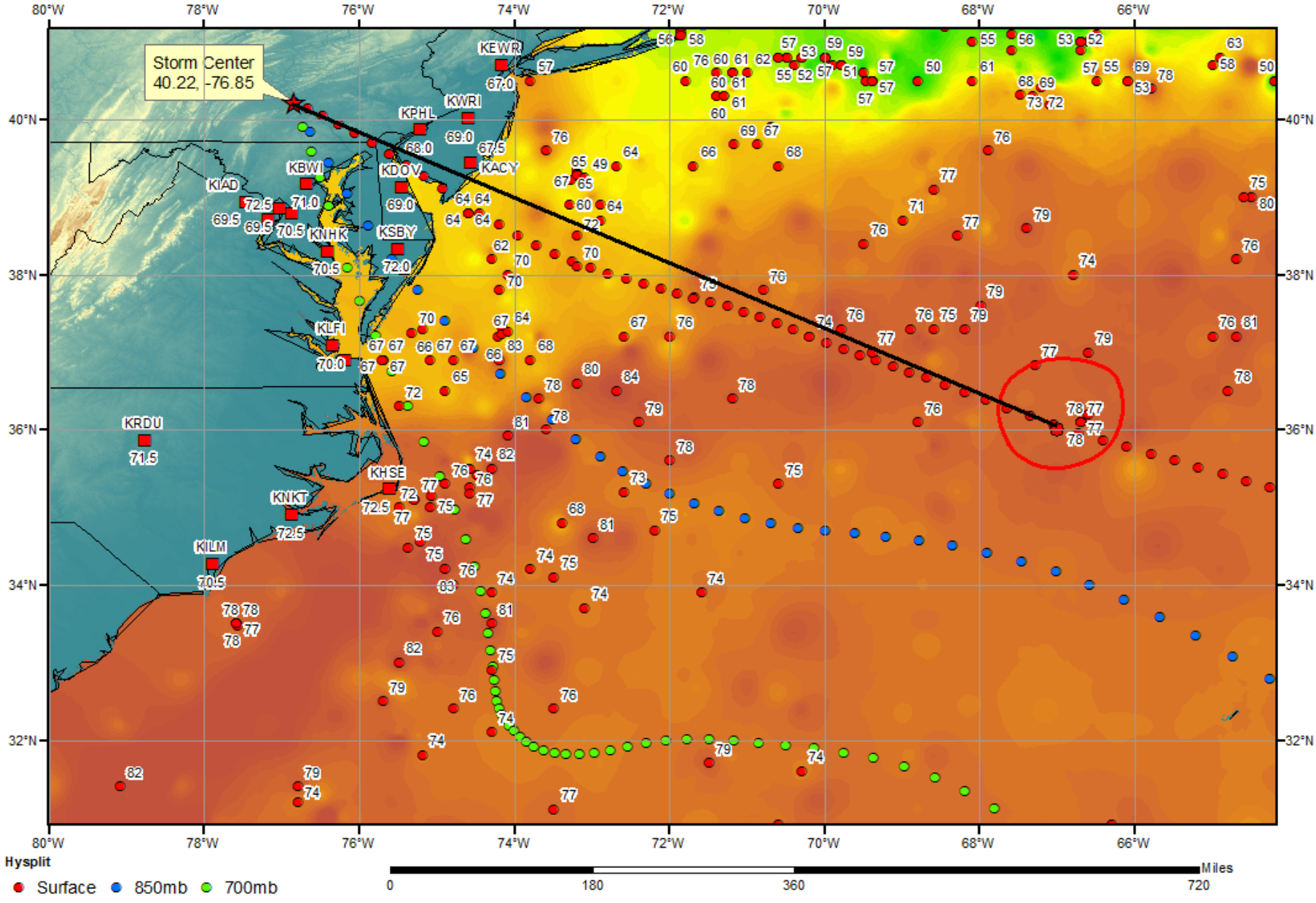
USACE NA 2-24A Zerbe, PA Storm Analysis

June 19, 1972

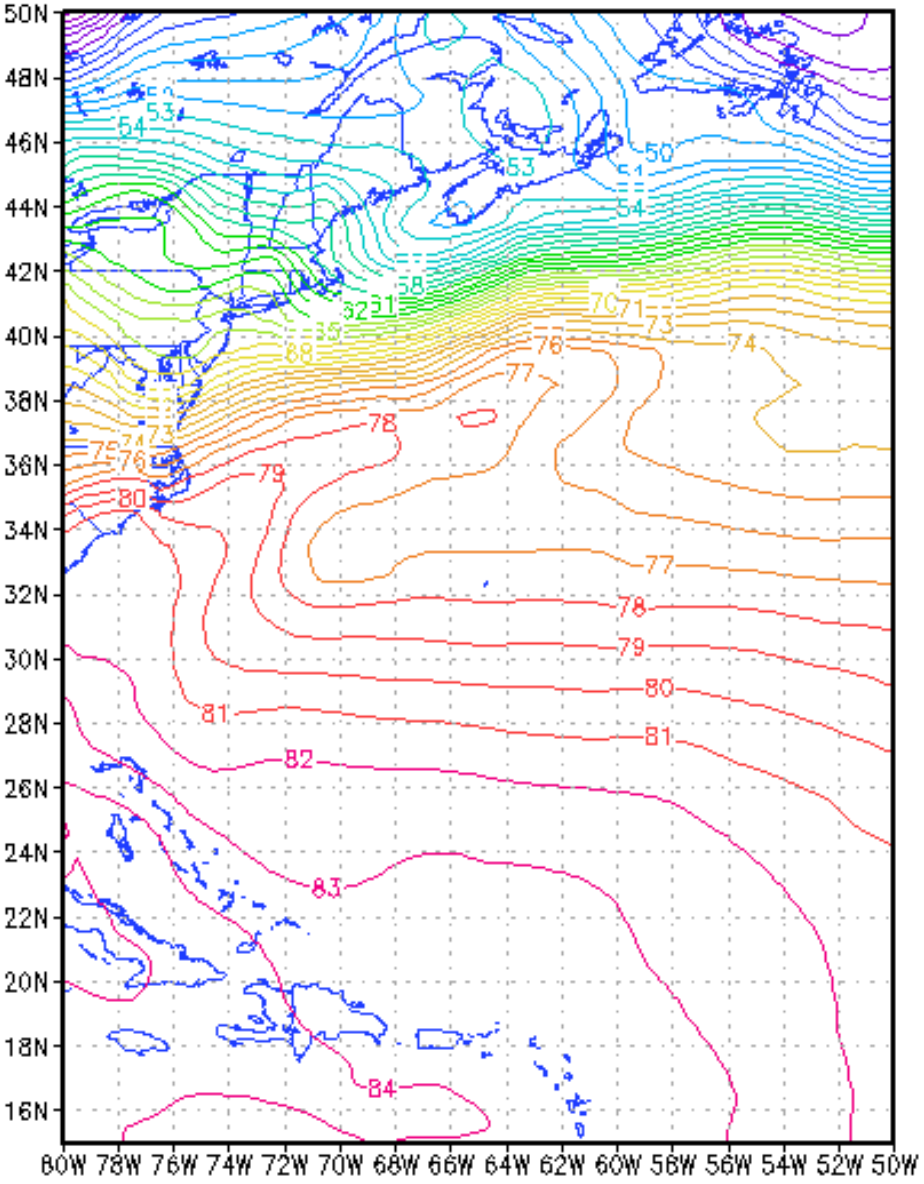


USACE NA 2-24A Zerbe, PA Storm Analysis

June 20, 1972

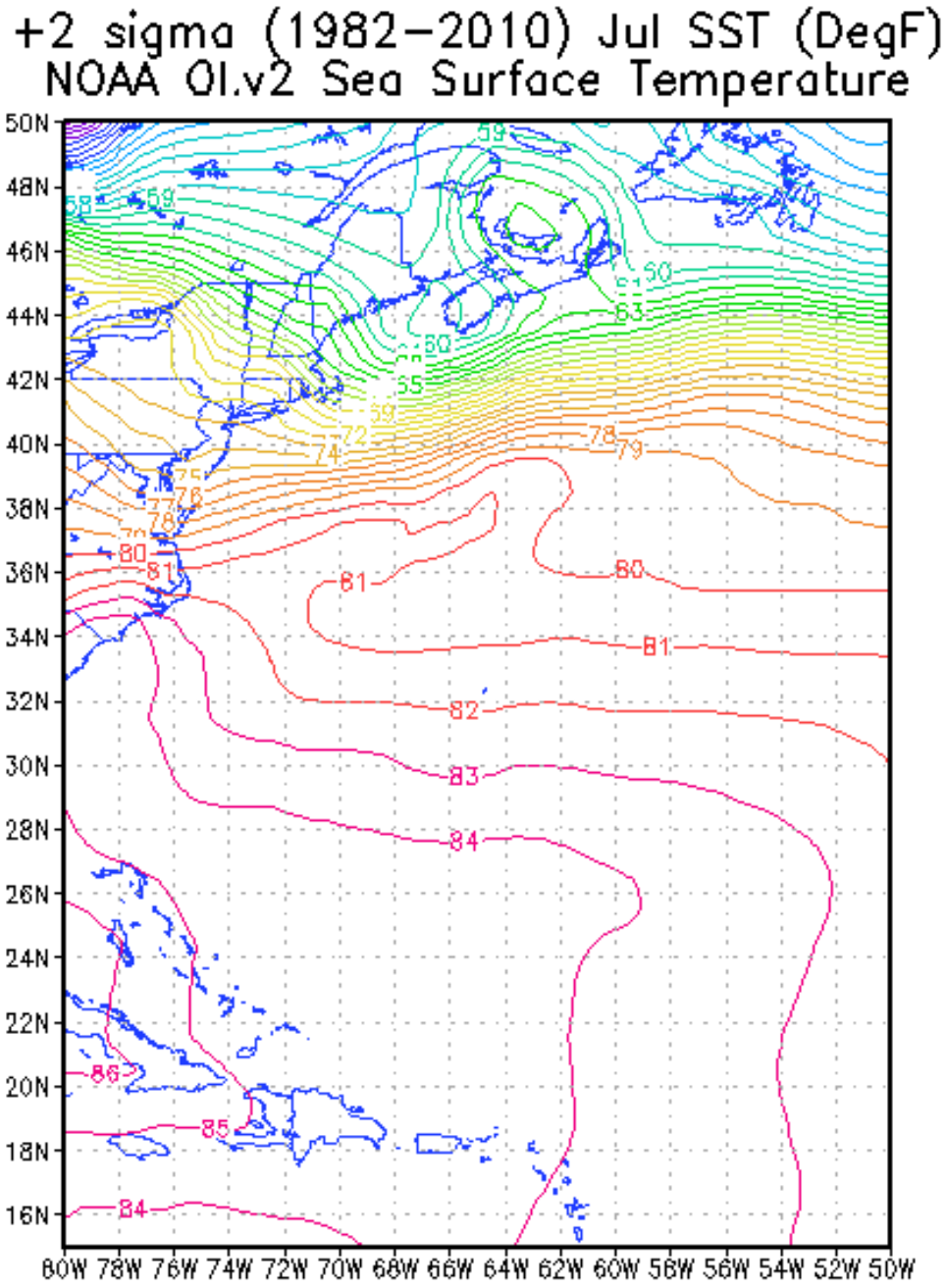


+2 sigma (1982-2010) Jun SST (DegF)
NOAA OI.v2 Sea Surface Temperature



GrADS: COLA/IGES

2010-12-09-21:34


+2 sigma (1982-2010) Jul SST (DegF)
NOAA OI.v2 Sea Surface Temperature
50N
48N
46N
44N
42N
40N
38N
36N
34N
32N
30N
28N
26N
24N
22N
20N
18N
16N
80W 78W 76W 74W 72W 70W 68W 66W 64W 62W 60W 58W 56W 54W 52W 50W
GrADS: COLA/IGES
2010-12-09-21:34

Storm Spreadsheet for Zerbe (Agnes)

Storm Name:	Zerbe, PA SPAS 1276-DAD Zone 2
Storm Date:	6/19-23/1972
AWA Analysis Date:	12/7/2013

Storm Adjustment for PBAPS Basin Centroid

Temporal Transposition Date	5-Jul	

	Lat	Long
Storm Center Location	40.54 N	76.62 W
Storm Rep Dew Point Location	36.00 N	67.00 W
Transposition Dew Point Location	36.70 N	67.20 W
Basin Location	41.26 N	76.90 W

Moisture Inflow Direction	ESE @ 610	miles
Basin Average Elevation	1,300	feet
Storm Center Elevation	1,650	feet
Storm Analysis Duration	24	hours
Effective Barrier Height	N/A	feet

The storm representative Td is	78.0 F	with total precipitable water above sea level of			3.29	inches.
The in-place maximum Td is	80.0 F	with total precipitable water above sea level of			3.60	inches.
The transpositioned maximum Td is	80.0 F	with total precipitable water above sea level of			3.60	inches.
The in-place storm elevation is	1,650	which subtracts	0.445	inches of precipitable water at	78.0 F	
The in-place storm elevation is	1,650	which subtracts	0.475	inches of precipitable water at	80.0 F	
The transposition basin elevation at	1,300	which subtracts	0.38	inches of precipitable water at	80.0 F	
The inflow barrier/basin elevation height is	N/A	which subtracts	0.38	inches of precipitable water at	80.0 F	

The in-place storm maximization factor is	1.10
The transposition/elevation to basin factor is	1.03
The barrier adjustment factor is	1.00
The total adjustment factor is	1.13

Notes: DAD values taken from HMR 51 storm #100 (NA2-24A). Used SST values on June 18-19 along with HYSPLIT backward trajectory. Values were selected in region where temperature did not vary more than a degree over a large area.

Observed Storm Depth-Area-Duration

	6 Hours	12 Hours	18 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours
10 sq miles	8.1	10.3	12.5	13.8	15.5	16.3	17.2	17.2	17.7	18.1
100 sq miles	7.9	10.1	11.5	13.1	15.0	15.6	15.7	15.8	16.9	17.4
200 sq miles	7.6	10.0	11.5	12.9	14.9	15.3	15.6	15.7	16.5	17.0
500 sq miles	7.2	9.5	11.1	12.6	14.5	14.9	15.2	15.2	16.0	16.3
1000 sq miles	6.7	8.5	10.6	11.9	13.9	14.3	14.6	14.6	15.3	15.5
2000 sq miles	5.9	8.1	10.1	11.3	13.0	13.4	13.8	13.9	14.6	14.9
5000 sq miles	5.4	7.1	8.6	9.9	11.1	12.2	12.7	12.7	13.4	13.6
10000 sq miles	4.6	6.2	7.4	8.5	9.4	10.7	11.4	11.5	12.0	12.2
20000 sq miles	3.3	5.1	6.2	7.2	8.5	8.9	10.0	10.0	10.5	10.7
50000 sq miles	2.1	3.1	4.1	4.9	6.4	7.2	7.9	8.1	8.3	8.5

Adjusted Storm Depth-Area-Duration

	6 Hours	12 Hours	18 Hours	24 Hours	36 Hours	48 Hours	72 Hours	96 Hours	120 Hours	144 Hours
10 sq miles	9.1	11.7	14.1	15.6	17.6	18.5	19.5	19.5	20.0	20.5
100 sq miles	9.0	11.4	13.0	14.8	17.0	17.6	17.8	17.9	19.1	19.7
200 sq miles	8.6	11.3	13.0	14.6	16.9	17.3	17.7	17.8	18.7	19.3
500 sq miles	8.1	10.7	12.6	14.2	16.4	16.9	17.1	17.1	18.1	18.5
1000 sq miles	7.6	9.6	12.0	13.4	15.7	16.2	16.5	16.5	17.4	17.6
2000 sq miles	6.7	9.1	11.4	12.8	14.7	15.2	15.7	15.8	16.5	16.8
5000 sq miles	6.1	8.0	9.8	11.2	12.6	13.8	14.3	14.4	15.2	15.4
10000 sq miles	5.1	7.0	8.4	9.6	10.6	12.1	12.9	13.0	13.5	13.8
20000 sq miles	3.7	5.7	7.0	8.1	9.6	10.1	11.4	11.4	11.9	12.1
50000 sq miles	2.4	3.5	4.6	5.6	7.3	8.1	9.0	9.2	9.4	9.6

Storm or Storm Center Name	Zerbe, PA SPAS 1276-DAD Zone 2				
Storm Date(s)	6/19-23/1972				
Storm Type	Hurricane Agnes				
Storm Location	40.54 N	76.62 W			
Storm Center Elevation	1,650				
Precipitation Total & Duration	17.77 Inches 72-hours SPAS 1276 DAD Zone 2				
Storm Representative SST	78.0 F	24			
Storm Representative SST Location	36.00 N	67.00 W		Jun	Jul
Maximum SST	80.0 F			77.5	81
Moisture Inflow Vector	ESE @ 610	Miles			
In-place Maximization Factor	1.10				
Temporal Transposition Date	5-Jul				
Transposition SST Location	36.70 N	67.20 W		Jun	Jul
Transposition Maximum SST	80.0 F			78	81
Transposition Adjustment Factor	1.03				
Average Basin Elevation	1,300				
Highest Elevation in Basin	3,120				
Inflow Barrier Height	N/A				
Elevation Adjustment Factor	1.03				
Total Adjustment Factor	1.13				

Probable Maximum Precipitation Study for Virginia

Task 5

Develop PMP

- Values will be provided on a gridded basis or other format
- Appropriate durations, 1-hr, 6-hr….as needed
  - Not confined to 72-hrs
  - ~2.5mi^2
- Analyze the orographic effects of elevated terrain
- Transposition limits for each storm will determined
  - Use the procedures developed in previous PMP studies
  - Precip frequency data to calculate the Orographic Transposition Factor
    - Corrects stippled region in HMR 51/52

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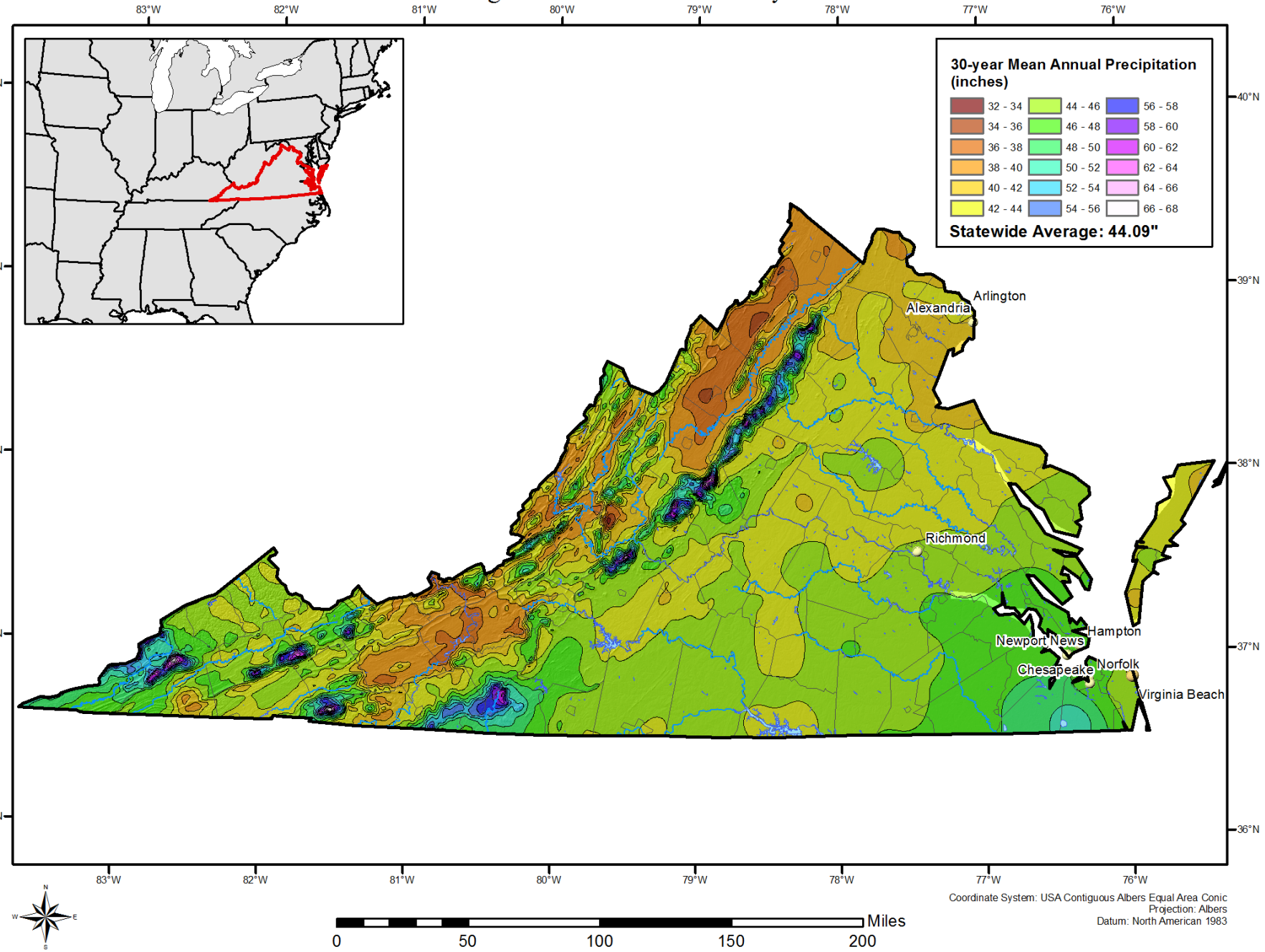
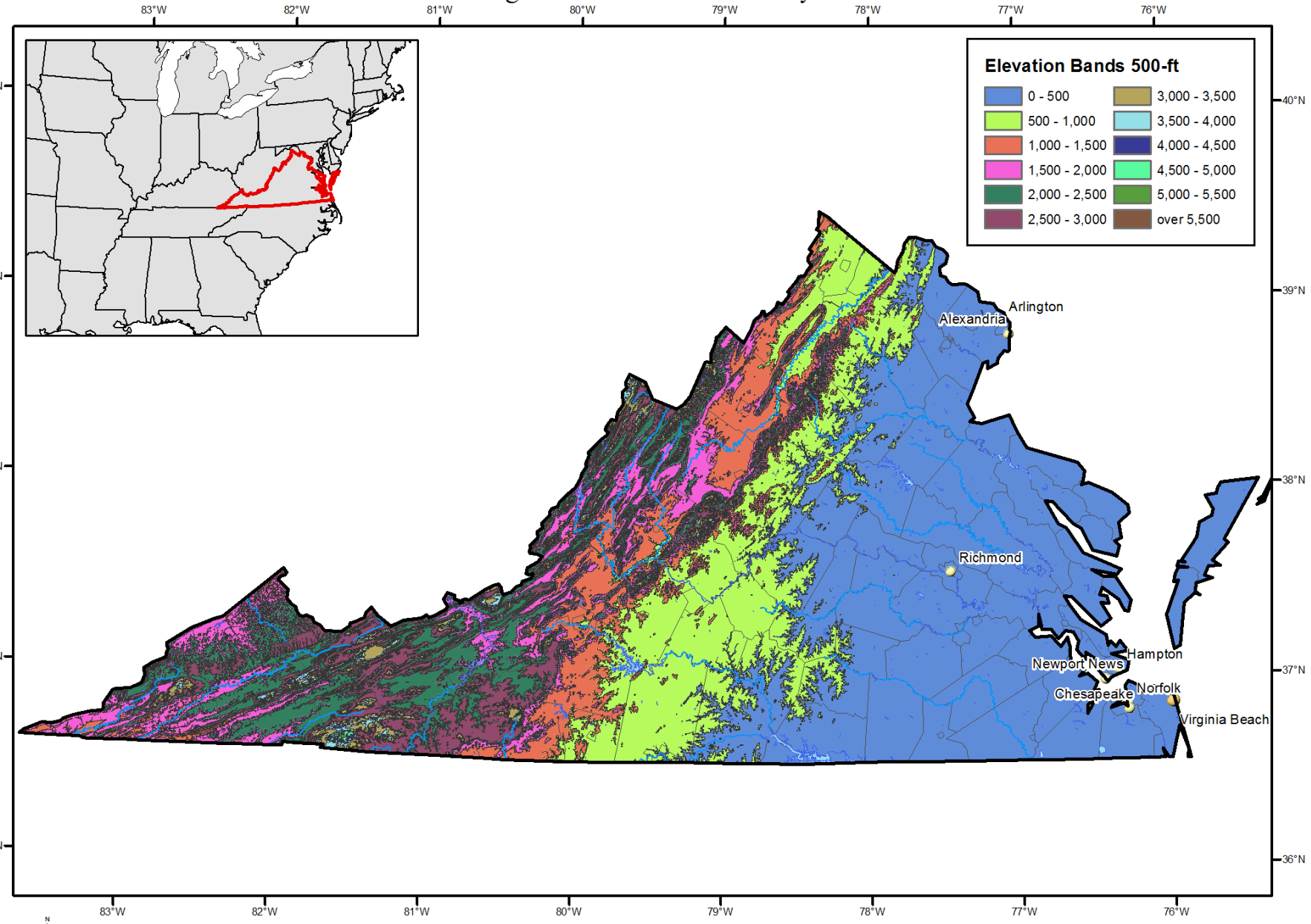
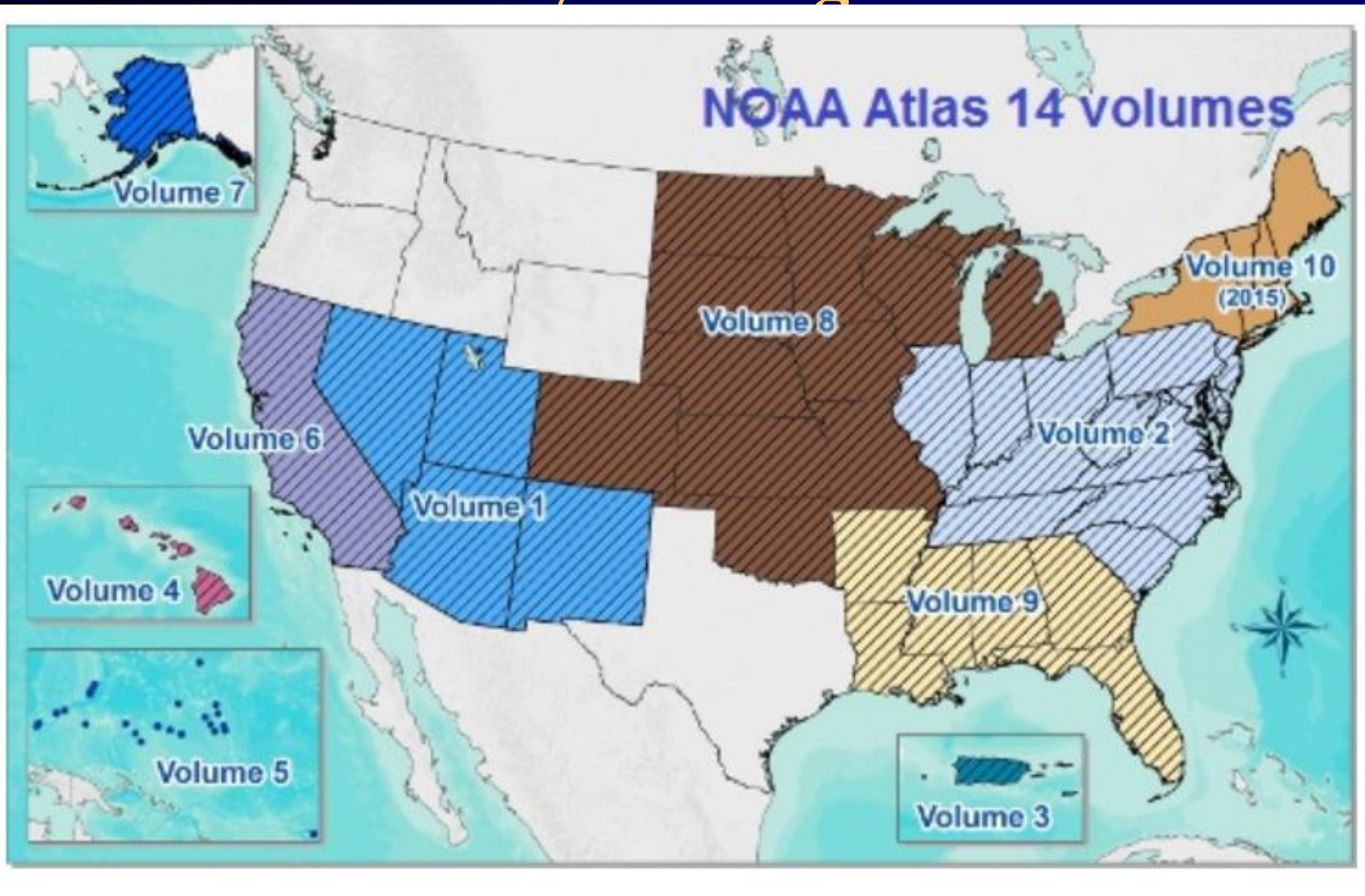
30-year Mean Annual Precipitation (1981-2010) in Inches
Virginia Statewide PMP Study



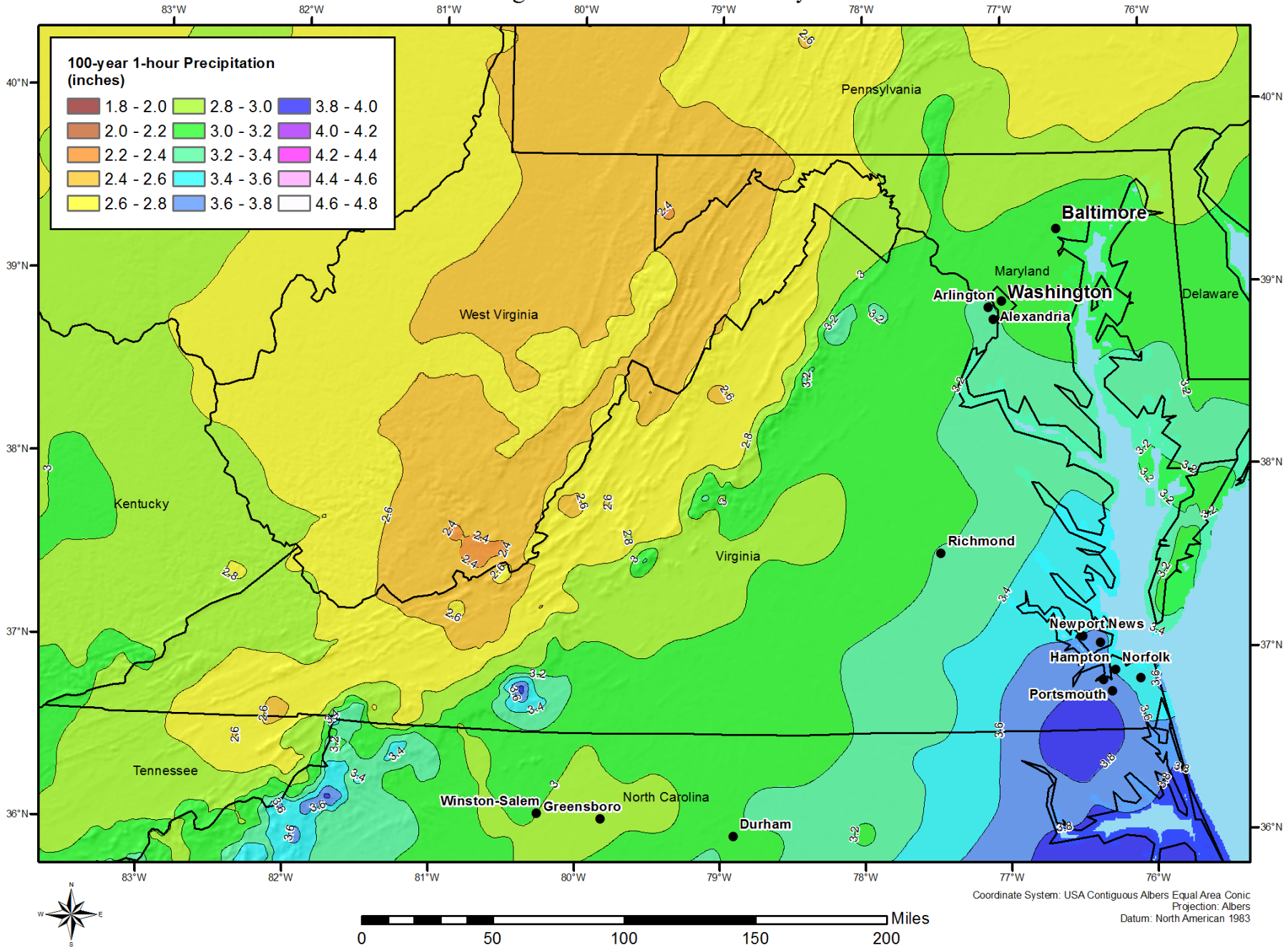
Elevation - 500 foot Contour Intervals
Virginia Statewide PMP Study



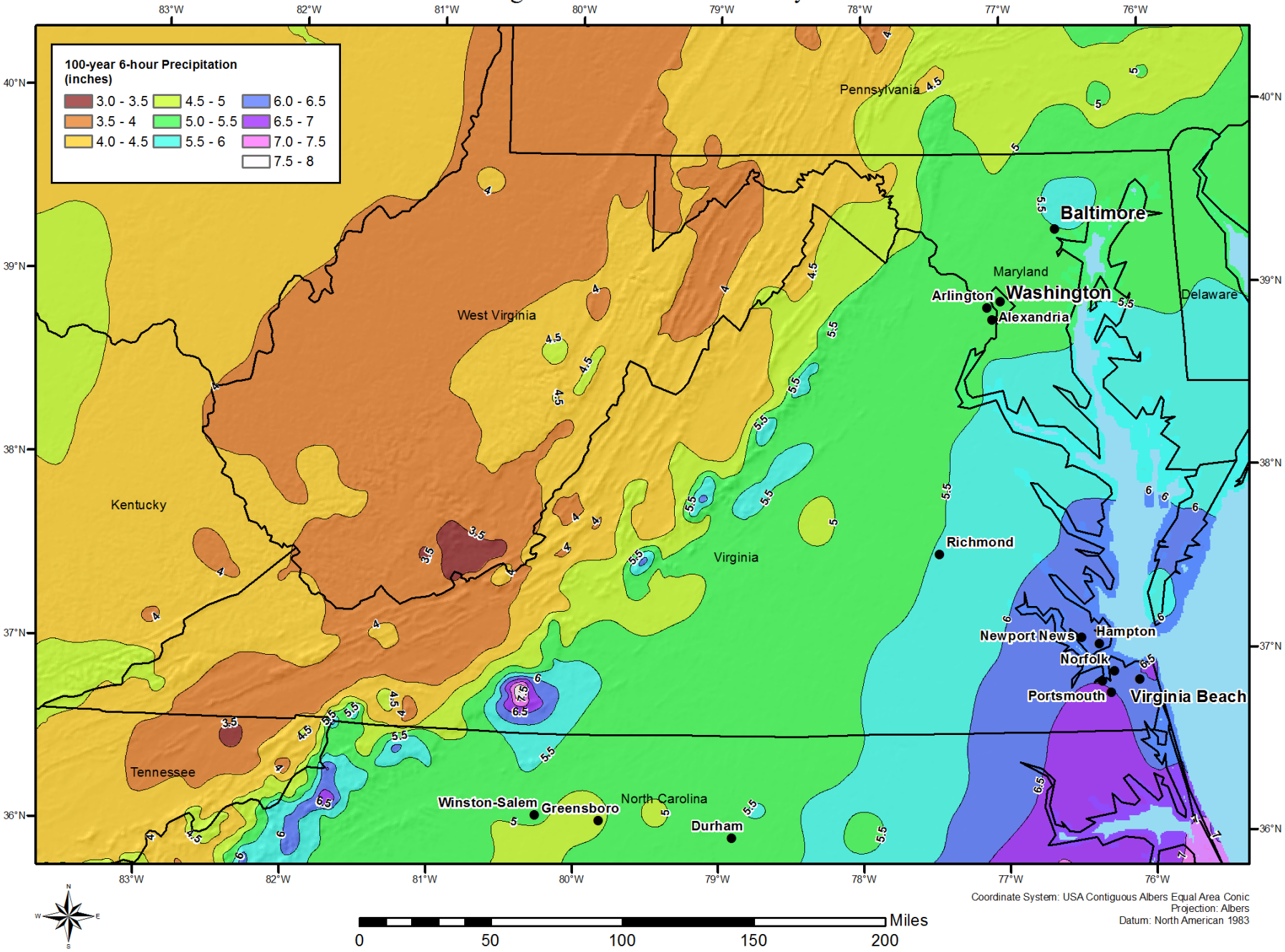
Probable Maximum Precipitation Study for Virginia



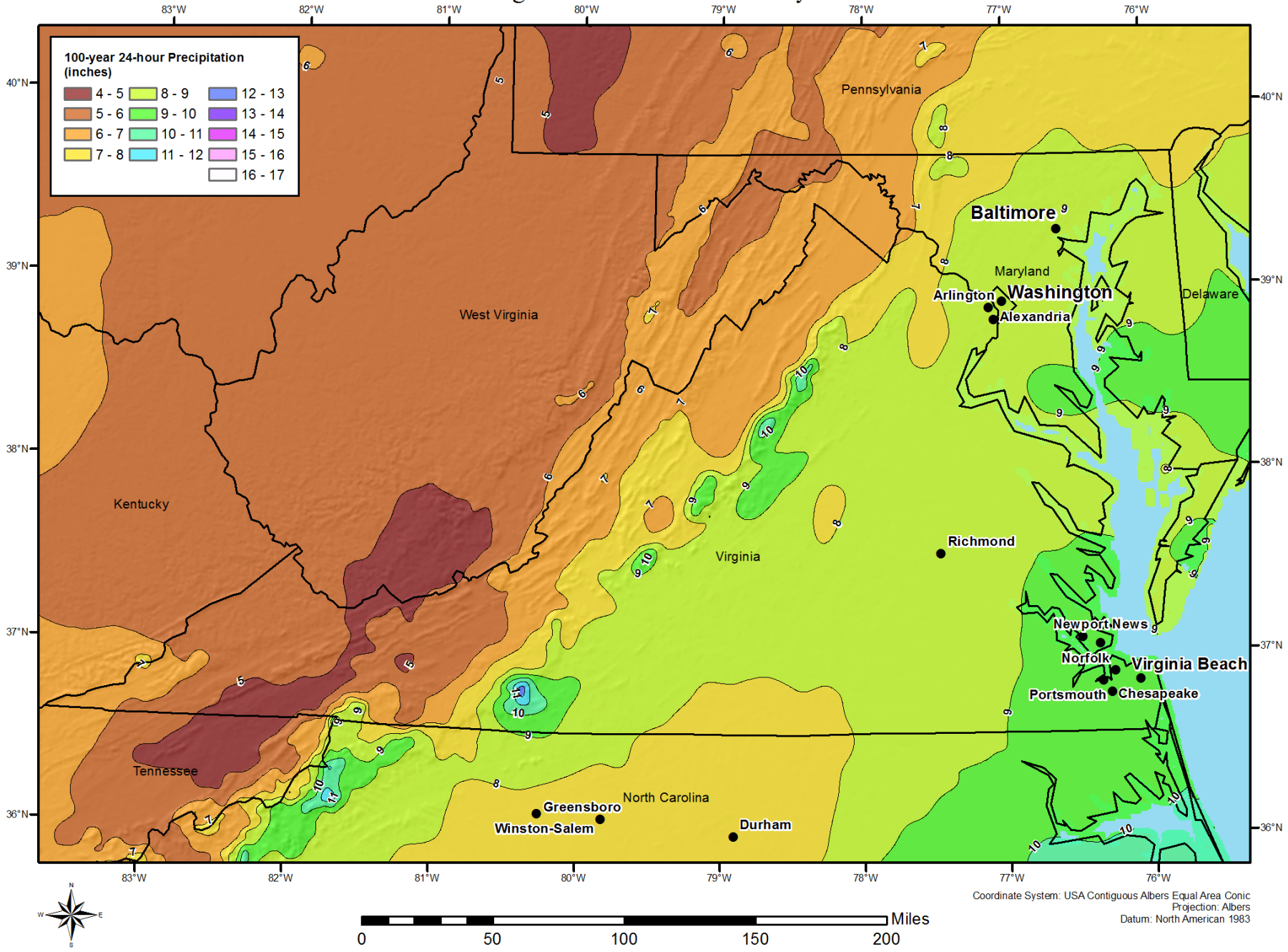
100-year 1-hour NOAA Atlas 14 Precipitation Estimates (inches)
Virginia Statewide PMP Study



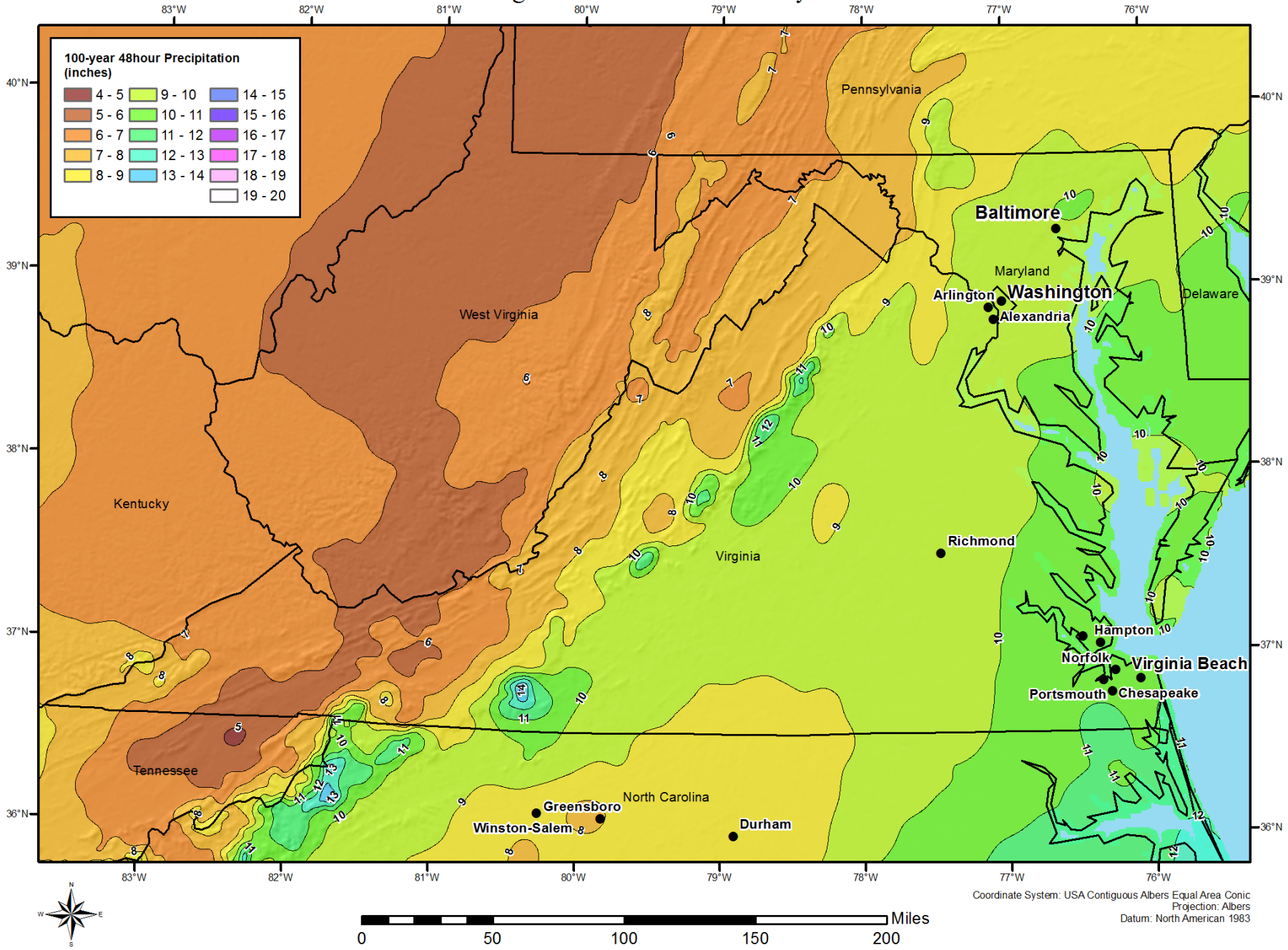
100-year 6-hour NOAA Atlas 14 Precipitation Estimates (inches)
Virginia Statewide PMP Study



100-year 24-hour NOAA Atlas 14 Precipitation Estimates (inches)
Virginia Statewide PMP Study



100-year 48-hour NOAA Atlas 14 Precipitation Estimates (inches)
Virginia Statewide PMP Study



Probable Maximum Precipitation Study for Virginia

Task 6

Quality Control and Sensitivity

- Compare results
  - HMR PMP values
  - NOAA Atlas 14 precip frequency data
- Discuss sensitivity of various parameters and assumptions on the final PMP values

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Probable Maximum Precipitation Study for Virginia

Task 7

Review Meetings

- Present and review the approach and procedures to be used as well as work completed
  - Pre-meeting packages will be provided to reviewers prior to each meeting
- Conference calls with reviewers and Virginia Dam Safety are planned between formal meetings to discuss technical issues
- A final meeting to present the results and provide discussions on the draft final report

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Probable Maximum Precipitation Study for Virginia

Task 8

Final Report

- A Draft final report will be submitted for review
- Review comments will be incorporated into a comprehensive final report as appropriate
- An appendix will be provided with all storm details and calculations used to determine the PMP values throughout the Virginia region
- Maps of PMP values will be provided both in the report as well as in GIS format

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Extra Slides

Questions

- Need peak flow data with date of occurrence for each watershed or major river/stream to help with seasonality and storm identification
- Seasonality
- How to handle TVA overlap and areas west of Appalachian crest

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