Current Capabilities for Developing Watershed Precipitation-Frequency Relationships and Storm-Related Inputs for Stochastic Flood Modeling for Use in Risk-Informed Decision-Making

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Acknowledgements

Many of the Advancements in Watershed Precipitation-Frequency and Storm-Related Inputs Were Accomplished in Assisting the Tennessee Valley Authority in Conducting Hydrologic Hazard Assessments for Dams in the Tennessee Valley

This was a Team Effort by:

MGS Engineering Consultants, Inc.

Meteorologists from MetStat Inc.

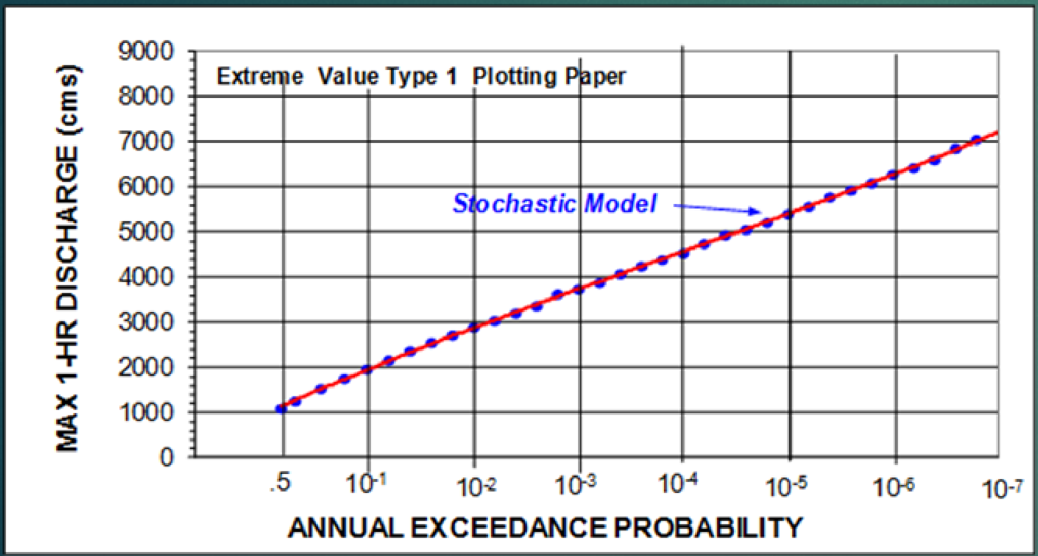
Hydrologists at RTI International

and Engineers at the Tennessee Valley Authority

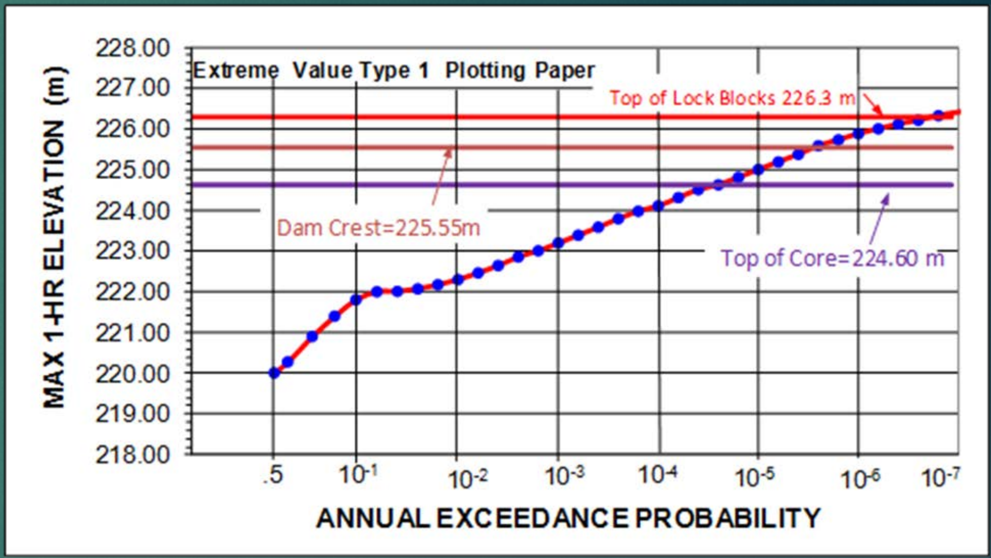
PFHA Application: Stochastic Flood Modeling

After Nearly 30-Years of Debate in the Dam Safety Community, Probabilistic Methods are Now an Accepted Alternative to Deterministic Methods for Assessing Hydrologic Performance at Dams

Flood Loading Condition - Hydrologic Hazard Curves



HHC for Peak Reservoir Inflow



HHC for Maximum Reservoir Level

Depth of Overtopping

Duration Above an Elevation of Interest

Reservoir Outflow

HHC for Any Flood Characteristic Generated in Flood Modeling for a Failure Mode of Interest

PFHA Application: Stochastic Flood Modeling

Detailed Stochastic Flood Modeling is the Preferred Method
for Assessing Hydrologic Risk at Federally Owned Dams in the U.S.
where Large Capital Expenditures are being Considered

Tennessee Valley Authority
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers

Detailed Stochastic Flood Modeling is also Being Conducted by:
BCHydro in British Columbia
Southern California Edison
Large Water Utilities in Australia

Why are Watershed PF Relationships Important?

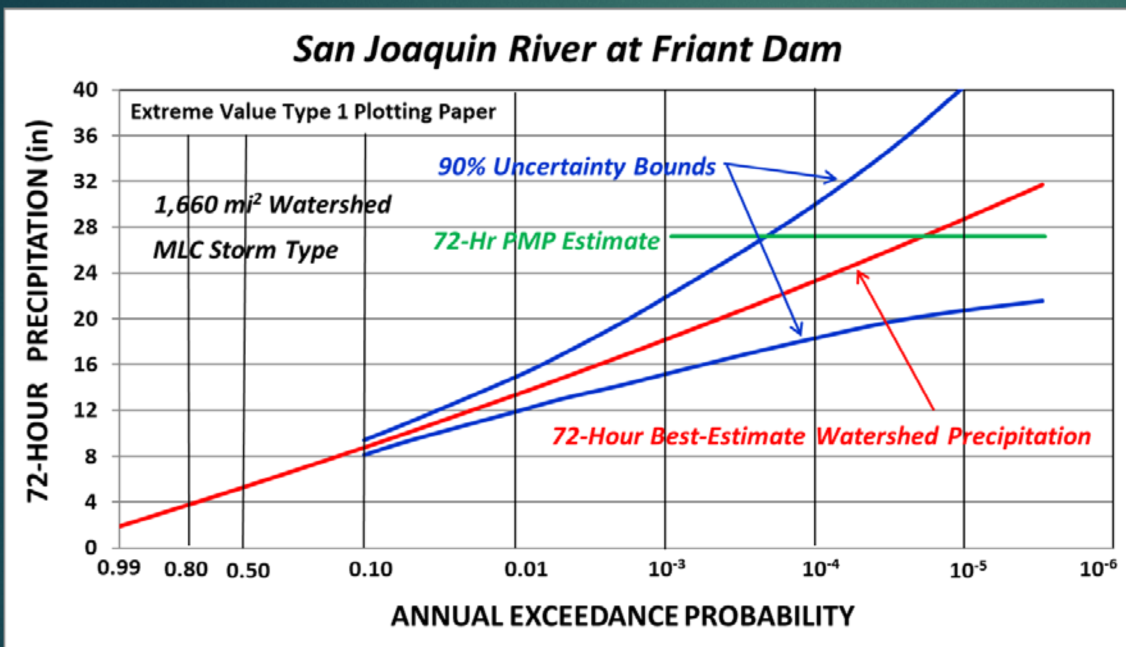
Watershed Precipitation-Frequency Relationship
is a Key Component in Stochastic Flood Modeling
for Assessing Hydrologic Risk

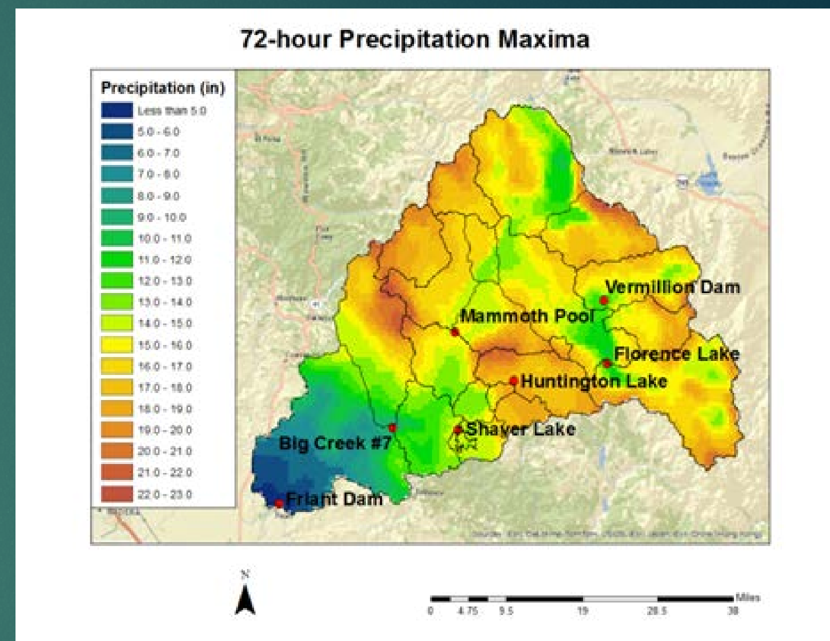
Decisions are Required by Federal Agencies and Private Companies
for Allocating Resources to Reduce Hydrologic Risks
at Large Capital Water Projects

Information about the Likelihood of Extreme Floods (10^{-5} and 10^{-6} AEP)
is Needed Because of the Very High Consequences of Failure
for Loss-of-Life and Economic Damages

Storm-Related Inputs are Dominant Inputs for Modeling

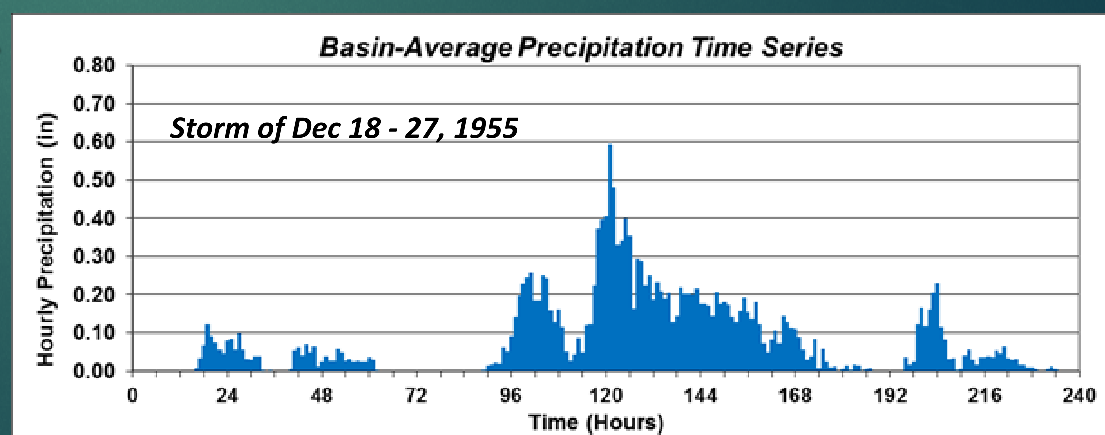
Watershed Precipitation-Frequency Relationship and Storm Spatial and Temporal Patterns are Dominant Inputs in Stochastic Flood Modeling





Large regional studies indicate PMP ranges from 10^{-4} to 10^{-9} AEP in North America

Generally more likely in coastal areas and less likely in inland areas with arid to semi-arid climates



Major Advancements in PFHA in Past 5 Years

Major Advancements Made in Meteorological Inputs in Past 5-Years for Conducting Probabilistic Flood Hazard Assessments (PFHA) for High Consequence Dams

Majority of Advancements Have Had Little Exposure Outside of Conference Proceedings

Presentation Goal:

Provide Update on Current Capabilities for Storm-Related Components Needed for Stochastic Flood Modeling

Major Advancements in Stochastic Flood Modeling

Methods are in Production Mode:

Storm Typing for Assembling Precipitation Annual Maxima Datasets

30-Year Evolution of SWT Climate Region Method for Regional PF Analysis

MetStorm Software: Storm Spatial and Temporal Analyses

Storm Transpositions using L-Moment Technology

Stochastic Storm Generation of Synoptic-Scale Storms

Stochastic Storm Transposition of Convective Mesoscale and Local Scale Storms

Precipitation-Frequency Areal Reduction Factors (ARFs) – by Storm Type

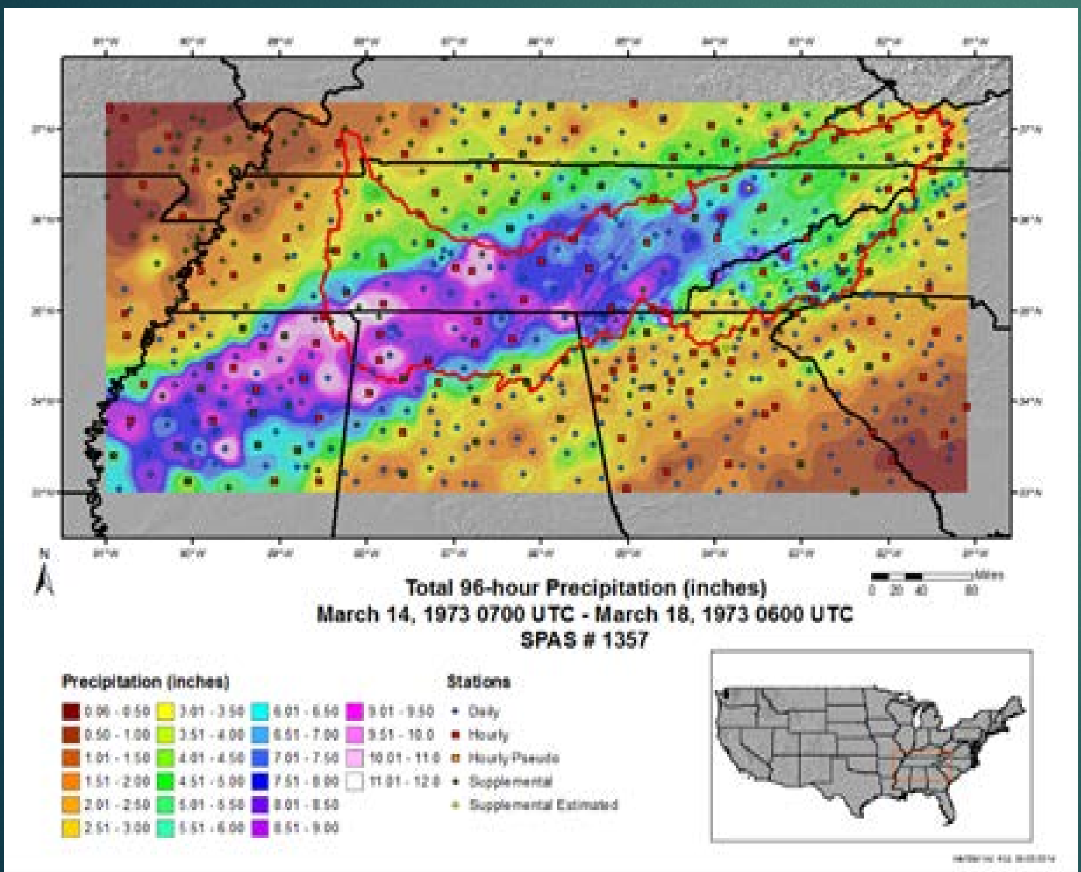
Use of Livneh Reanalysis Datasets to Aid Meteorological Inputs

Major Advancements in Past 5-Years in Watershed Precipitation-Frequency Development

Storm Typing (2014)

Create Homogeneous Datasets for Similar Meteorological Processes for Regional Precipitation-Frequency (PF) Analysis

Synoptic Scale Storms; Convective Mesoscale and Local Scale Storms



Example Synoptic Scale

Mid-Latitude Cyclone (MLC)

March 14-18, 1973

Tennessee, Alabama, Mississippi

Why is Storm Typing Important

Different Storm Types Have Different Characteristics

Important for Realistic Rainfall-Runoff Modeling

- Watershed Precipitation-Frequency Relationship
- Spatial and Temporal Storm Patterns
- Seasonality of Storm Occurrence

Preserve as Package

- Seasonality is a Consideration for:

  Antecedent Soil Moisture; Initial Streamflow, Reservoir Level,

  Antecedent Snowpack, 1,000-mb Temperature, Freezing Level

Storm-Related Inputs Must be Preserved as a Package

for Realistic Hydrologic Modeling of Floods, Particularly Extreme Floods

Storm Typing

Synoptic Scale Storm Types

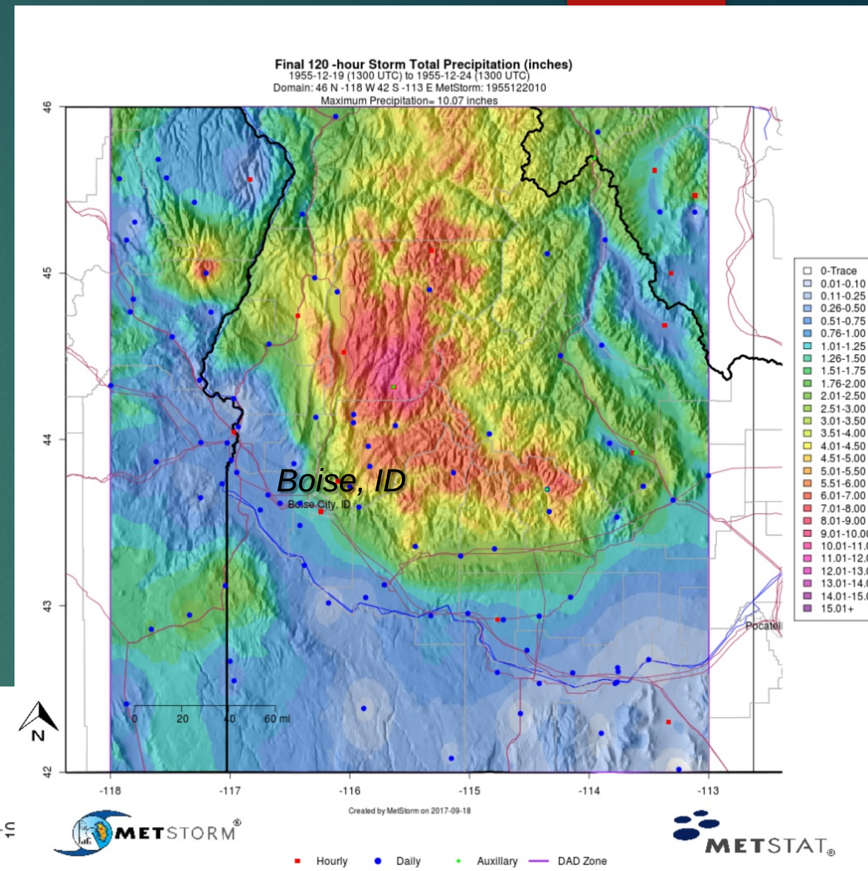
Mid-Latitude Cyclone (MLC)

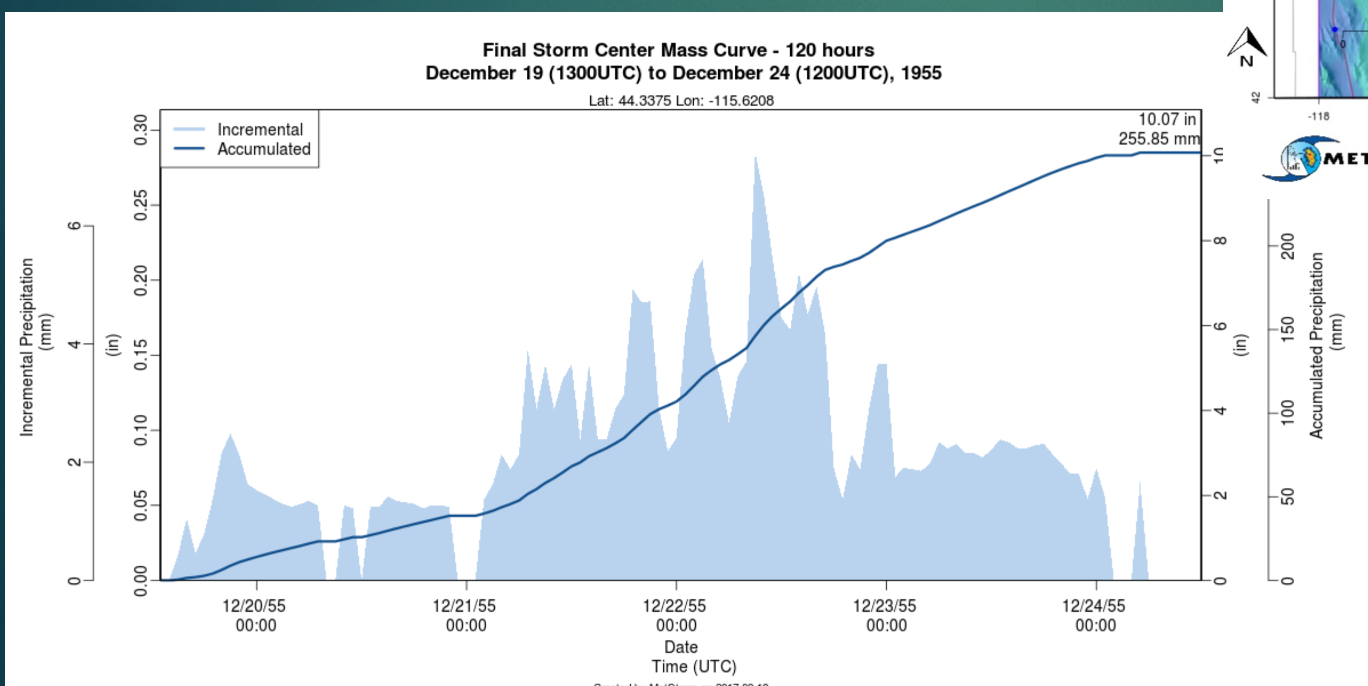
Tropical Storm Remnant (TSR)

Large Areal Coverage

Long-Duration (multi-day)

Low to Moderate Intensities





Max Intensity for

12/24/1955 Storm

0.27 in/hr

Storm Typing

Mesoscale Storm Type

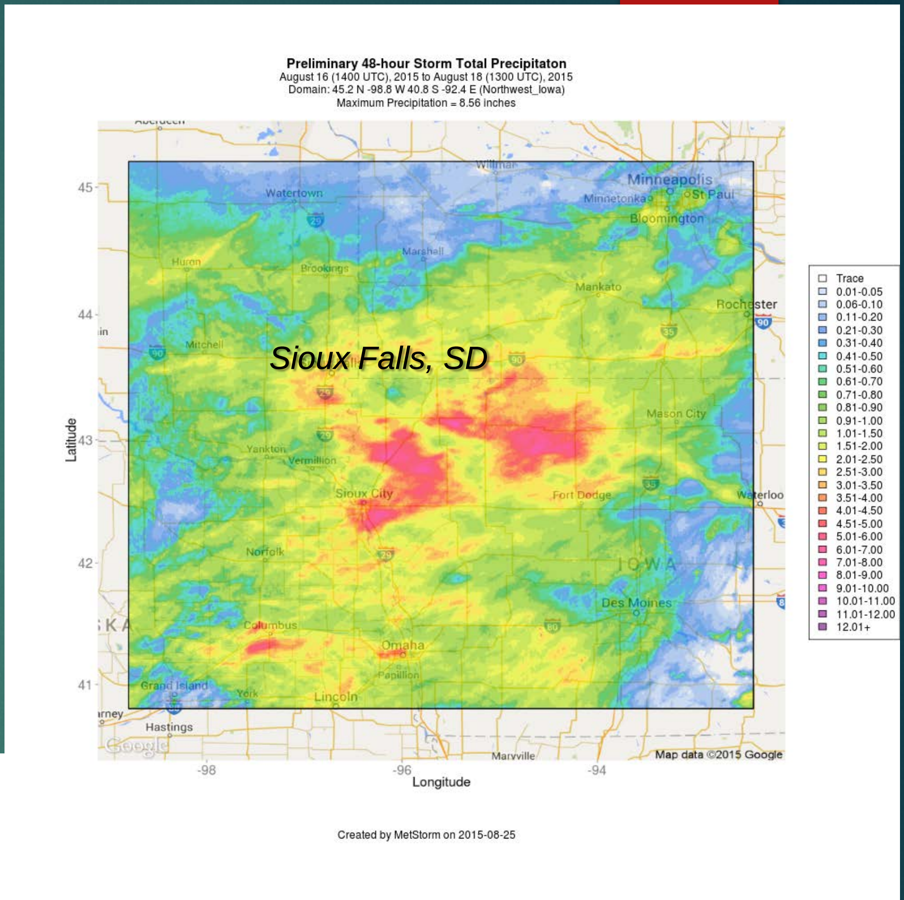
Mesoscale Storm

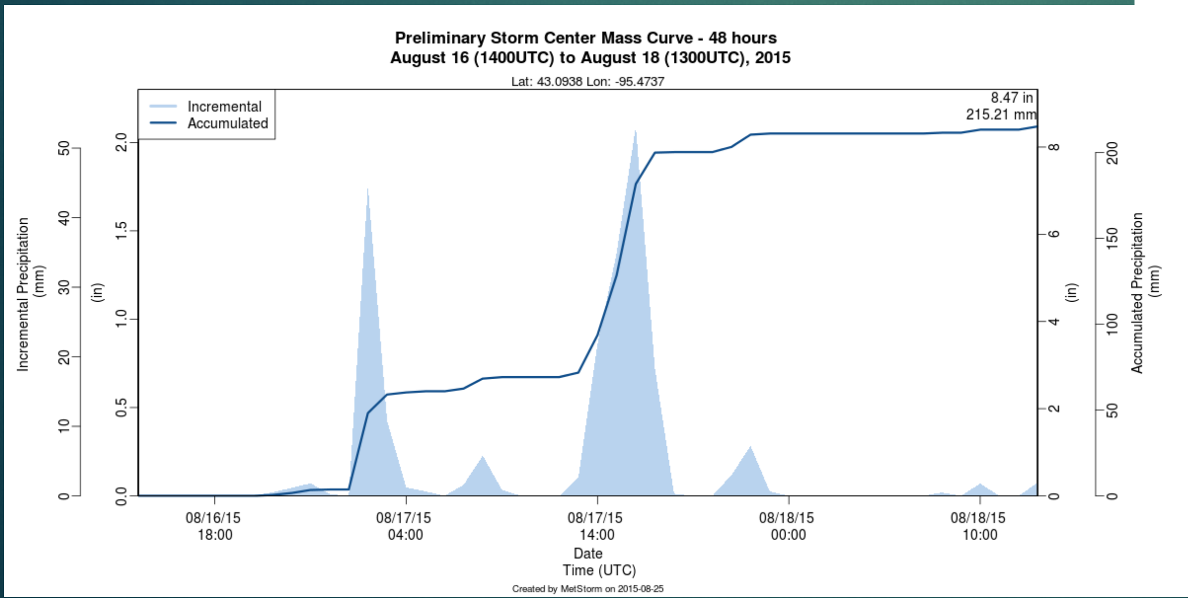
with Embedded Convection (MEC)

Moderate Areal Coverage

Intermediate-Duration (3 to12-hrs)

Moderate to Very High Intensities





Max Intensity for

8/17/2015 Storm

2.10 in/hr

Storm Typing

Local Scale Storm Type

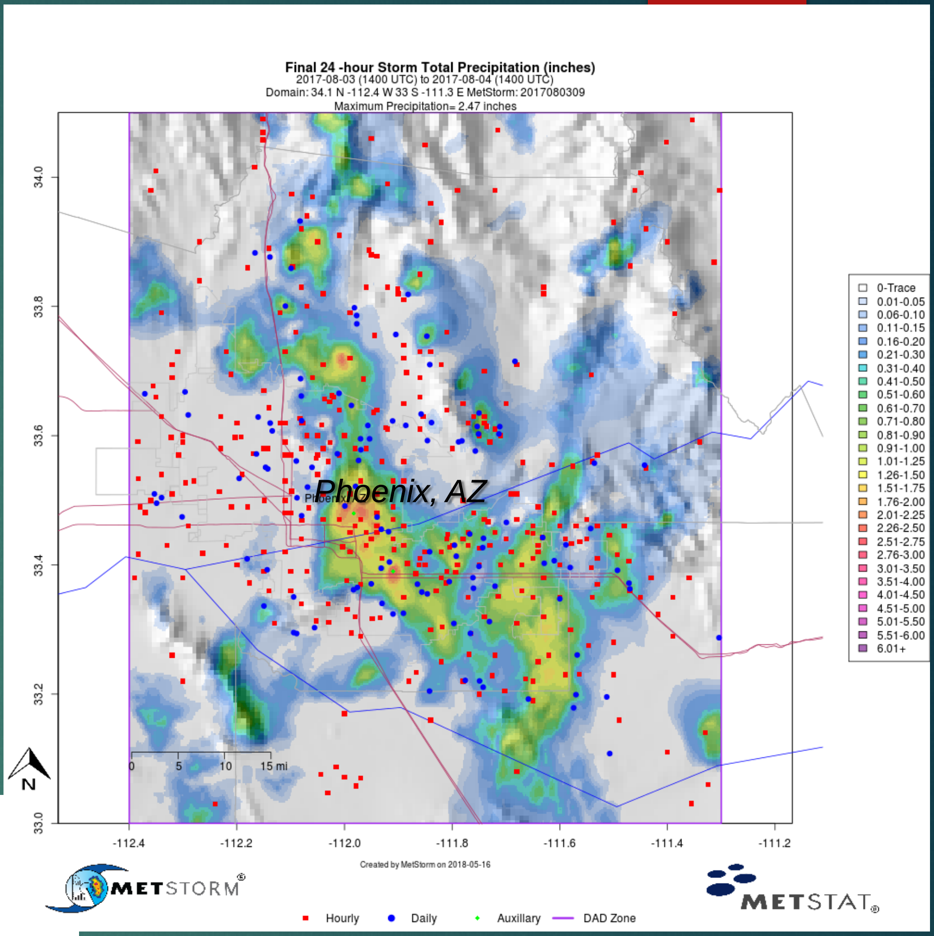
Local Storm (LS)

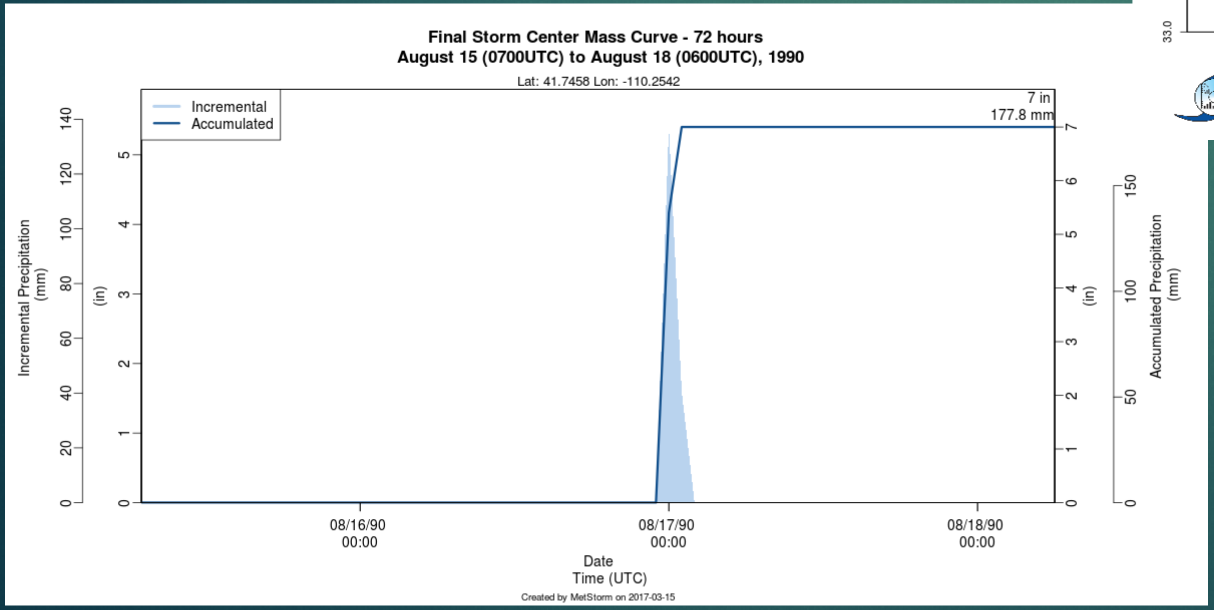
(Convective Event)

Small Areal Coverage

Short-Duration (0.5 to 3-hrs)

High to Very High Intensities





Max Intensity for

8/16/1990 Storm

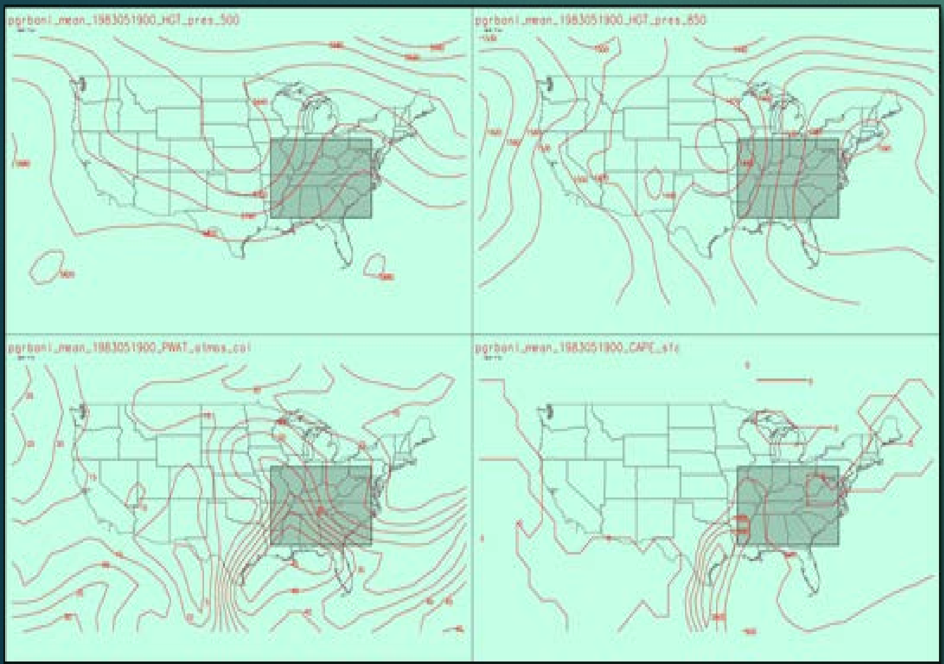
5.00 in/hr

How is Storm Typing Conducted

Several Hundred of the Largest Storms at Different Durations are Manually Storm-Typed by Meteorologists

Expert System is Created based on Metrics from Manually Typed Storms

Database of Daily Storm Types (DDST) is Created for 2° x 2° Grid-cells over Study Area



- *Areal Extent of Observed Precipitation*
- *Surface, 850-mb and 500-mb Heights*
- *Magnitude of Pressure Gradients*
- *Magnitude of Precipitable Water (mm)*
- *Magnitude of Convective Available Potential Energy (CAPE)*
- *Storm Seasonality*

Storm Typing Leads to Flood Typing

Separate Precipitation Annual Maxima Series Datasets are Created for Each Storm Type of Interest

Allows Development of Separate Watershed PF Relationships, Spatial and Temporal Storm Patterns and Seasonality Applicable to Each Storm Type

Separate Stochastic Flood Models are Developed for Each Storm/Flood Type

Allows Separate Hydrologic Hazard Curves to be Developed for Each Storm/Flood Type which Addresses the Problem of <u>Mixed Populations of Floods</u>

Continued 30-Year Evolution of Regional Precipitation-Frequency Analysis

Schaefer-Wallis-Taylor (SWT) Climate Region Method (1989)

Spatial Mapping of L-Moments for Selected Storm Types

Locations where Large Regional Studies have been Conducted

http://www.mgsengr.com/downloads/RegionalPrecipFrequencyReports_2019.zip

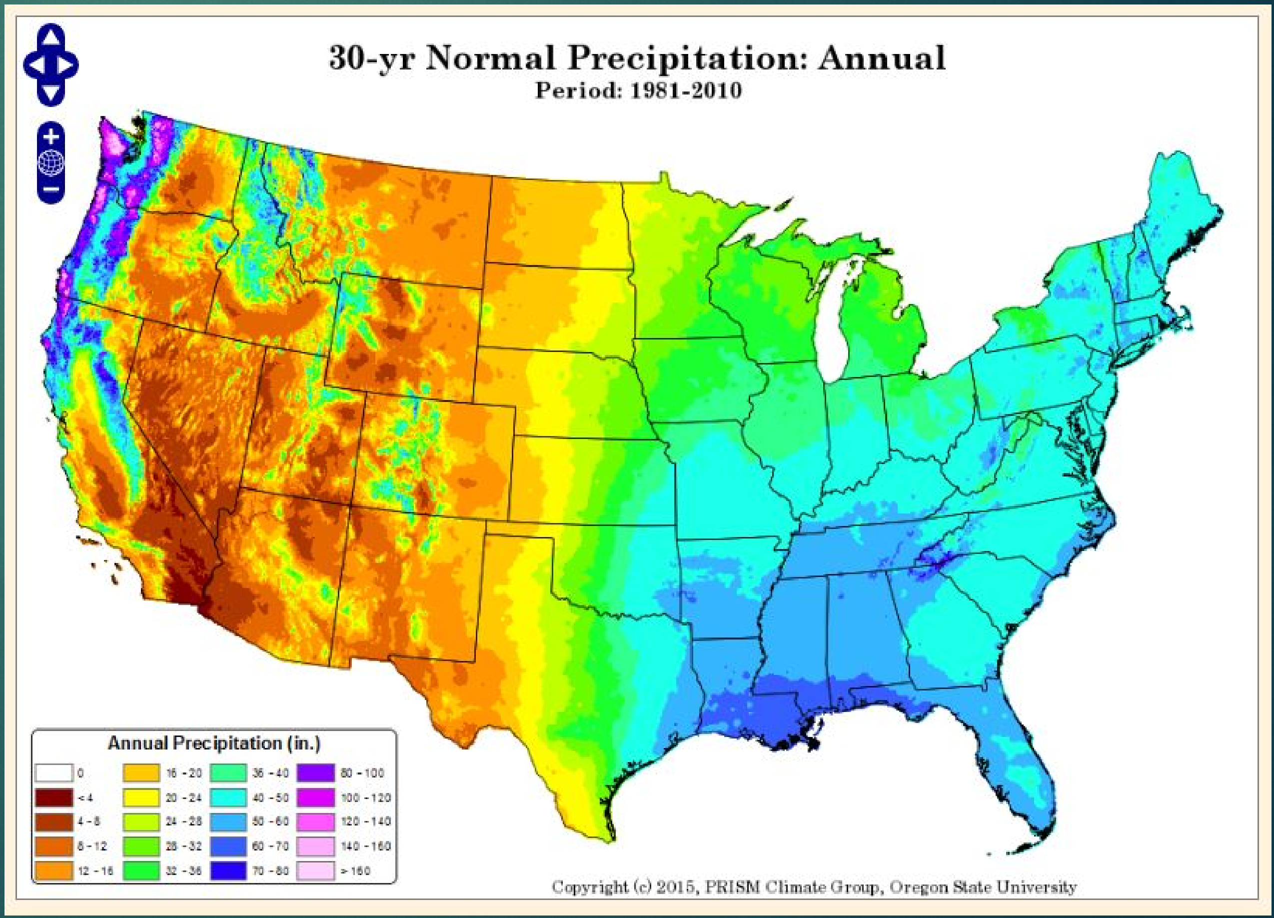
Technical Memoranda: SWT Method; Stochastic Storm Generation (MLC, TSR) and Stochastic Storm Transposition (MEC)

SWT Method → Spatial Mapping of L-Moments

Experience from Large Regional Studies have shown systematic variation of At-Site Means and Regional L-Cv and L-Skewness with Climatological Indicators such as Mean Annual Precipitation (MAP) and Mean Monthly Precipitation (MMP) for Dominant Months for a Storm Type

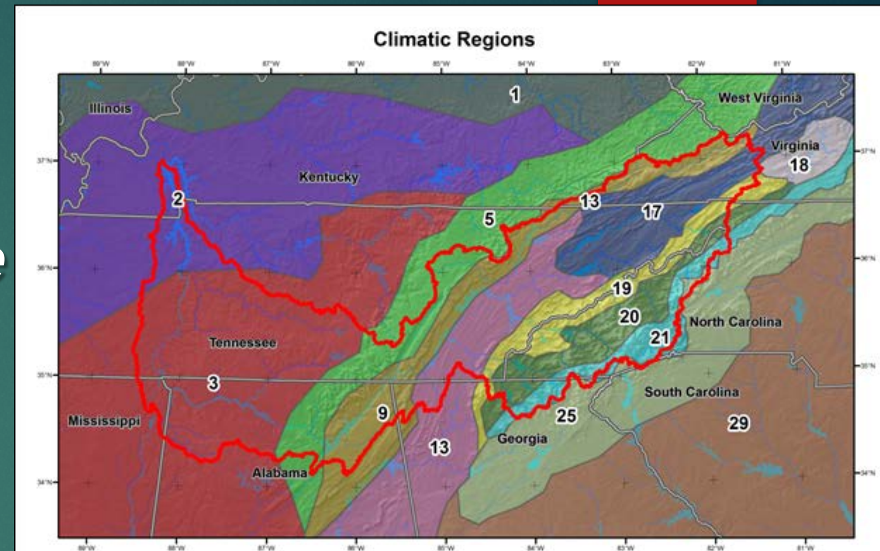
MAP and MMP have provided high explanatory power in areas with a wide range of MAP or MMP

Latitude and Longitude have also been used as auxiliary variables in areas of modest climate variability

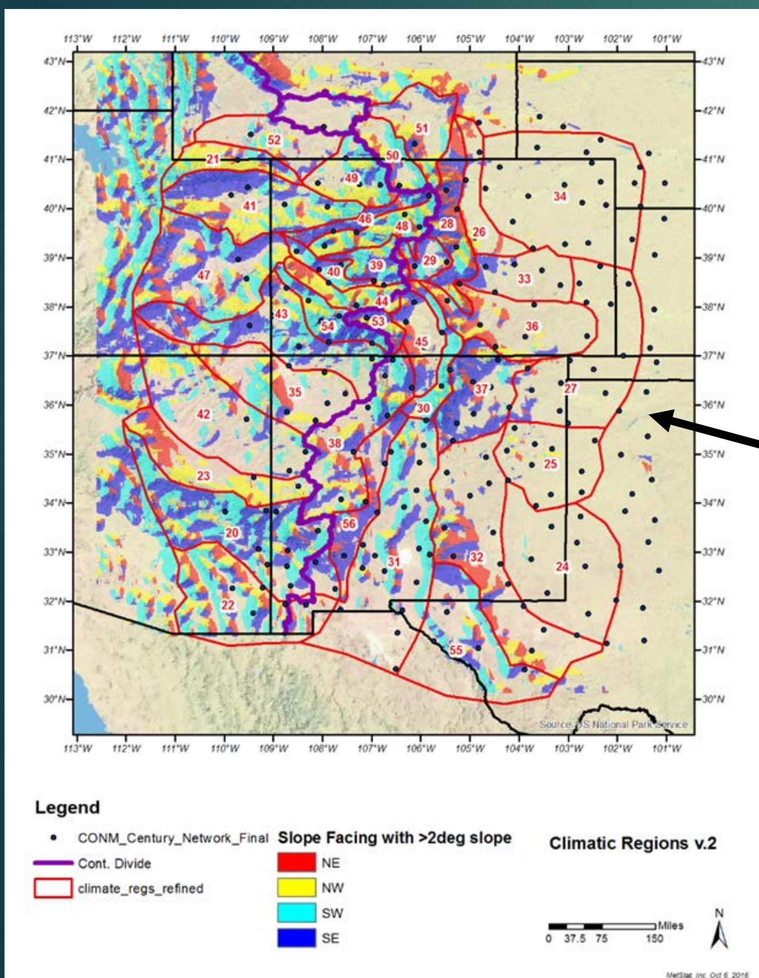


SWT Climate Region Method

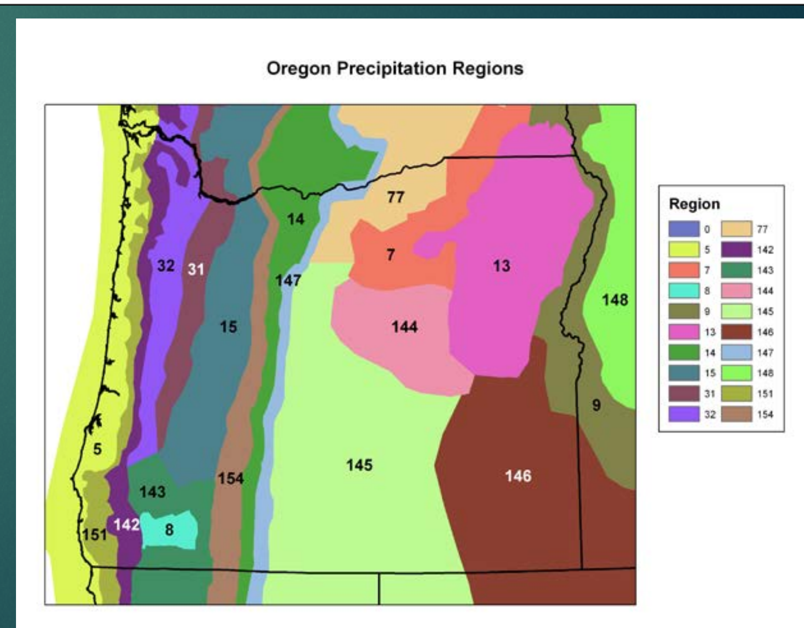
Heterogeneous Climate Regions
are a temporary construct
to facilitate spatial mapping of
L-Moment Statistics for a given Storm Type



Tennessee Valley Study Area
13 Heterogeneous Climate Regions

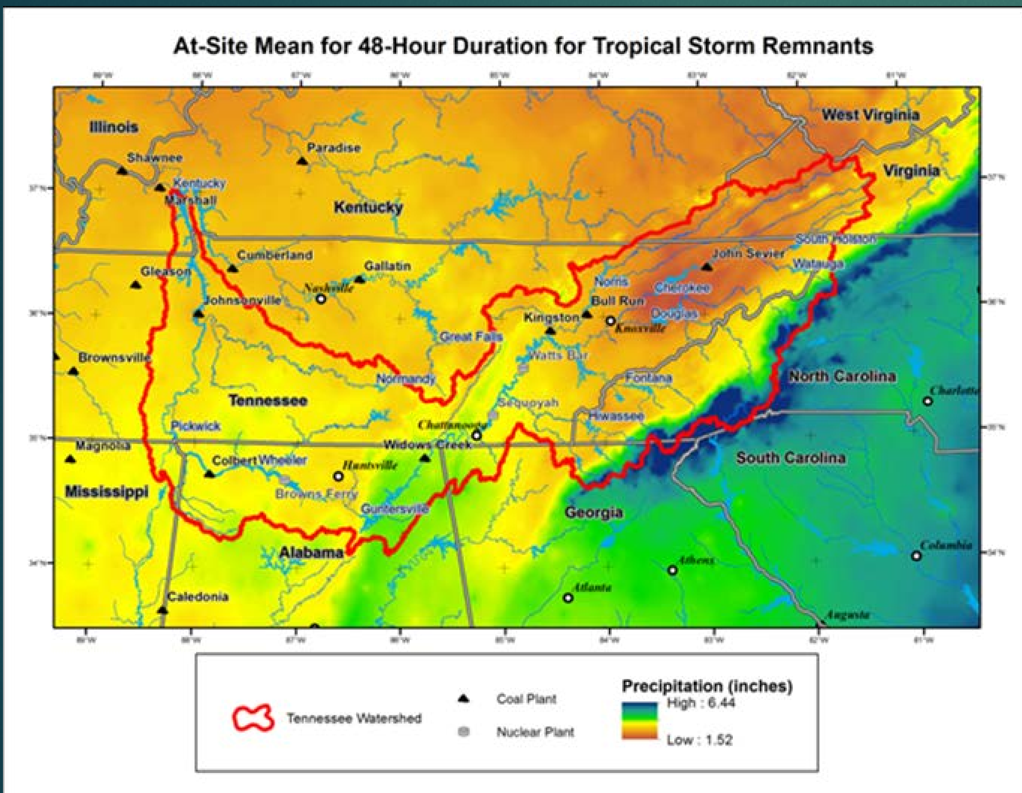


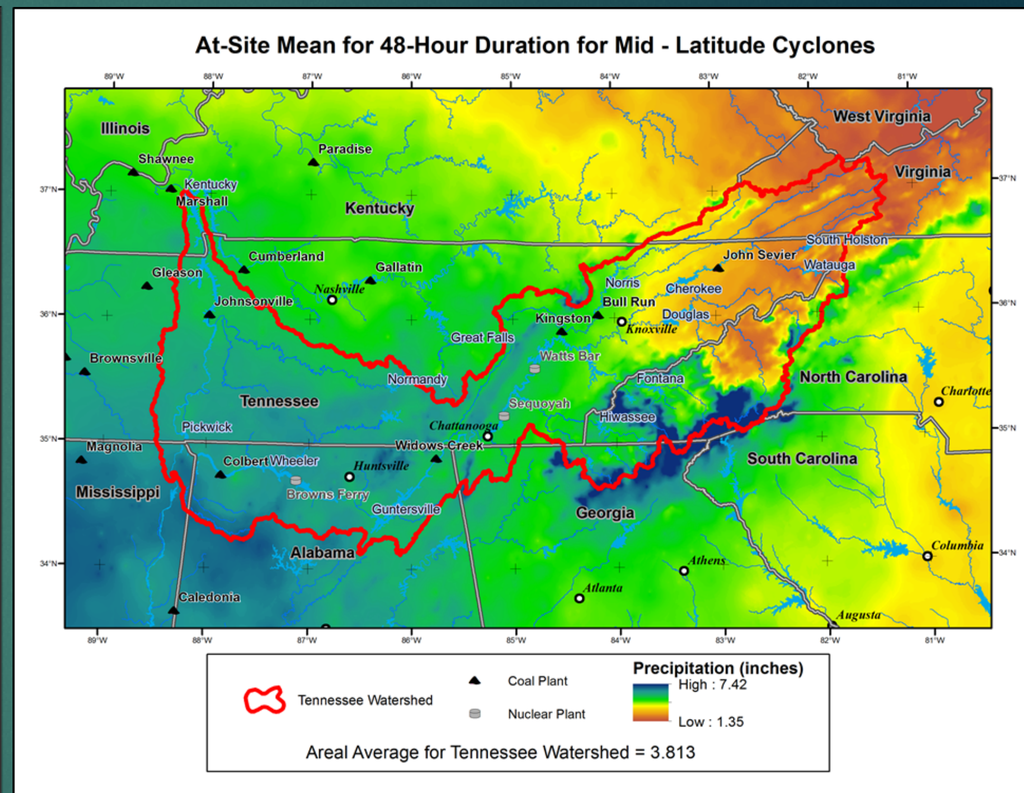
Colorado
and New Mexico
Study Area
41 Heterogeneous
Climate Regions
based on MAP,
Slope and Aspect
of Mountainous
Terrain



Spatial Mapping of L-Moments

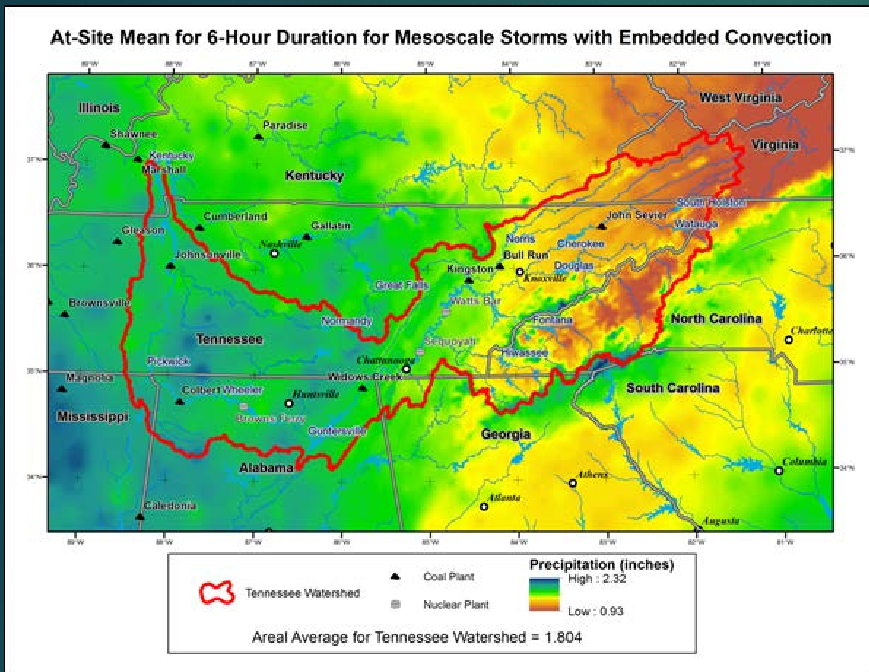
L-Moments Spatially Vary in a Systematic Manner with Climatic, Meteorological and Physiographic Conditions

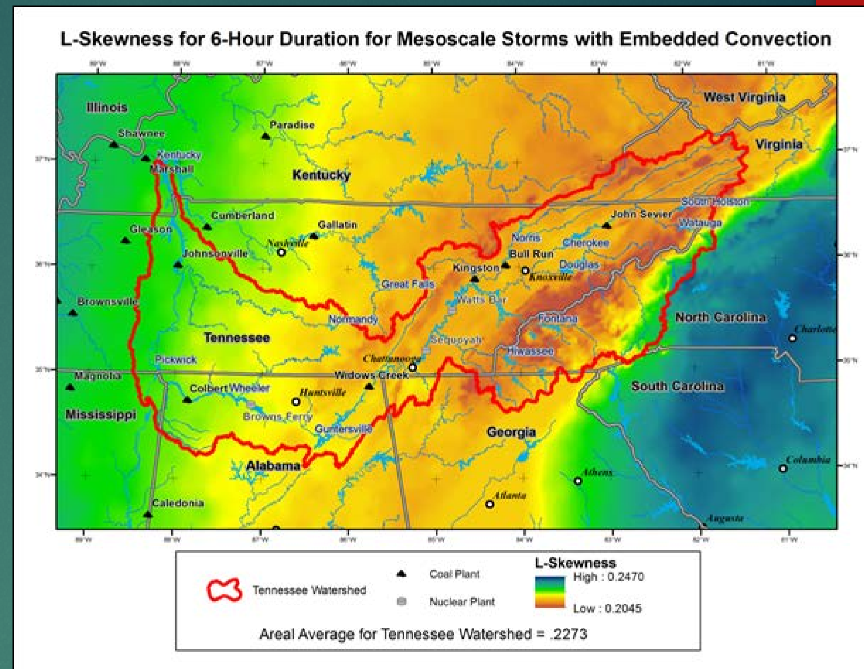




Frequency Analysis of Precipitation Associated with Tropical Storms and Tropical Storm Moisture Sources Now Possible With Use of Storm Typing

Quantile Estimates for Selected Locations

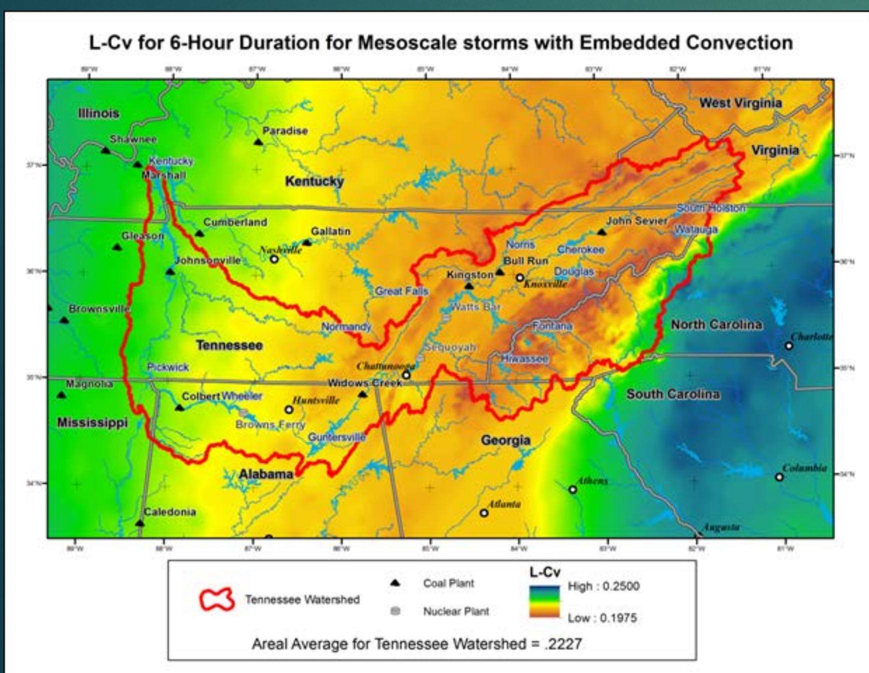


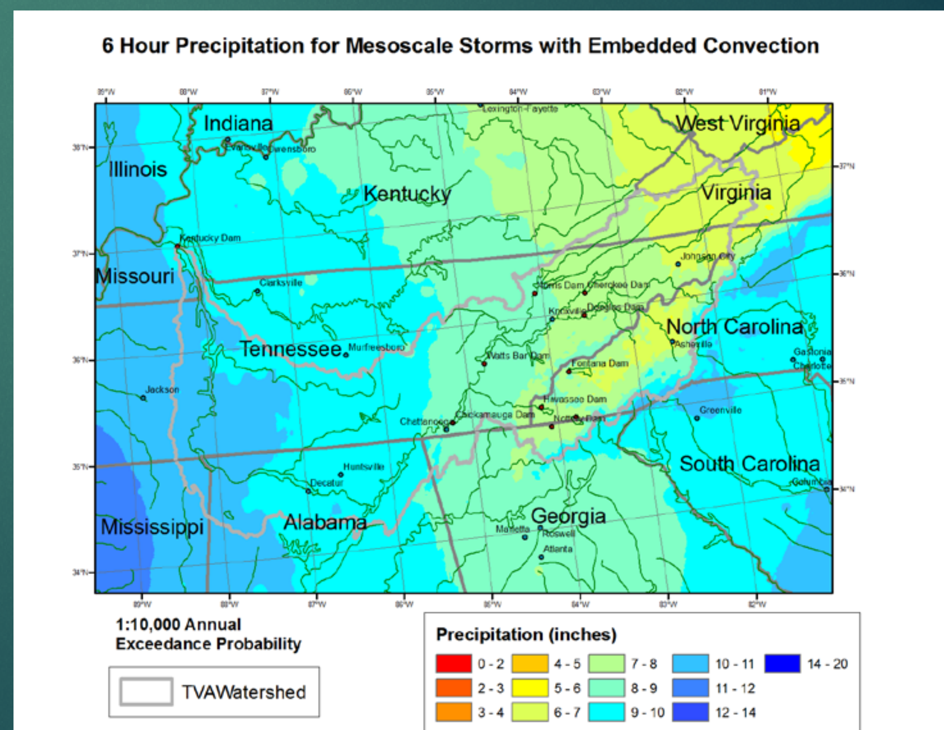


MEC

Storm

Type





Major Advancements in Past 5-Years in Watershed Precipitation-Frequency Development

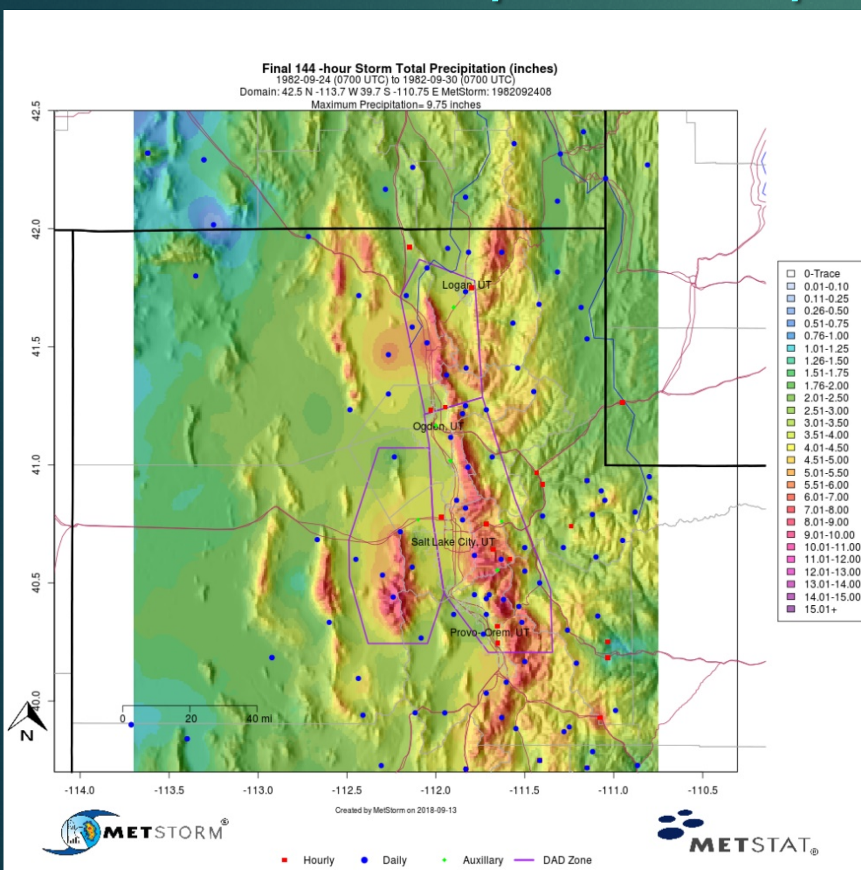
MetStorm - Storm Analysis Software by MetStat (2014-2015)

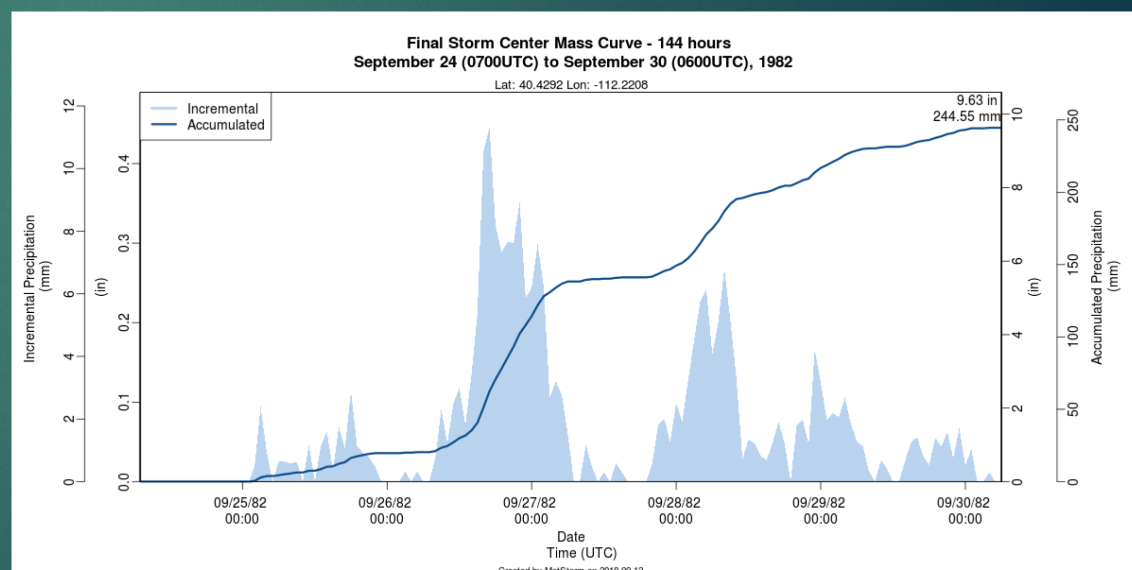
MetStorm is the Second Generation of SPAS

for Spatial and Temporal Analysis of Storms

Adds Capability for Dual-Pole Radar, Satellite Data

and Advanced Spatial Interpolation Particularly for Mountainous Terrain





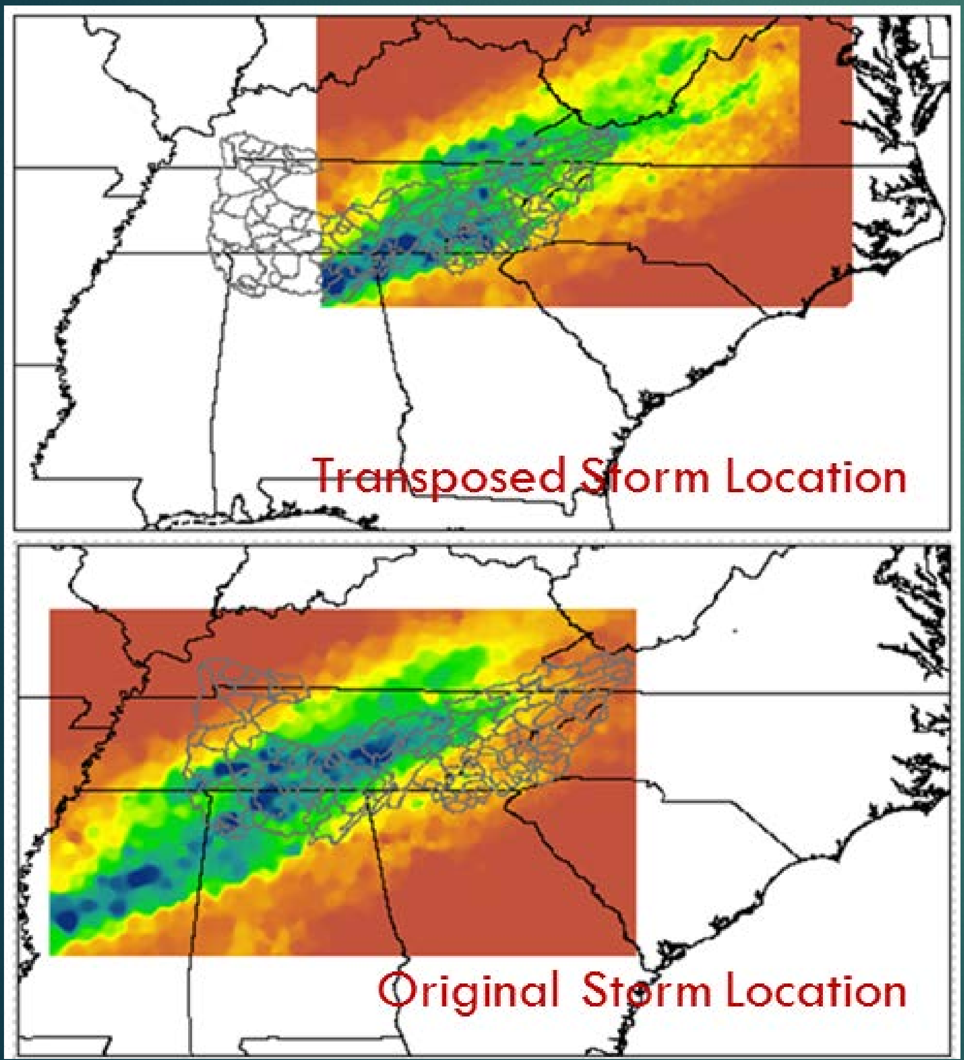
Synoptic Scale Mid-Latitude Cyclone

Wasatch Mountains, Utah

Major Advancements in Past 5-Years

Enhanced Storm Transposition Procedure (ESTP) (2015-2016)

Storm Transpositions using L-Moment Statistics



Provides for

Spatial and Temporal Patterns

to be Transposed Whole-Cloth

while Accounting for

Climatic Differences

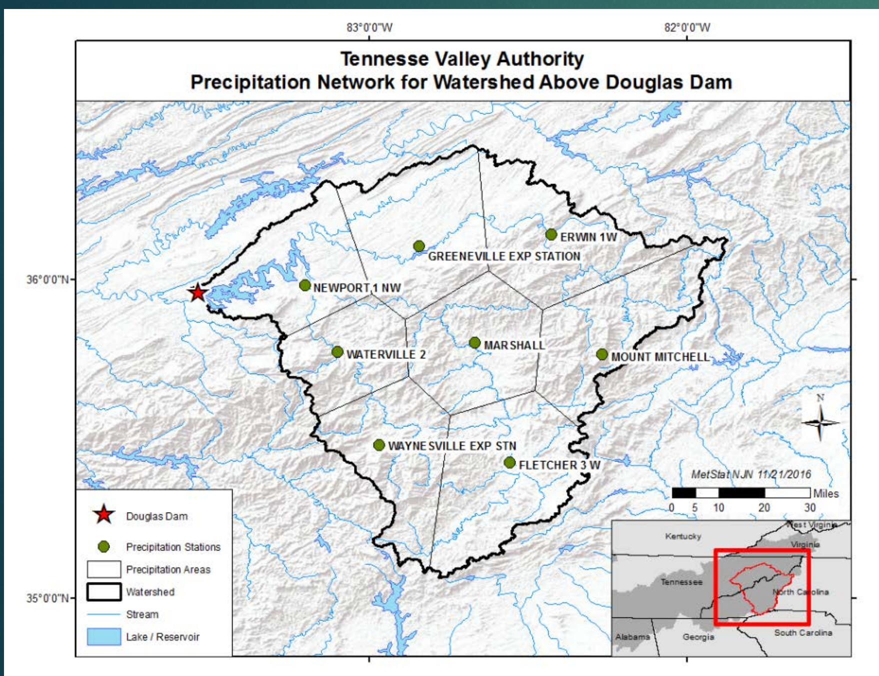
in Storm Source and Target Locations

Major Advancement Over Past Practice
of Transferring D-A-D Statistics

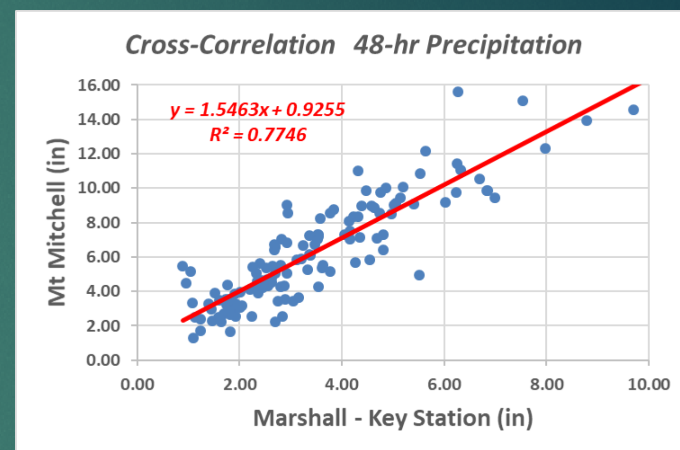
Major Advancements in Past 5-Years in Watershed Precipitation-Frequency Development

Stochastic Storm Generation for Synoptic-Scale Storms (2015)

Use Point PF Findings and Spatial Correlation Structure of Historical Storms to Generate Watershed PF Relationship



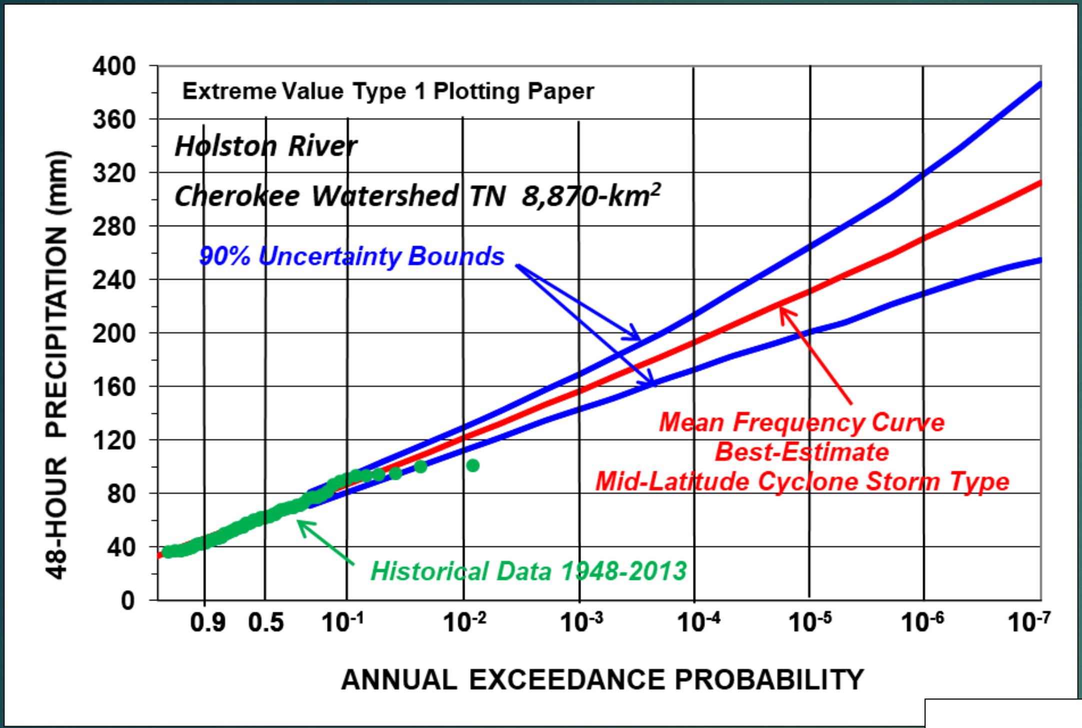
Station Network
Douglas Dam Watershed 4,540 mi²

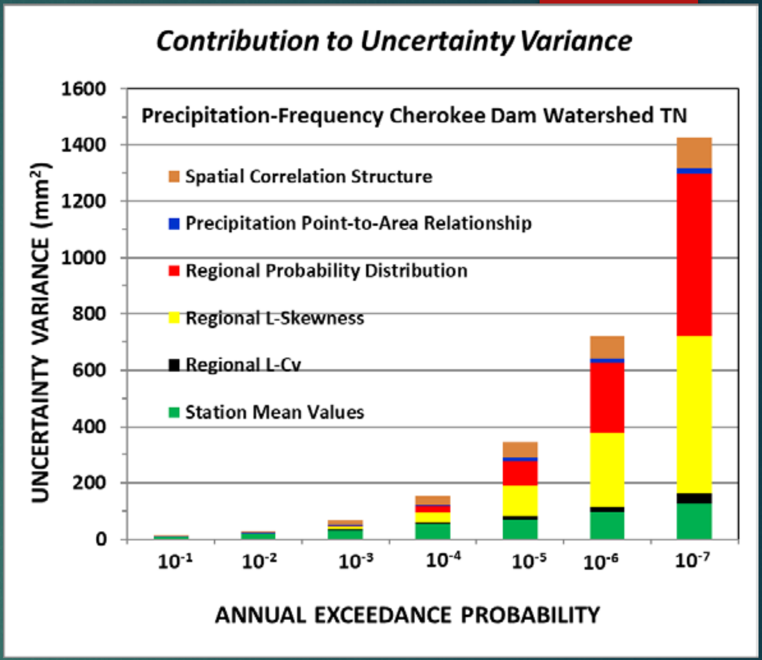


	Marshall	Newport 1NW	Greeneville ES	Erwin 1W	Mt Mitchell	Fletcher 3W	Waynesville ES	Waterville 2
Marshall	1.000							
Newport 1NW	0.709	1.000						
Greeneville ES	0.777	0.899	1.000					
Erwin 1W	0.855	0.772	0.858	1.000				
Mt Mitchell	0.894	0.645	0.693	0.816	1.000			
Fletcher 3W	0.785	0.543	0.577	0.685	0.862	1.000		
Waynesville ES	0.861	0.703	0.731	0.752	0.856	0.808	1.000	
Waterville 2	0.815	0.866	0.890	0.810	0.716	0.608	0.780	1.000

Spatial Correlation Structure 128 Storms

MLC Watershed Precipitation-Frequency Relationships





Synoptic Scale

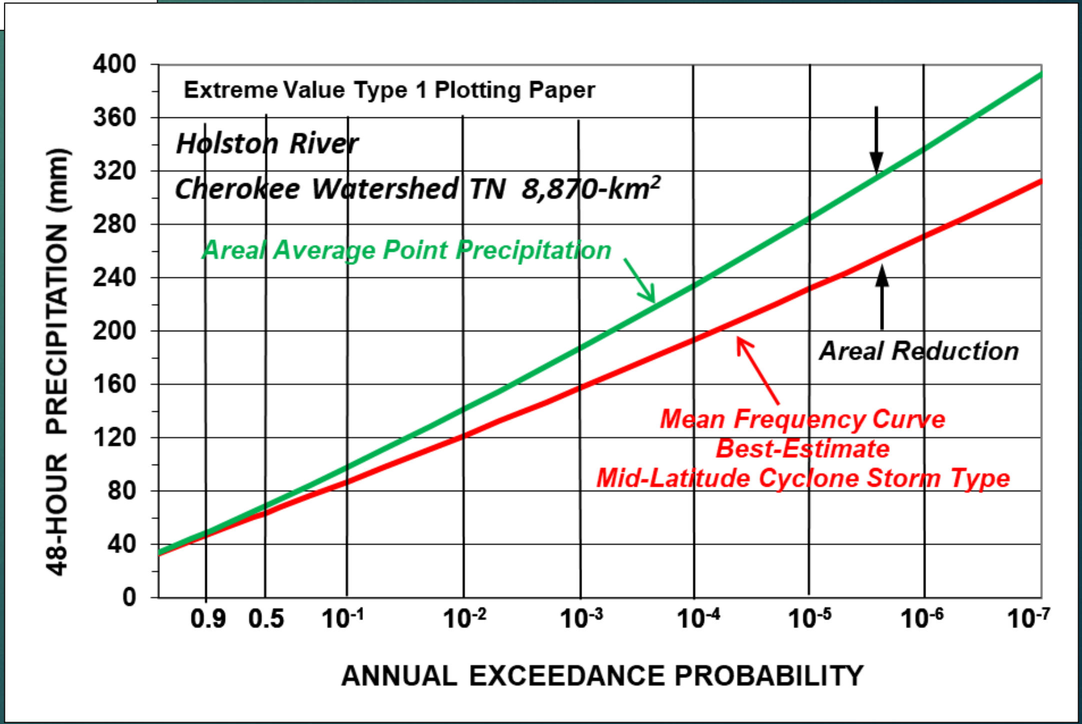
Mid-Latitude Cyclone Storm Type

981 Stations; 50,186 Station-Years

Spatial Analyses 90 Mid-Latitude Cyclones

74 Historical Storms on Watershed

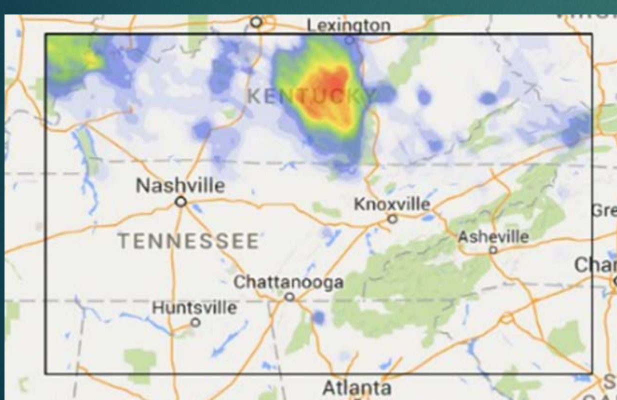
16 Storms Transposed to Watershed

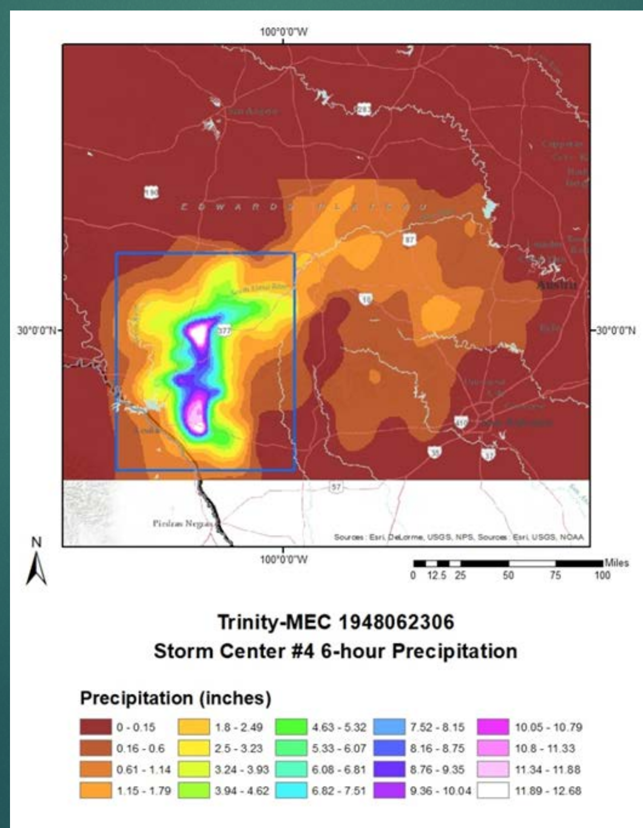


Major Advancements in Past 5-Years in Watershed Precipitation-Frequency Development

Stochastic Storm Generation for Convective Storms (2015)

Use Point PF Findings and Resampling of Spatial Patterns of Convective Historical Storms (Stochastic Storm Transposition) to Generate Watershed PF Relationship for Geographically Fixed Areas

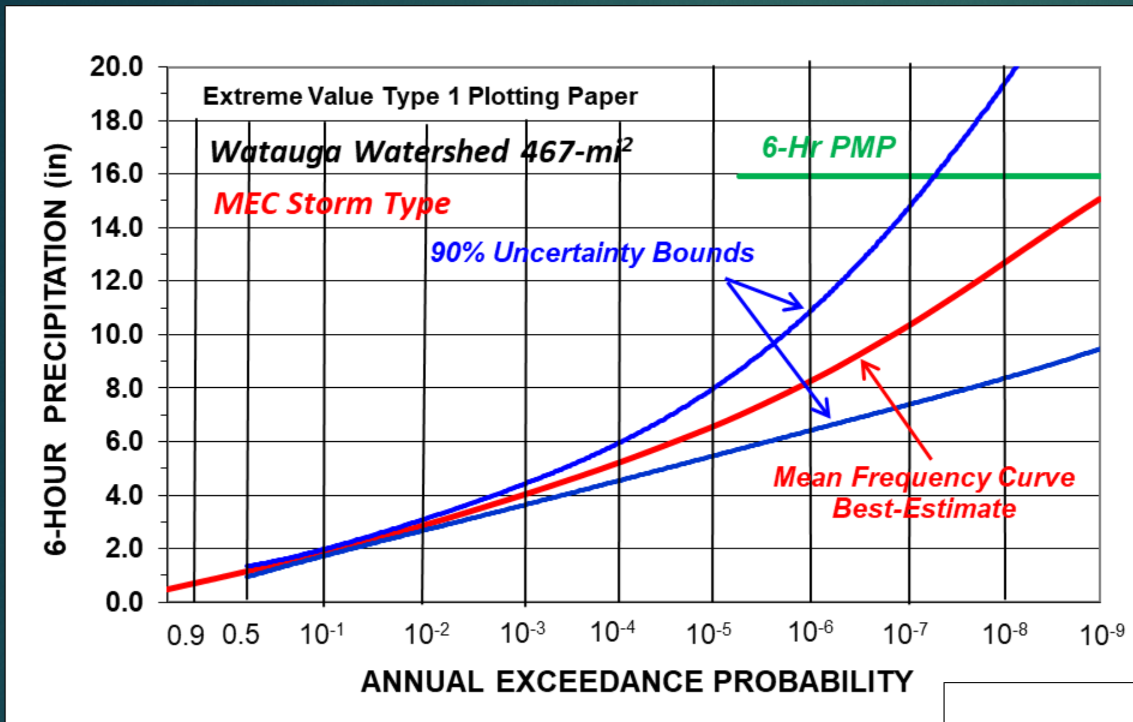


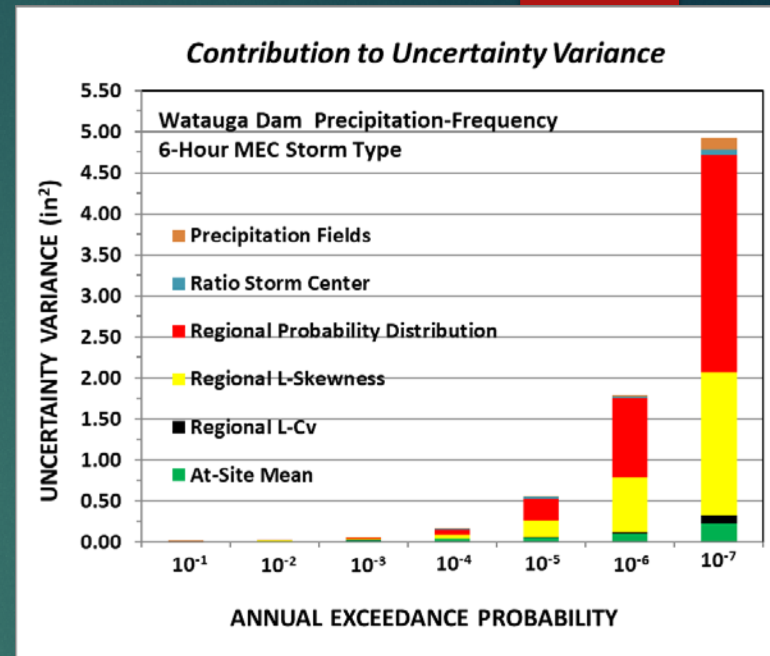


118 Historical Spatial Patterns
TVA Study

32 Historical Spatial Patterns
Trinity River, Texas Study

MEC Watershed Precipitation-Frequency Relationships





Mesoscale Storm

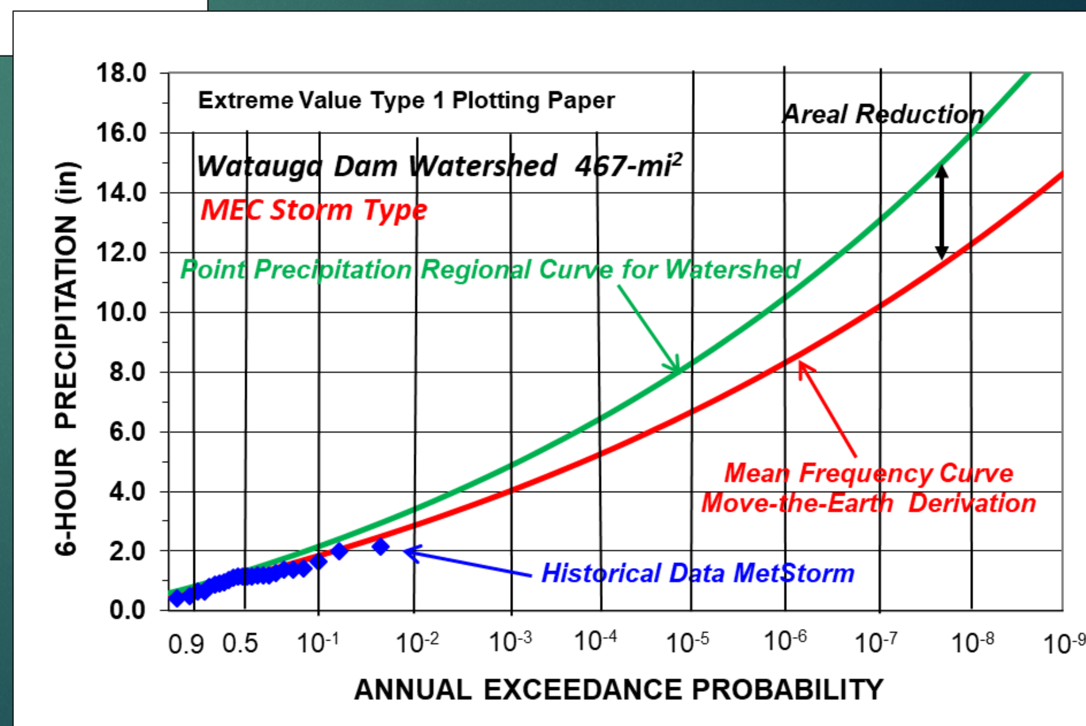
with Embedded Convection (MEC)

340 Stations; 12,039 Station-Years

Spatial Analyses 118 MEC Storms

24 Historical Storms on Watershed

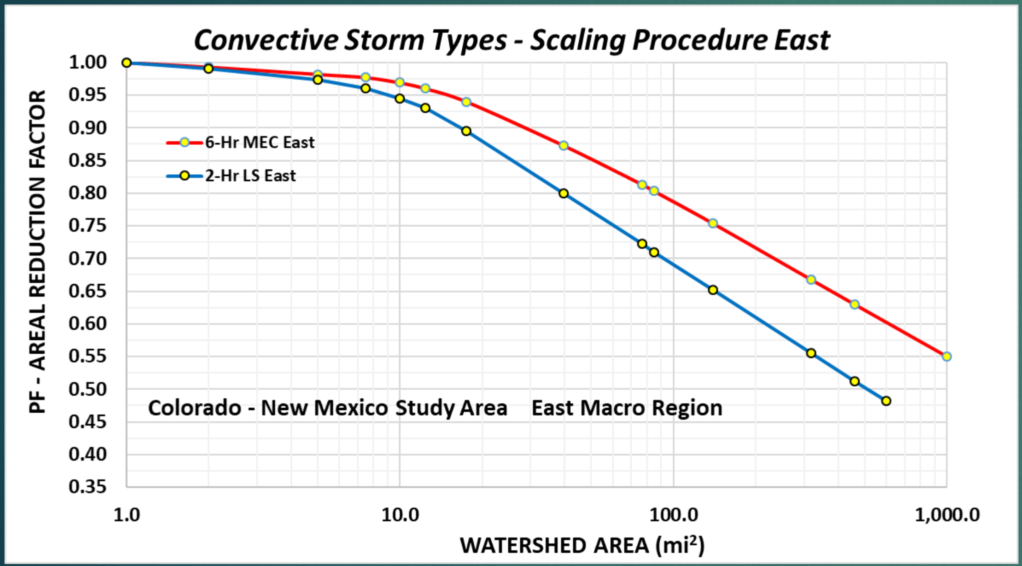
94 Storms Transposed to Watershed

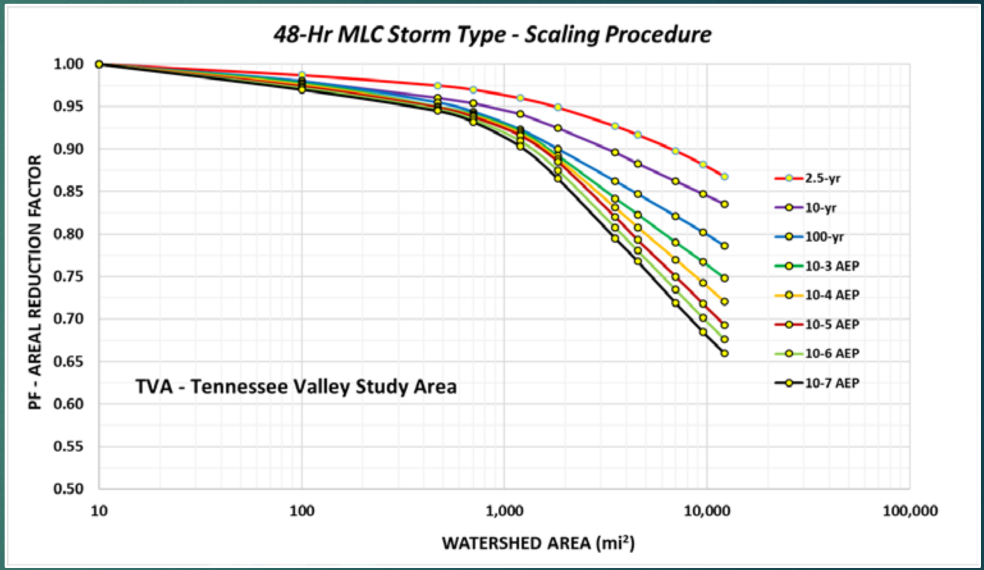


Major Advancements in Past 5-Years in Watershed Precipitation-Frequency Development

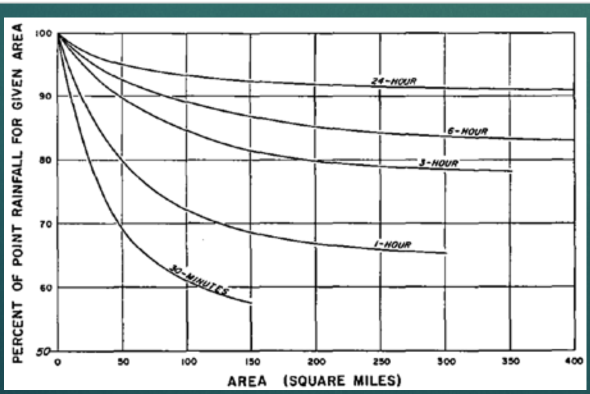
PF Areal Reduction Factors (ARFs) by Storm Type (2016-2018)

Findings from Prior Detailed Precipitation Studies
provide for Development of Precipitation-Frequency Based ARFs
for Converting from Point PF to Watershed PF for Geographically Fixed Areas





NOAA Technical Paper No 29 (1957)



Major Advancement Over Past Practice of Applying Storm Centered ARFs

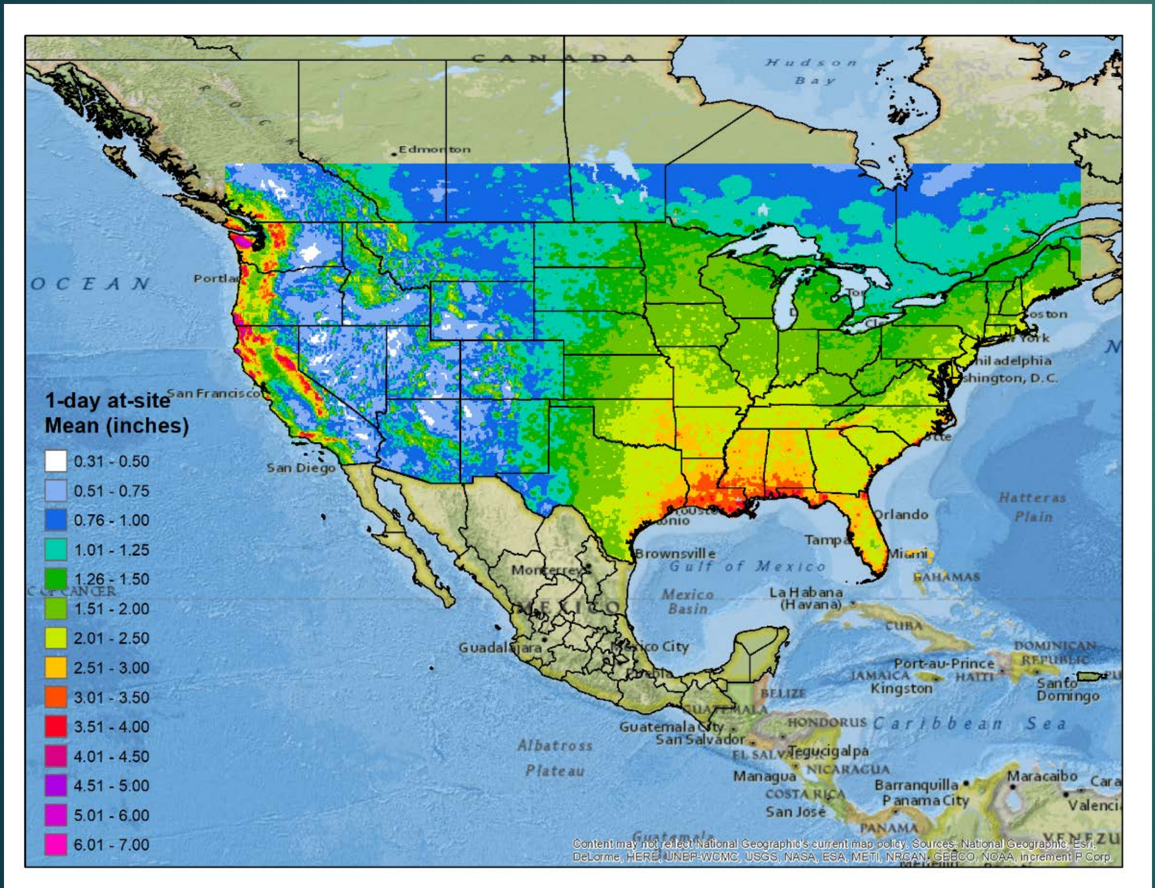
Major Advancements in Past 5-Years

Livneh Reanalysis Datasets to Augment Meteorological Inputs (2017)

Daily, High-resolution (1/16 degree) Gridded Dataset

Across southern Canada, the United States, and Mexico

Jan 1915 to Dec 2015



Used for:

Storm Typing

Augmenting Spatial Storm Analyses and Storm Transpositions in Data Sparse Areas

Summary

Many Advancements Made in Past 5-Years

on Methods of Analysis and Software Tools

for Developing Watershed Precipitation-Frequency Relationships

and Storm-Related Inputs for Specific Storm Types

These Methods and Software Tools are in Production Mode

to Support Stochastic Flood Modeling

for use in Hydrologic Risk Analyses

Recent Applications:

Dams in Tennessee Valley, TVA

Colorado-New Mexico Extreme Precipitation Study

Trinity River System – USACE

Hydropower Dams in British Columbia, BCHydro

Large Water Supply Dams in Australia

End of Slides

Discussion