Utilizing Regional Precipitation-Frequency Relationships for Multiple Storm Types for Probabilistic Flood Hazard Analysis in the Tennessee River Watershed

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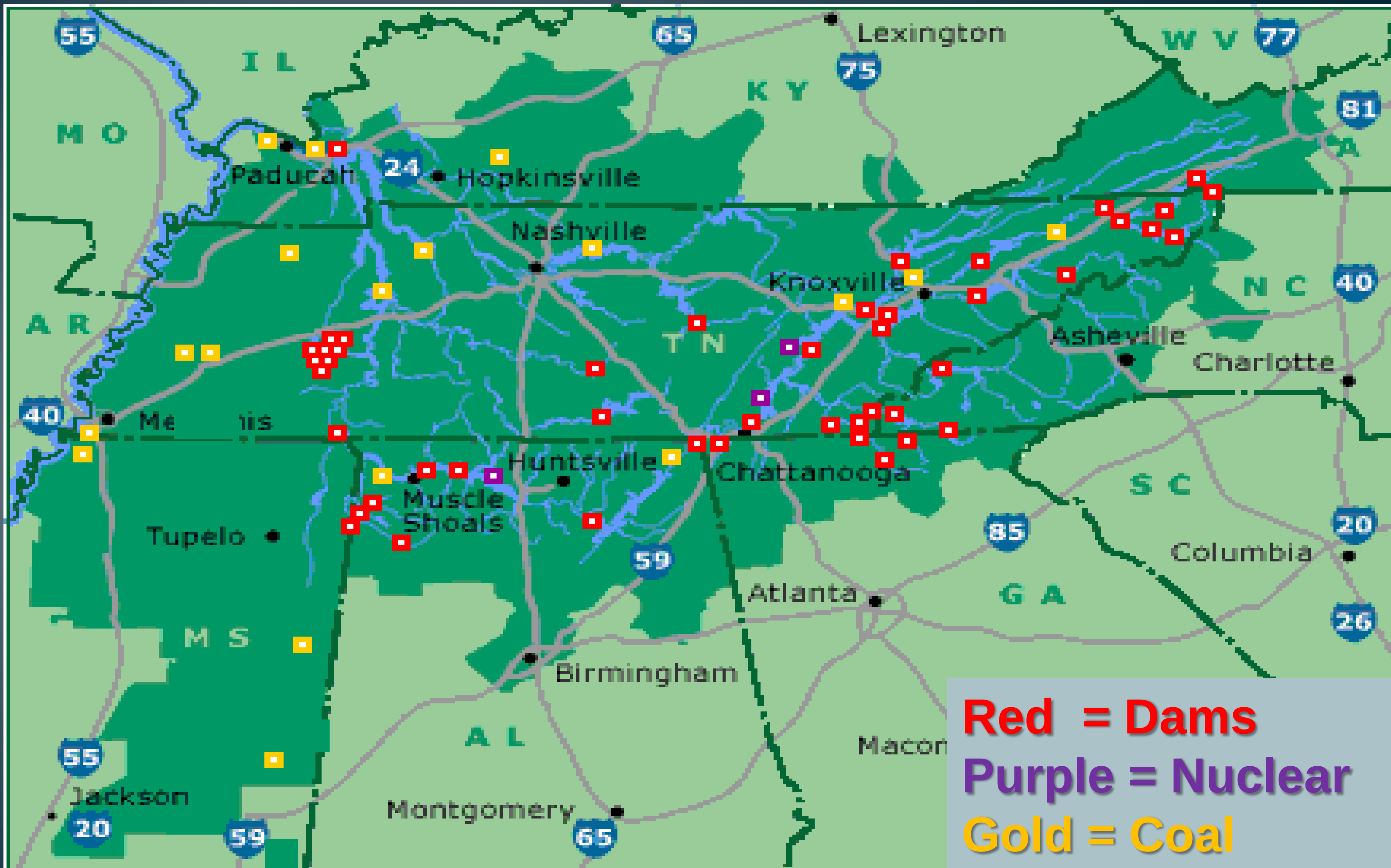
G Taylor, Applied Climate Services
T Parzybok, MetStat

USSD Conference, Denver 2016

The TVA System

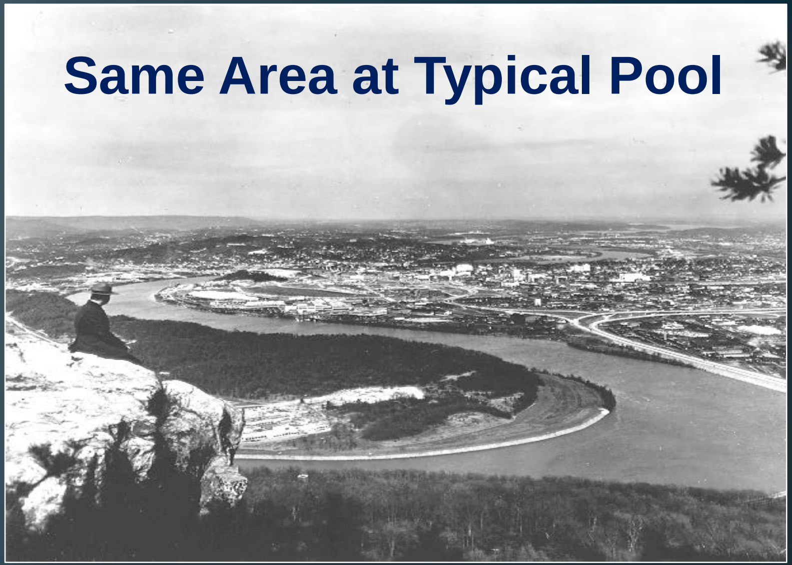


49 Multipurpose Dams on Tennessee River System

Navigation, Flood Control, Hydropower, Water Supply, Recreation, Water Quality

High Consequence Settings

Several Hundred-Thousand Residents
Located in Tennessee Valley
Downstream of Large TVA Dams

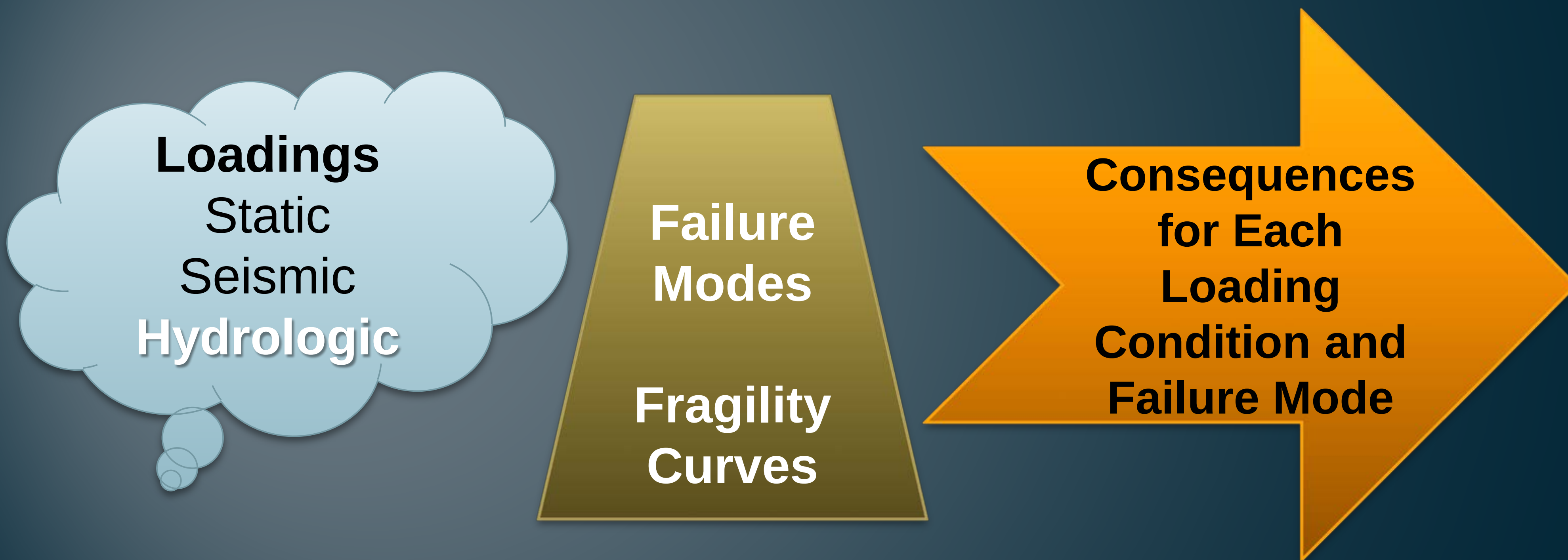


Tens of Billions of Dollars in
Economic Damages
Could Result from a Dam Failure

Current Situation - - Considerable Uncertainty
in Likelihoods of Extreme Precipitation and Flood Events
and Magnitude of Hydrologic Risk

Risk-Informed Decision-Making (RIDM)

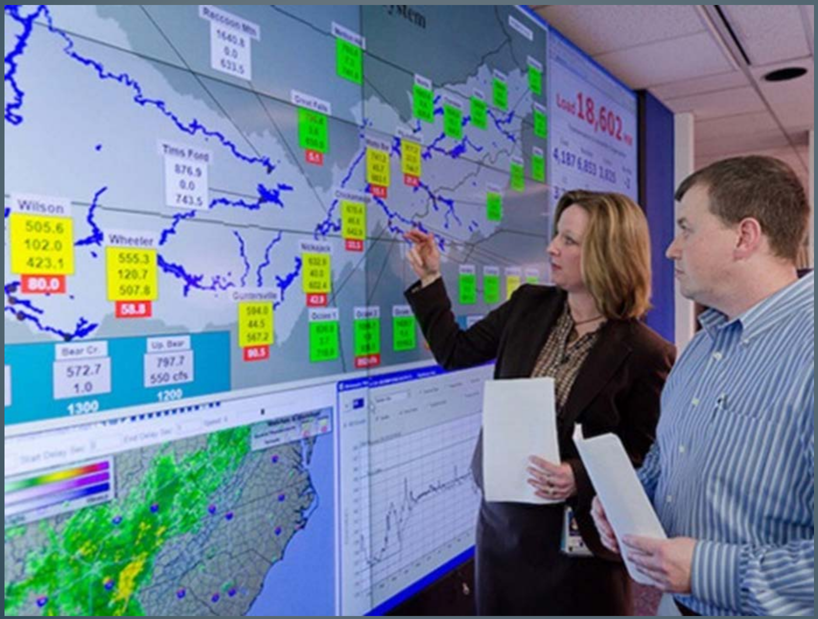
TVA initiated a multi-year program in 2014 to implement Risk Analysis and RIDM for TVA Dams in the Tennessee River Watershed



Project Team Tasked with Developing Probabilistic Flood Loadings for Hydrologic Risk Analysis

Complex River Operations

TVA River Operations Center is Responsible for
Coordinating Dam/Reservoir Operations During Floods



More Than a Dozen Large Dams
in the Upper Watershed
are used for Flood Control

Flood Control Operations
are Highly Inter-Related
Amongst Dams

Complexity of Dam Operations Significantly Increases
Complexity of Hydrologic Modeling
and Assessment of Hydrologic Risks

HYDROLOGIC RISK – STUDY COMPONENTS

TVA

Study Component	Performed By
Storm Typing **Regional Point Precipitation-Frequency** **Watershed Precipitation-Frequency** **Spatial and Temporal Storm Patterns**	Applied Climate Services MGS Engineering MetStat
Stochastic Hydrometeorological Inputs **Stochastic Watershed Modeling**	MGS Engineering Riverside Technology
Dam Operations and Flood Routing	Riverside Technology TVA
Risk Analysis	TVA RAC Engineers and Economists

Need for Storm Typing

Watersheds for TVA Dams

Vary from 60-mi^2 to over 40,000-mi^2

Watersheds are affected by

Mixed Population of Storm Types

with <u>Differing Spatial and Temporal Characteristics</u>

Mid-Latitude Cyclones (MLC)

Tropical Storm Remnants (TSR)

Mesoscale Storms with Embedded Convection (MEC)

Local Storms (LS)

Need for Storm Typing

TVA

Various Storm Types

Produce a Mixed Population of Flood Characteristics

for Various Ranges of Watershed Sizes

Each Watershed and Storm Type Requires Separate:

Watershed Precipitation-Frequency Relationship

Spatial and Temporal Storm Patterns

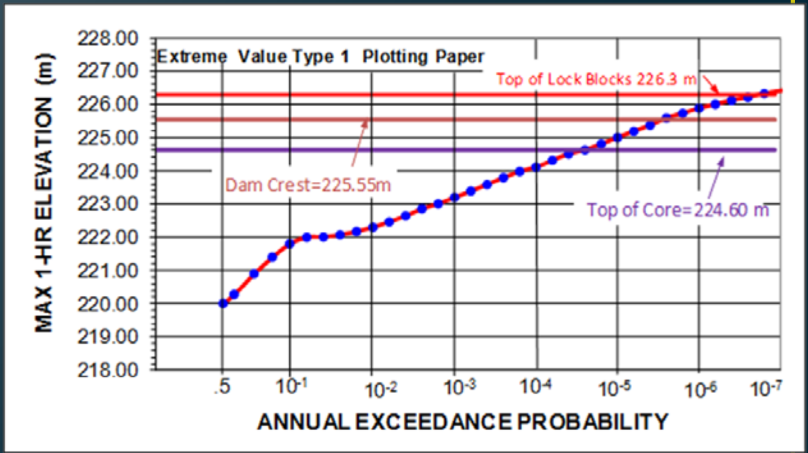
Stochastic Flood Model

Resultant Hydrologic Hazard Curve

Obtained by Combining CDFs

for Hydrologic Hazard Curves

from Each Storm/Flood Type



Analysis Overview – Present 3 Topics

Storm Typing for Use in Assembling
Precipitation Annual Maxima Datasets
for Each Storm Type

Regional Point Precipitation-Frequency Analysis
for Each Storm Type

Stochastically Generated
Watershed Precipitation-Frequency Relationships
for the Mid-Latitude Cyclone (MLC) Storm Type

Storm Typing is a Game Changer !

Biggest Advancement in

Precipitation-Frequency Analysis since:

Updating of Regional Analysis Methodologies (Wallis, 1982)

Development of L-Moment Statistics (Hosking, 1986)

Storm Typing is a <u>Necessity</u>

for Regional Precipitation-Frequency Studies

in Areas Subjected to

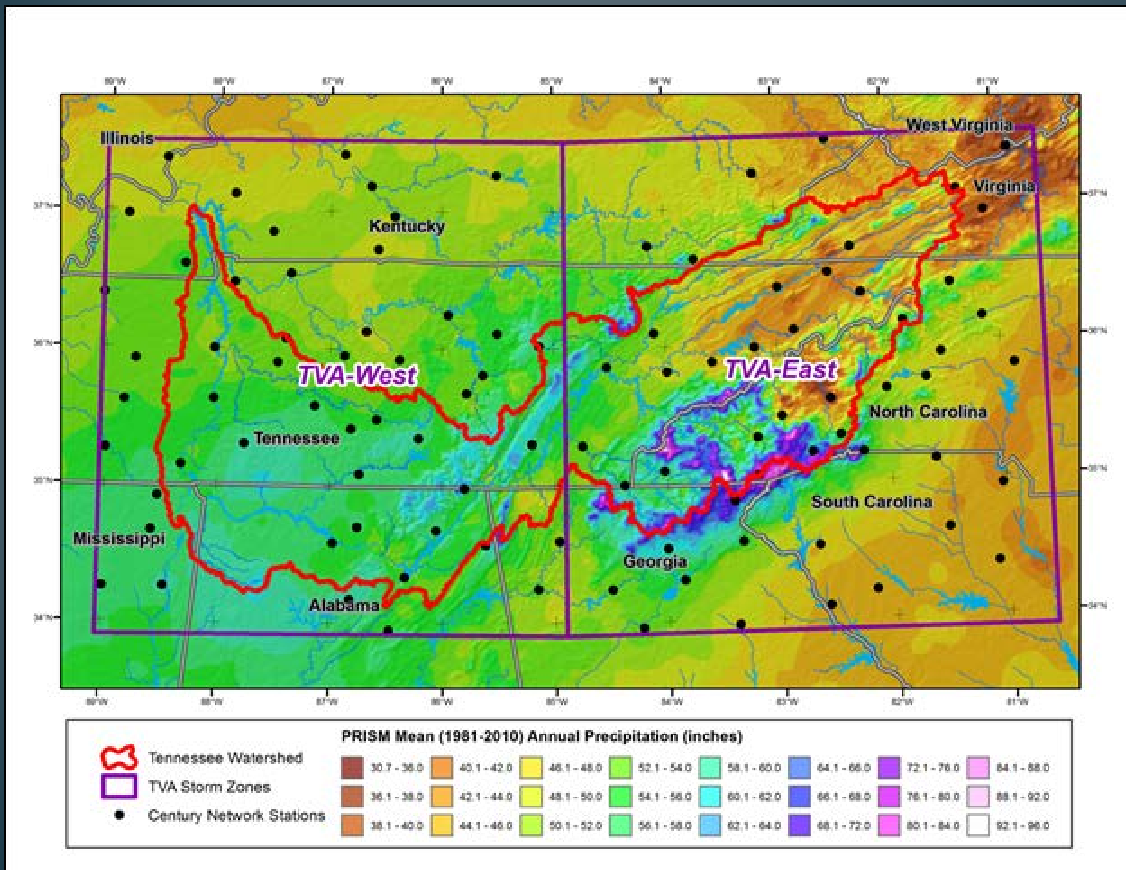
<u>Mixed Populations of Storms and Floods</u>

Particularly for Extreme Events

Storm Typing Procedures

TVA

Hands-On Storm Typing for 1,100 Noteworthy Storms



Identify Storm Scale:

~ Synoptic-Scale

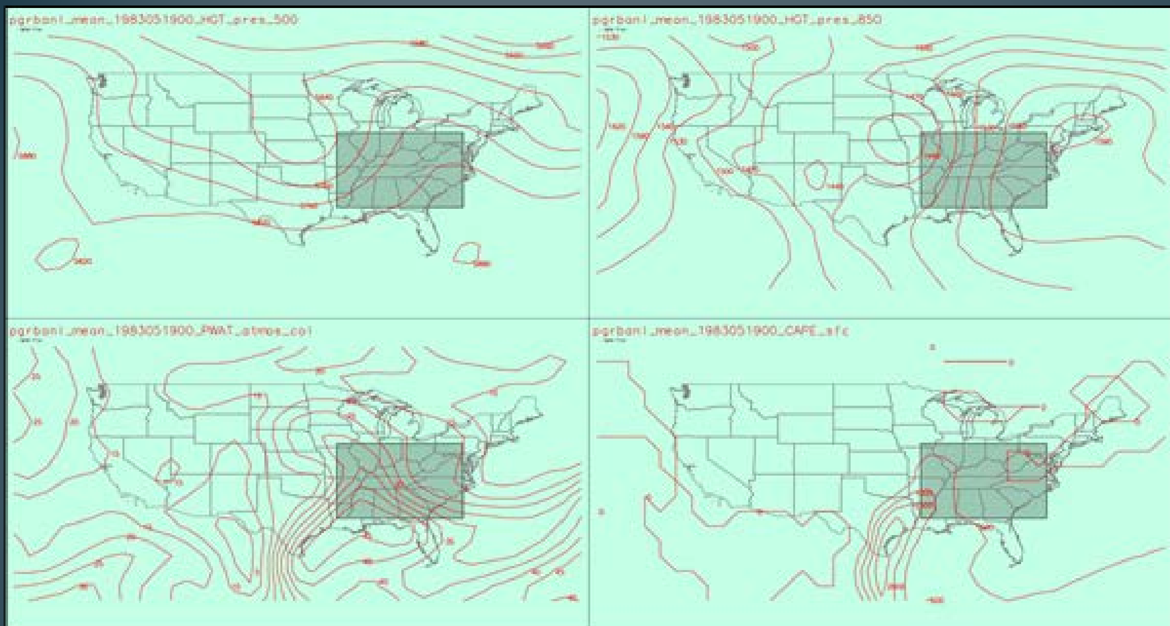
~ Mesoscale

~ Local Scale

Storm Scale Identified by Percentage of
100 Station Network Exceeding 0.5-in of Daily Precipitation

Storm Typing Procedures

Hands-On Storm Typing for 1,100 Noteworthy Storms



~ Surface Weather Maps

~ 850-mb and 500-mb Contour Heights

6-Hour Time-Series

NOAA CIRES 20^{th} Century Global Reanalysis Version II Datasets

Precipitable Water (Pw)

Convective Available Potential Energy (CAPE)

Storm Typing – Tropical Storms

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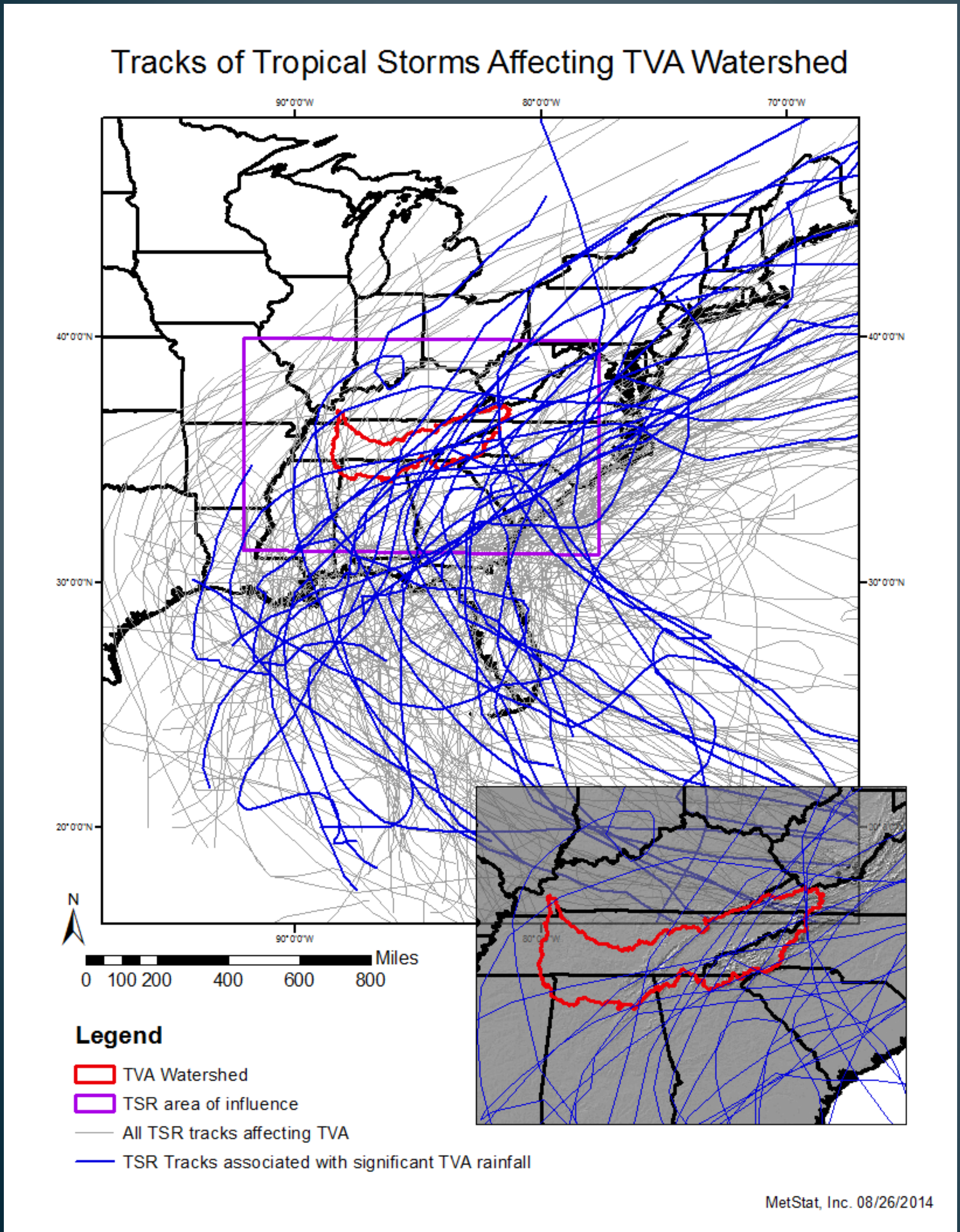
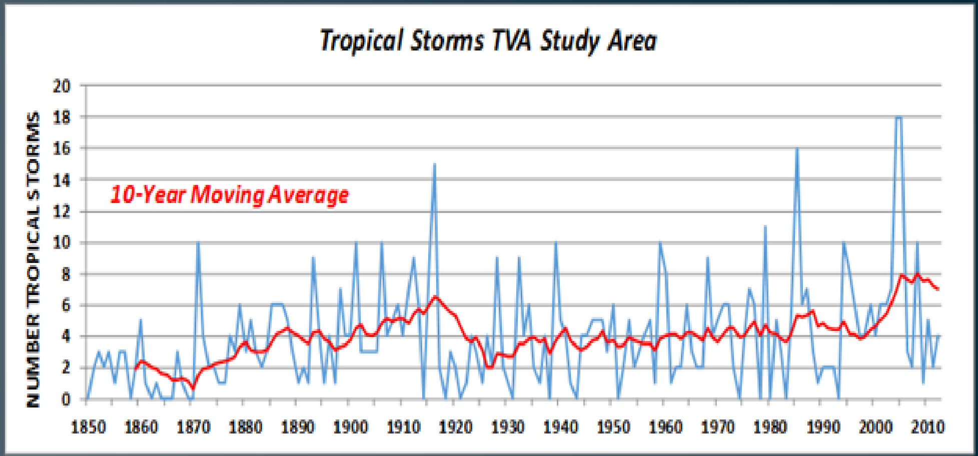


NOAA Database
of Tropical Storm Tracks

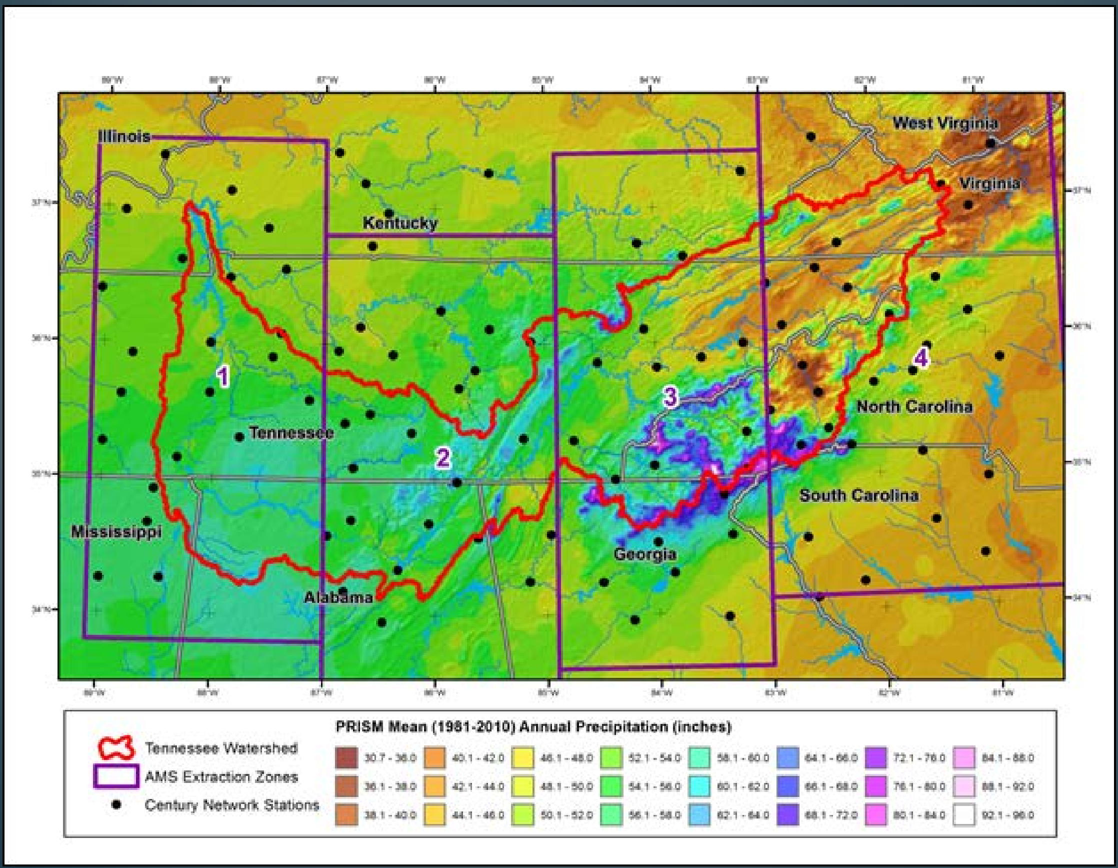


Ranges from 0-18 per Year
Average of 4 per Year

Several Years with Zero TSRs
Affecting Study Area

Database of Daily Storm Types (DDST)

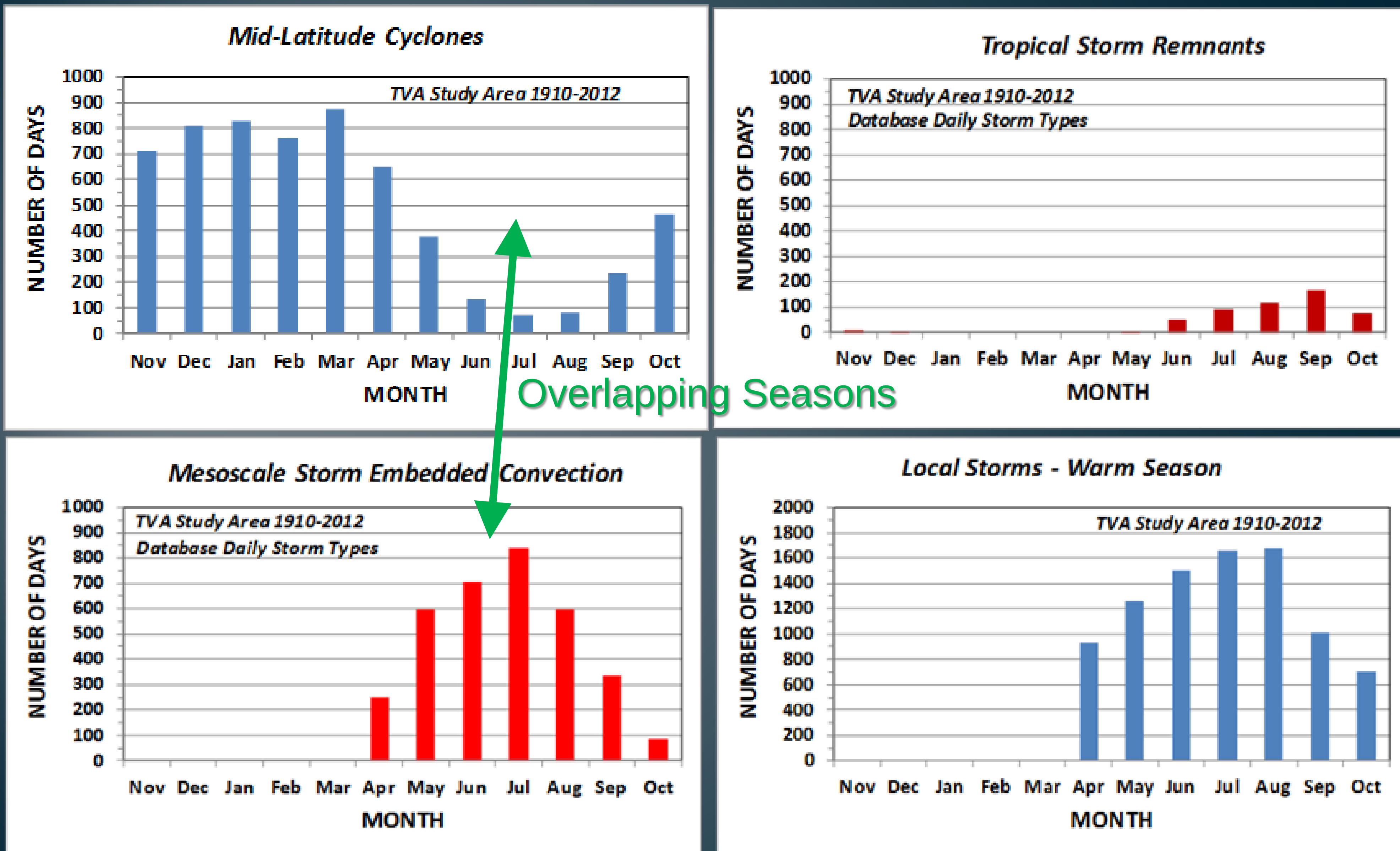
Findings of Manual Storm Typing for 1,100 Storms were used to Create Automated System for Daily Storm Typing for 4 Zones in TVA Study Area for 1881-2014



MLC	24, 48, 72-hr
TSR	24, 48, 72-hr
MEC	2, 6, 12-hr
LS	1, 2-hr

Separate Precipitation Annual Maxima Datasets Created for Each Storm Type at Several Durations

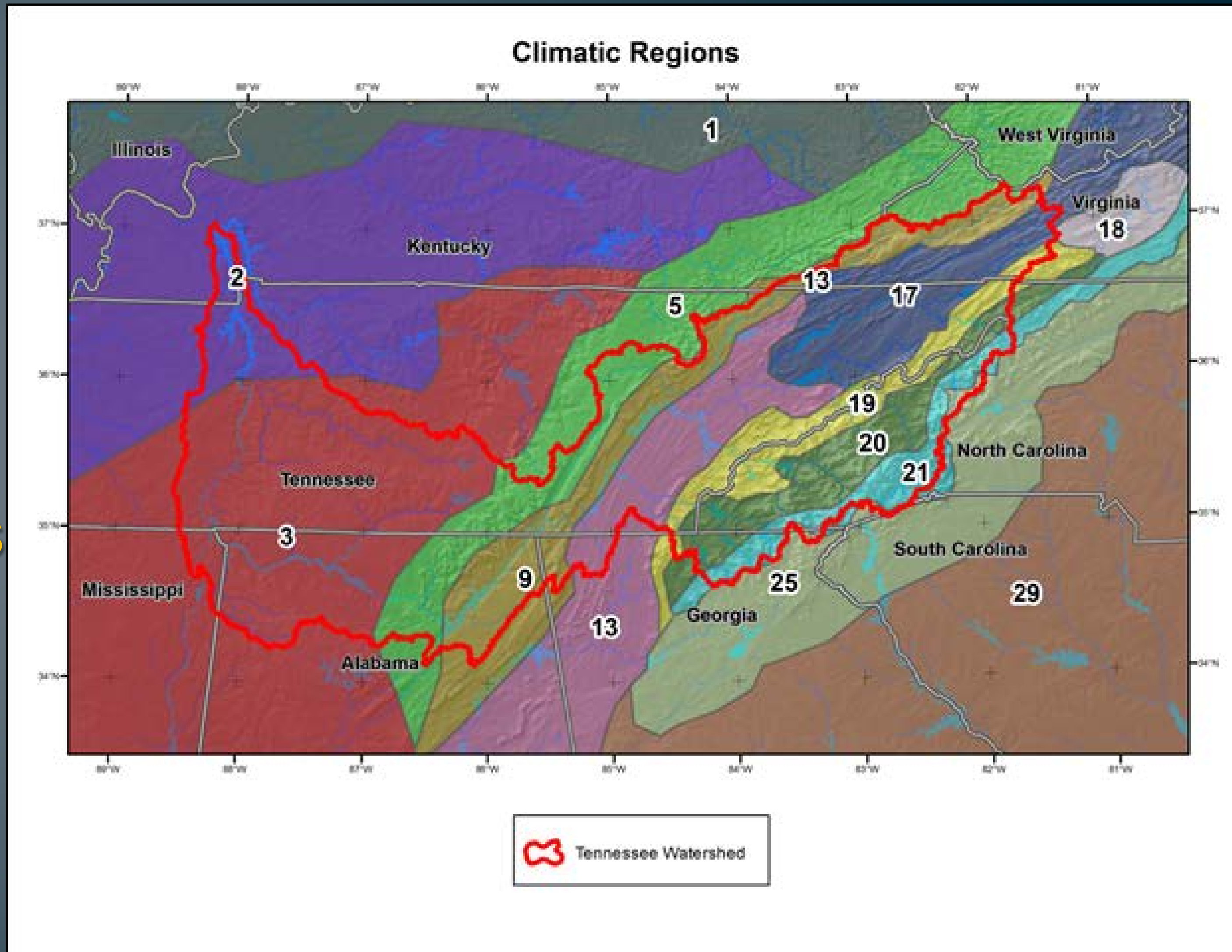
Seasonality of Storm Types



Note: Small Number of Tropical Storms and Large Number of Local Storms

Regional Precipitation-Frequency

Study Area Initially Divided into 13 Climatic Regions



Heterogeneous

Climatic Regions

for Valley Bottoms

Coastal Plains,

and

Mountain Faces

for Cumberland, Appalachian and Blue Ridge Mountains

Network of Precipitation Stations

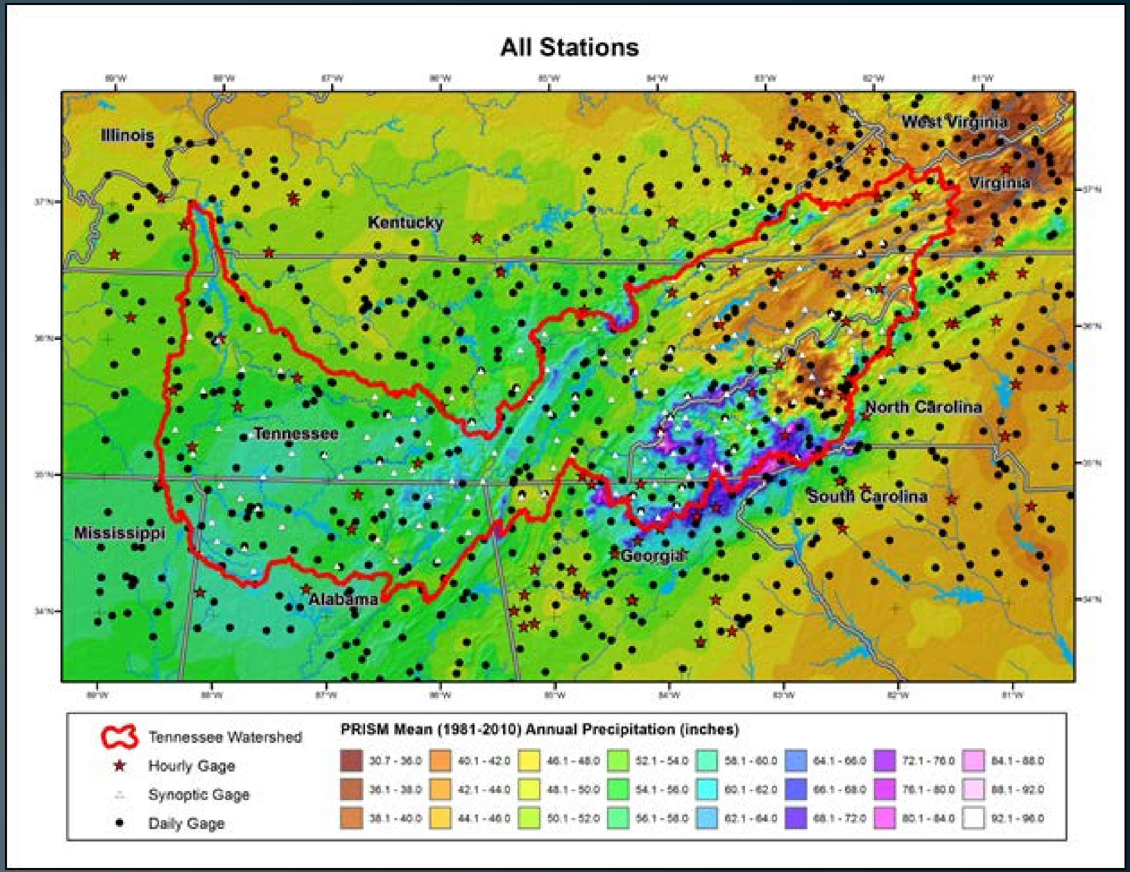
Very Large Datasets

for Precipitation

Annual Maxima

235 Stations with
over 70-Years of Record

86 Stations with
over 100-Years of Record



PRECIPITATION GAGE TYPE	NUMBER OF STATIONS/GAGES	STATION-YEARS OF RECORD
NOAA Daily Gages	857	46,580
NOAA Hourly Gages	221	9,160
TVA Synoptic Gages	172	4,356
TOTAL	1,250	60,096

Forming Homogeneous Regions

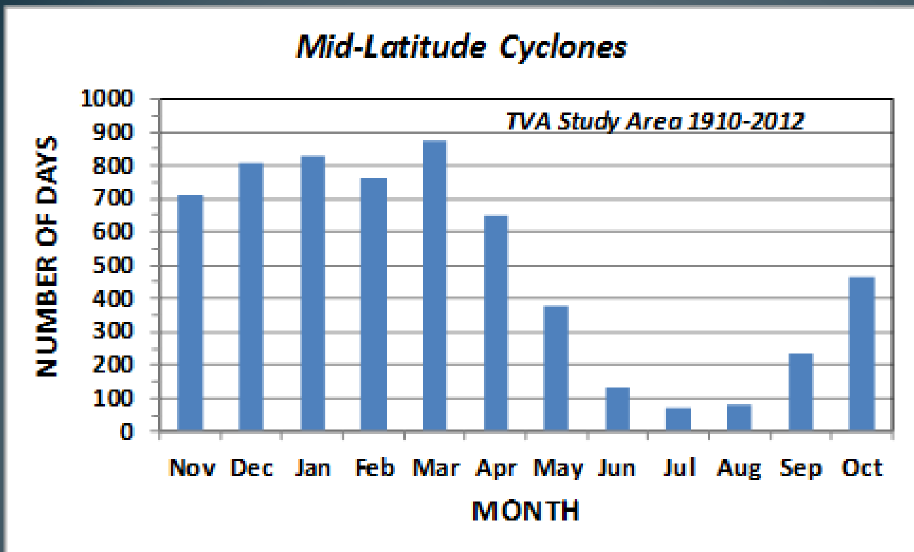
L-Moments Regional Analysis Conducted
based on Hosking-Wallis Index-Flood Methodology
and Spatial Mapping Enhancements Developed
for Mountainous Areas Over the Last 15-Years

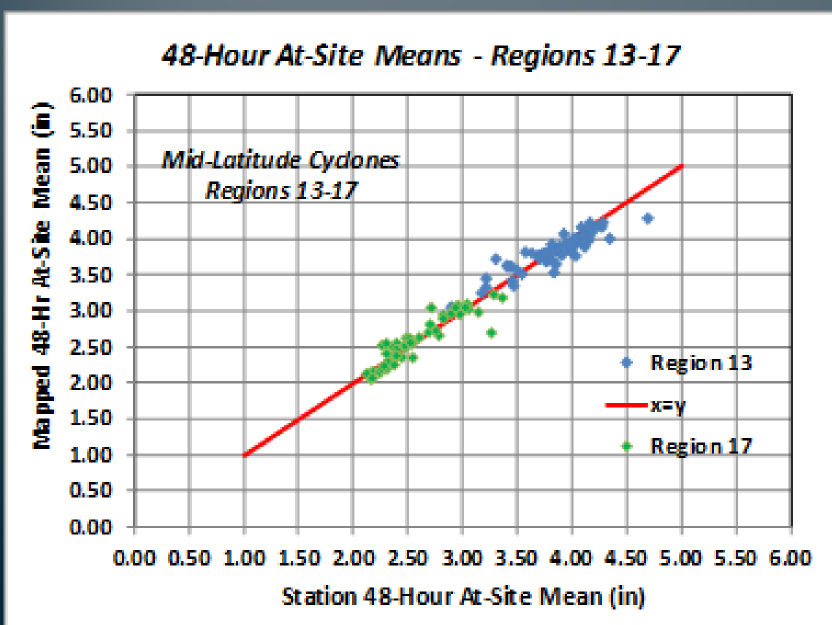
Homogeneous Regions Comprised of Stations
within a Small Range of the Pertinent Explanatory
Variable(s) for Spatial Mapping of L-Moment Statistics

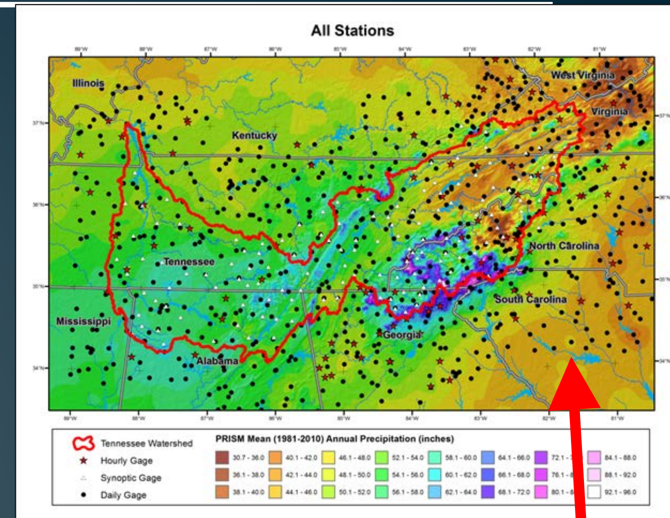
1) Climatic Variable for Storm Type of Interest
2) Longitude

Spatial Mapping At-Site Means

Mid-Latitude Cyclones







Explanatory Variable

for Spatial Mapping:

~ PRISM Gridded Datasets

December - March

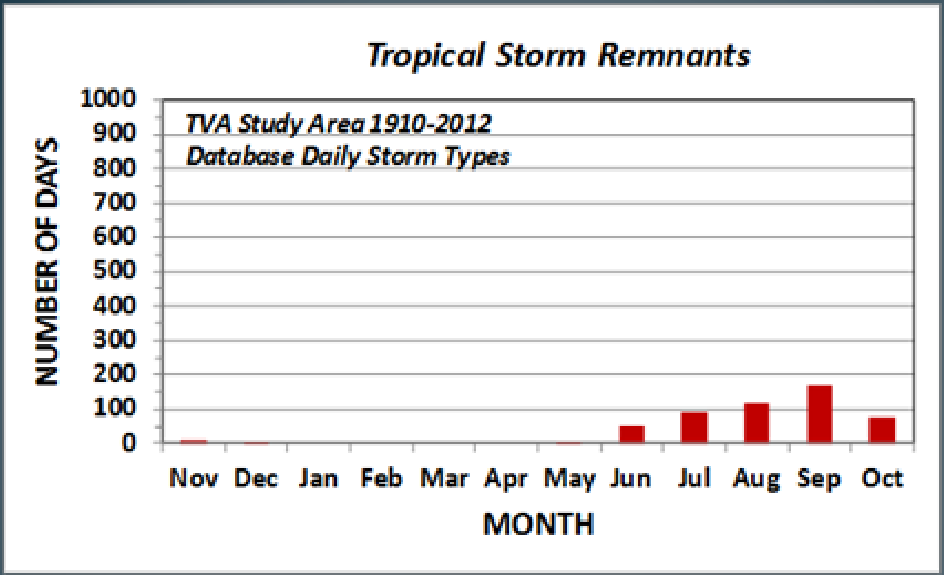
Mean Monthly Precipitation

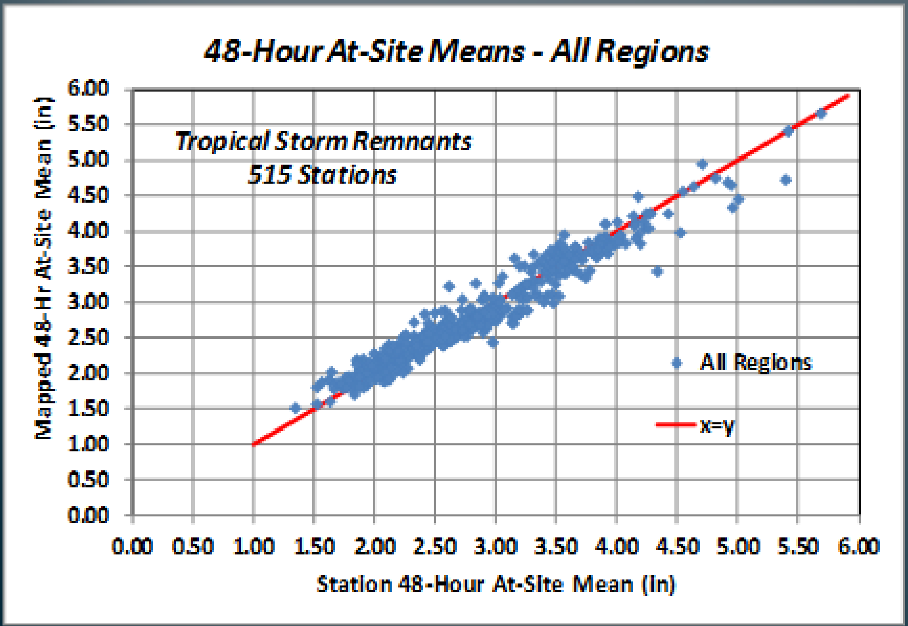
MLC At-Site Mean Mapping

RMSE = 4.4%

Spatial Mapping At-Site Means

Tropical Storm Remnants





Explanatory Variables

for At-Site Mean

Spatial Mapping:

~ PRISM Gridded Datasets

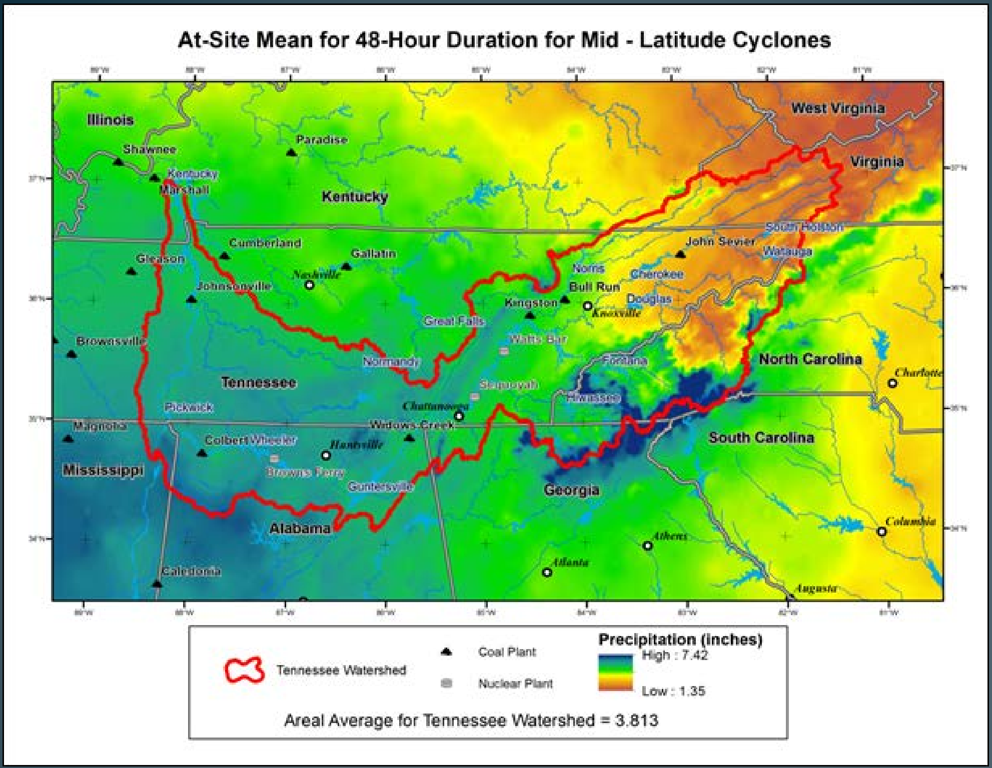
Mean Annual Precipitation

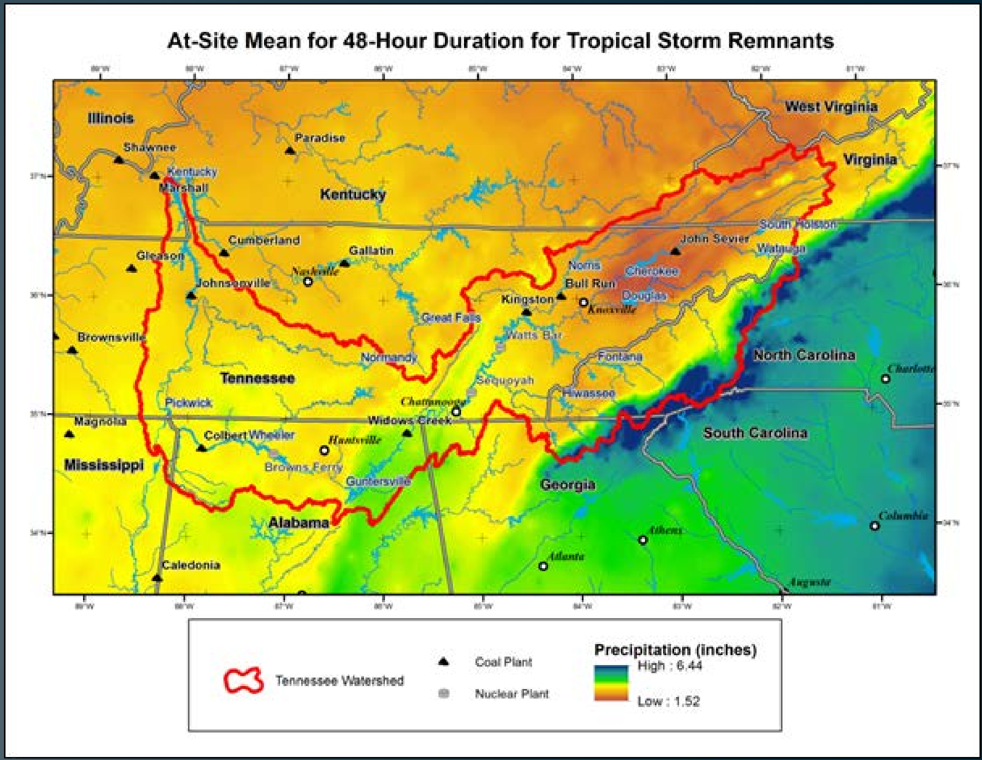
Longitude

TSR At-Site Mean Mapping

RMSE = 6.2%

Spatial Mapping At-Site Means



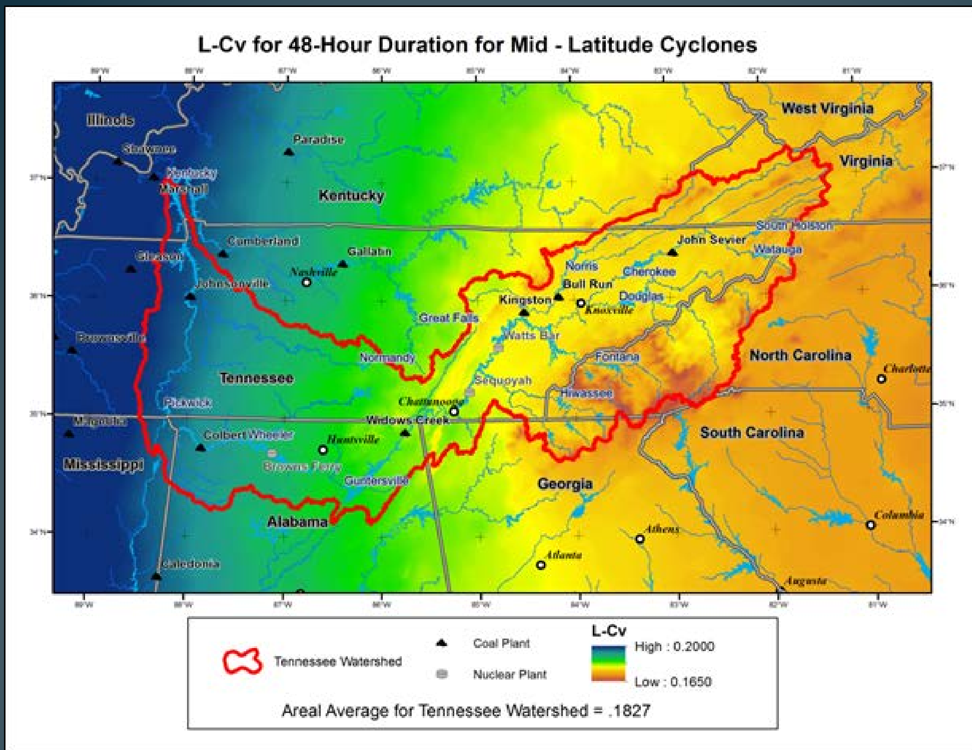


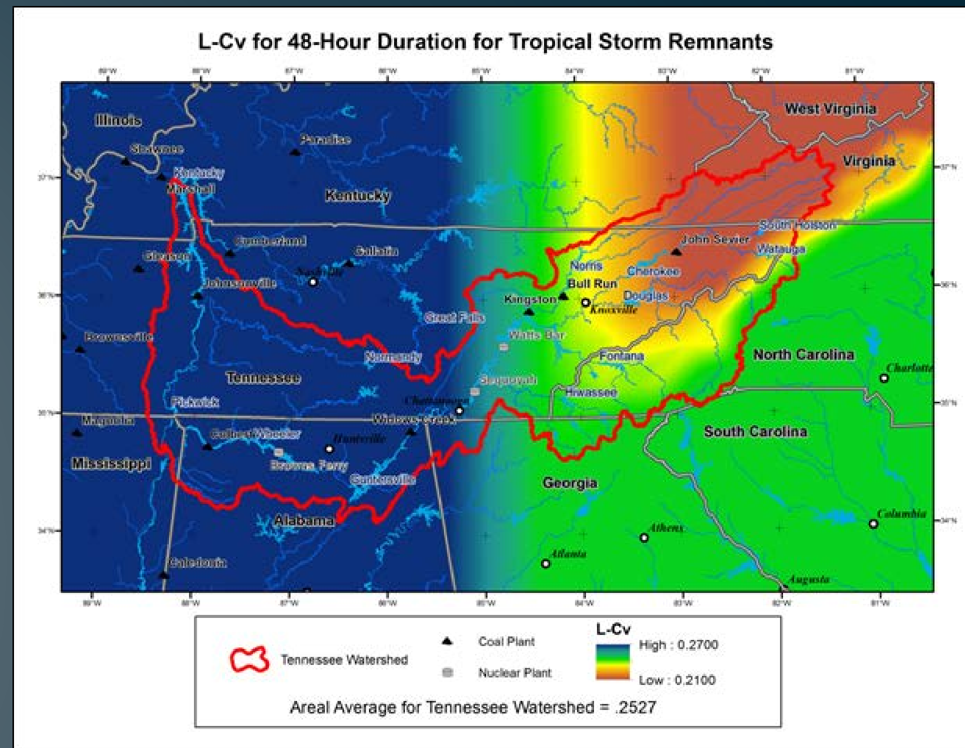
Note: Differences Between At-Site Means for MLC and TSR Storm Types

Heavy Precip on Atlantic Coast and Blue Ridge Mountains

Analysis Possible – Only with Storm Typing !!

Spatial Mapping Regional L-Cv



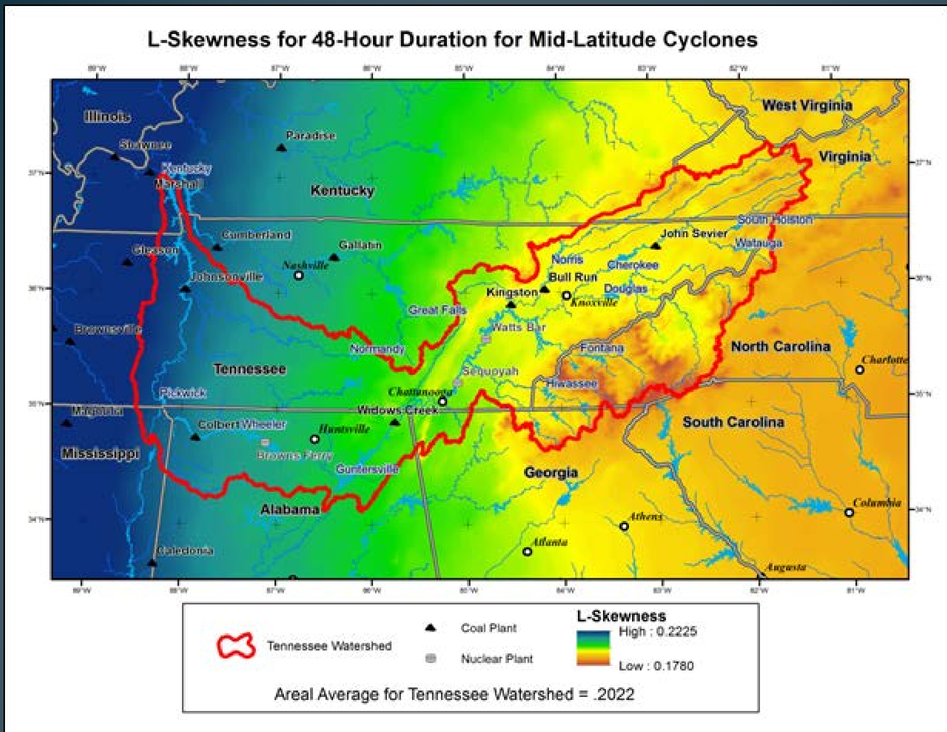


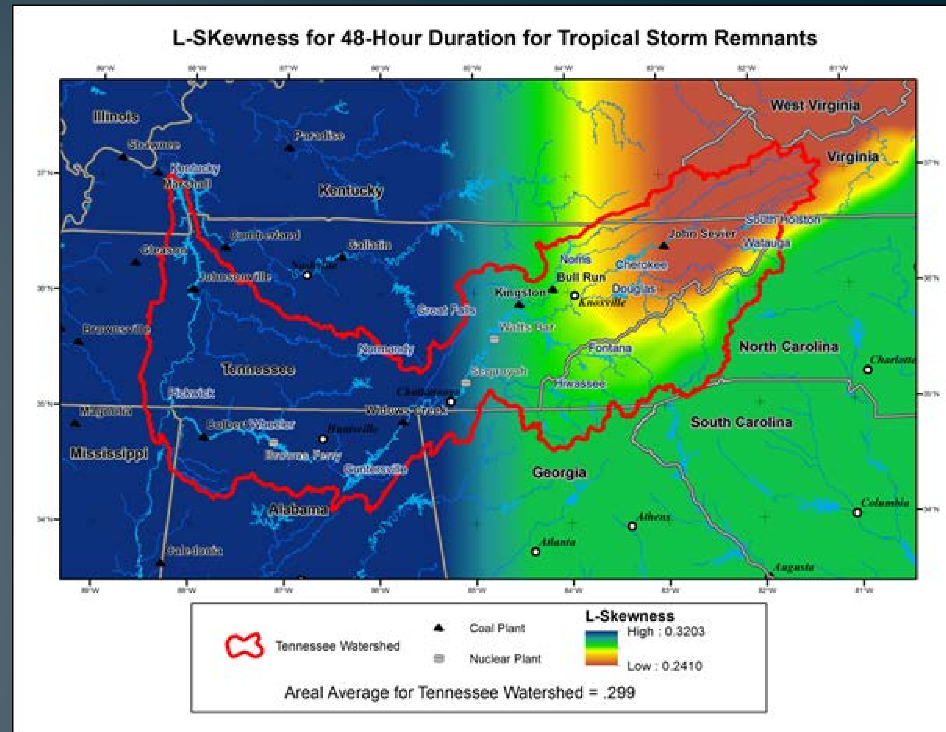
Higher Variability of L-Cv for TSRs

Particularly for Atlantic Coastal Plains

Major Rain Shadow in Upper Tennessee Valley

Spatial Mapping Regional L-Skewness





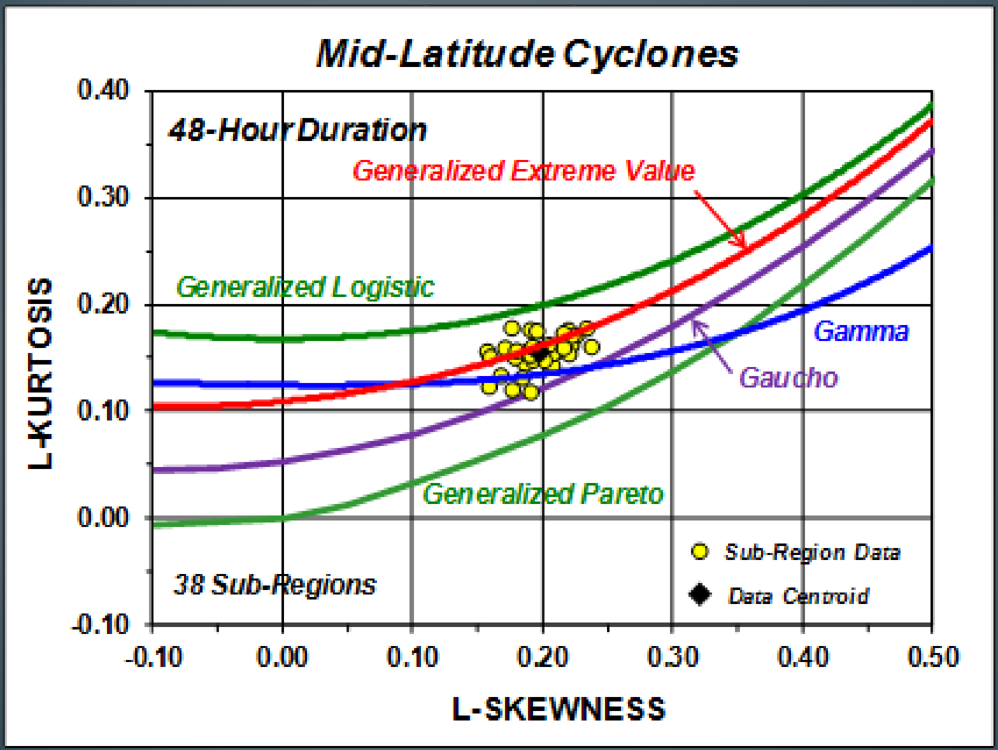
Higher Variability of L-Skewness for TSRs

Particularly for Atlantic Coastal Plains

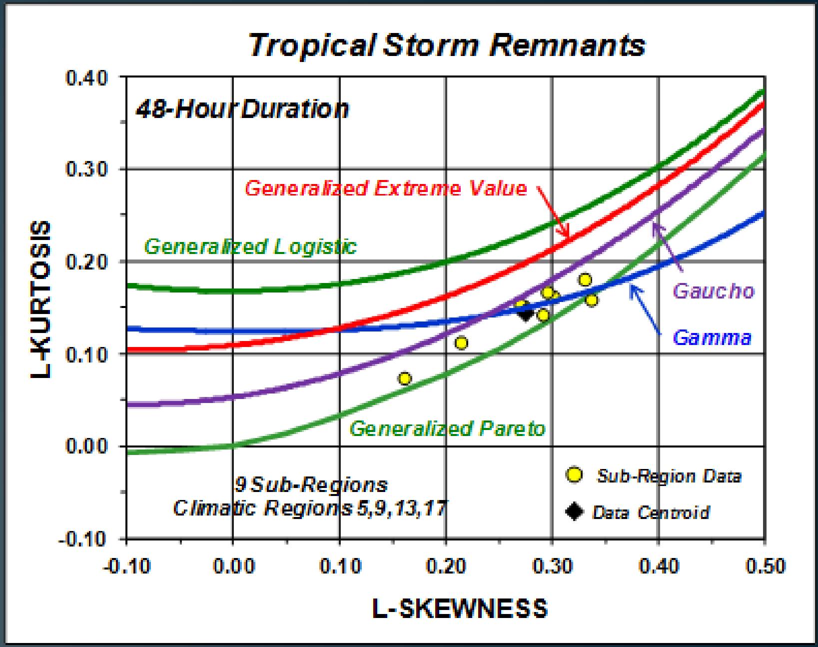
Major Rain Shadow in Upper Tennessee Valley

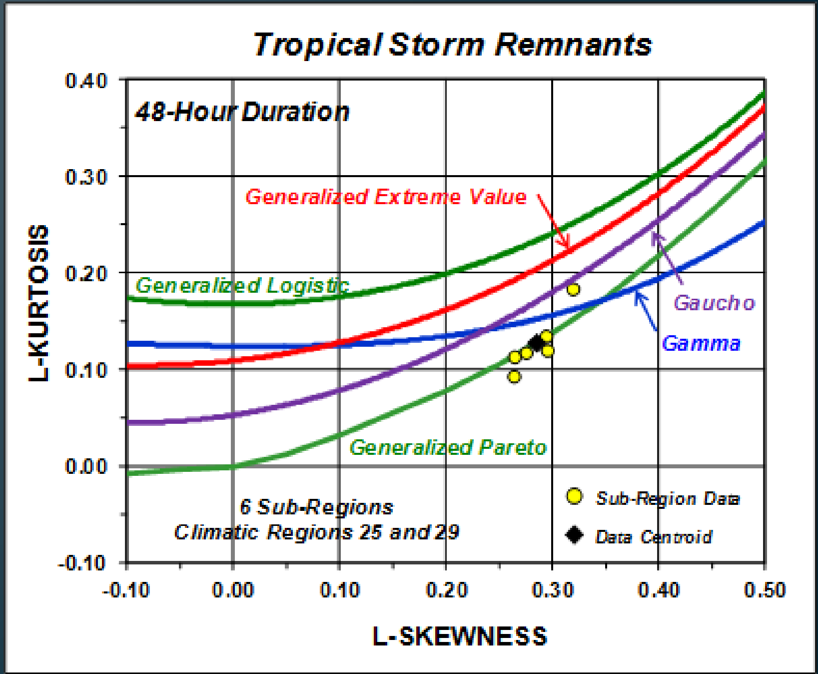
Regional Probability Distributions

Very Near Generalized Extreme Value (GEV) for Mid-Latitude Cyclones

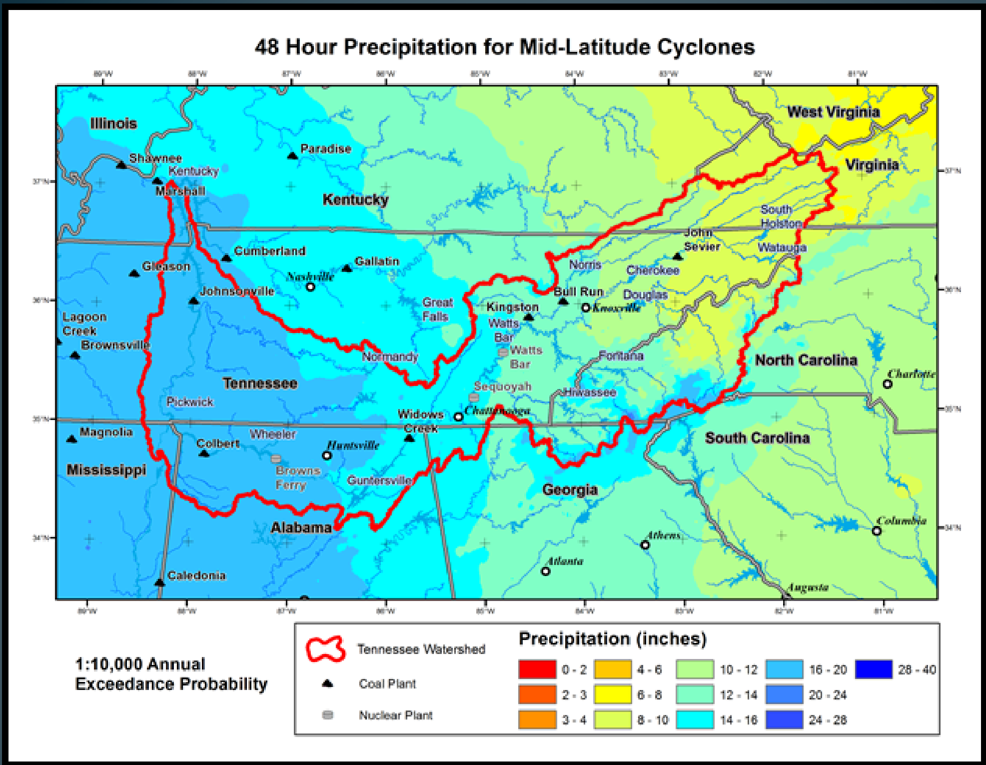


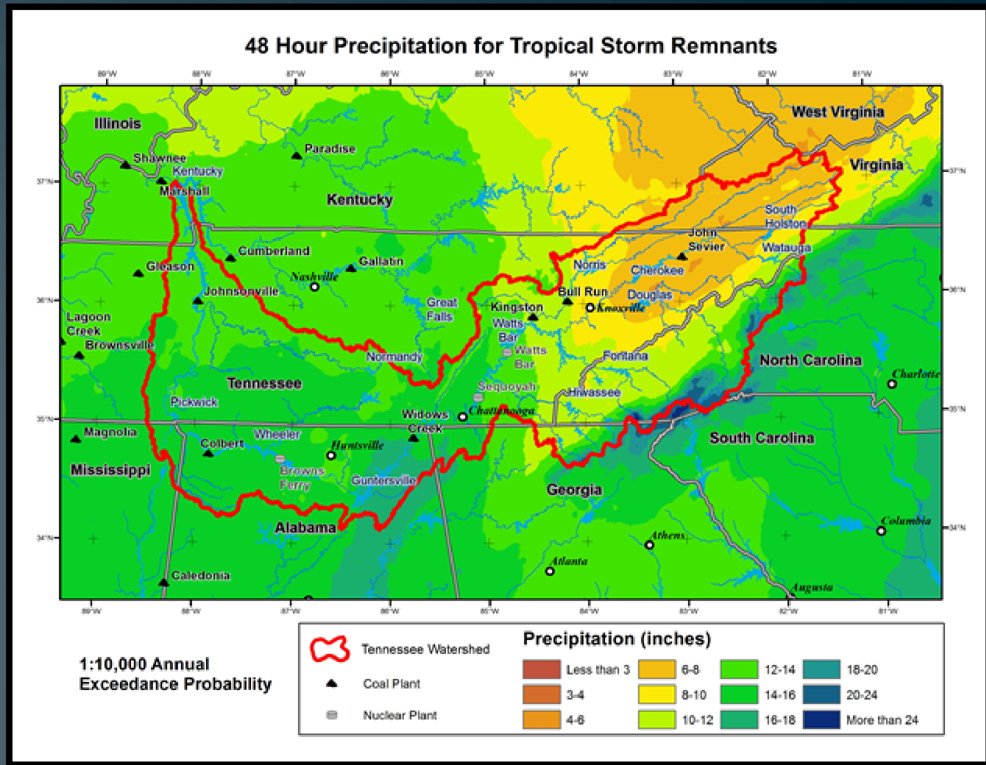
Near Generalized Pareto (GP) for Tropical Storm Remnants (TSR)





Isopluvial Maps





Spatial Mapping of L-Moments

Along With Regional Probability Distribution

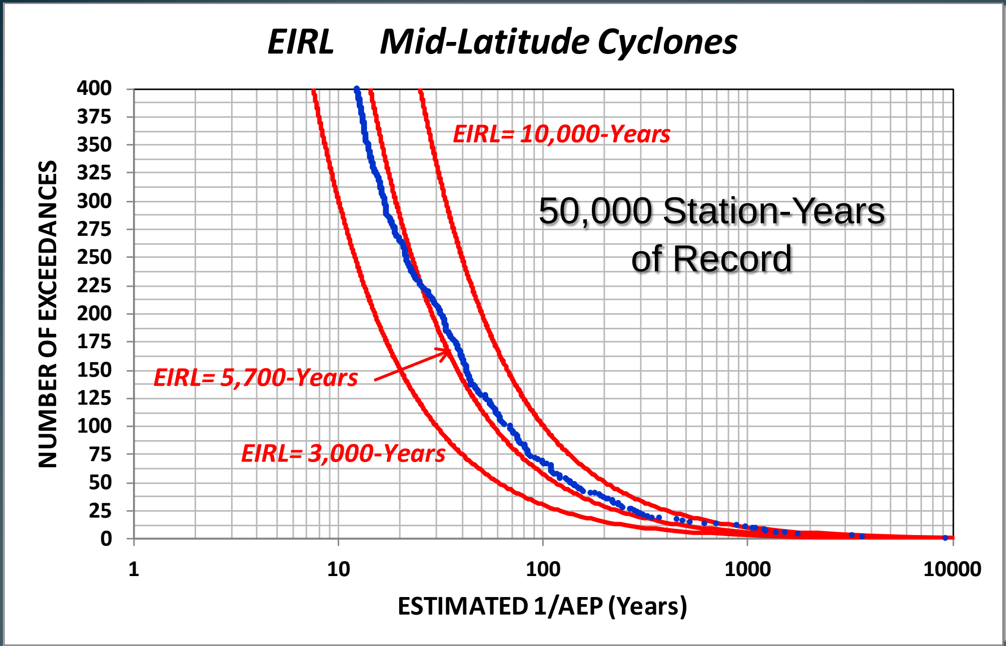
Provides Ability to Produce Isopluvial Maps

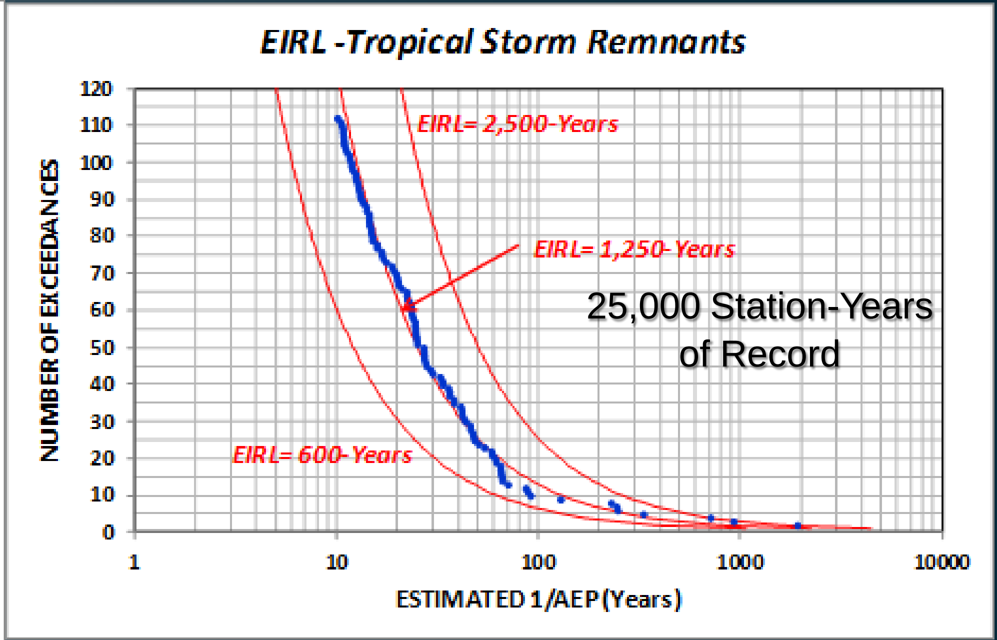
for Selected Annual Exceedance Probabilities (AEPs)

Storm Typing Makes This Possible !!

Equivalent Independent Record Length (EIRL)

TVA





Trading Space Sampling for Time Sampling

Many Independent Storms Per Year

(Different Storm Dates)

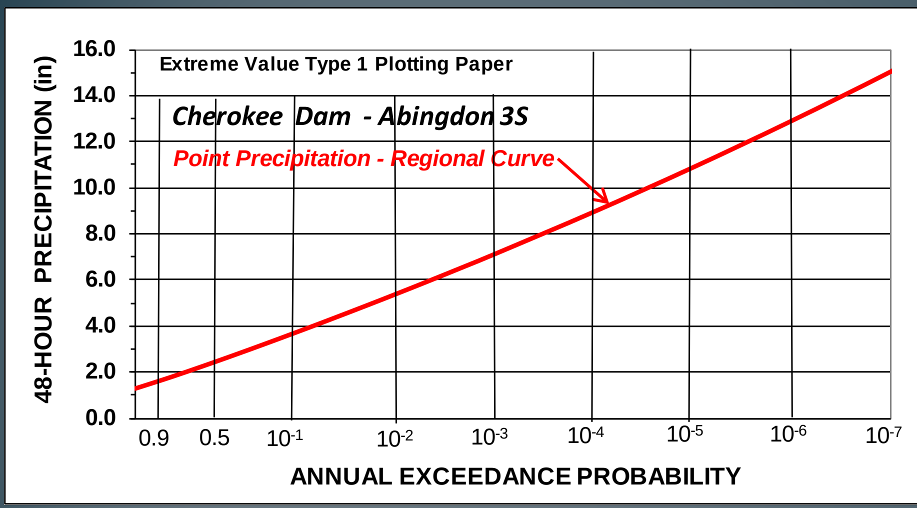
EIRL is Many Times Greater Than

Length of Chronological Record

Large Sample Size Increases Reliability of Results

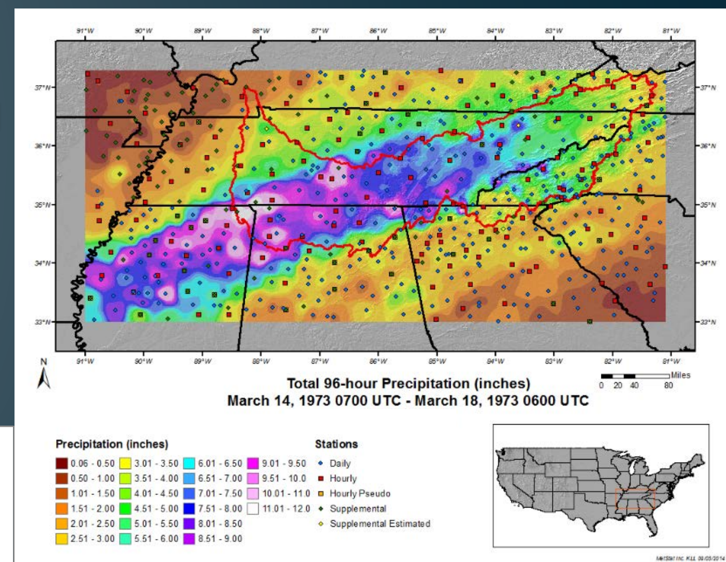
Watershed Precipitation-Frequency Curves

Watershed Precipitation-Frequency Relationships are Stochastically Generated using Findings from:



Regional Point Precipitation-Frequency Analyses

MetStorm Software



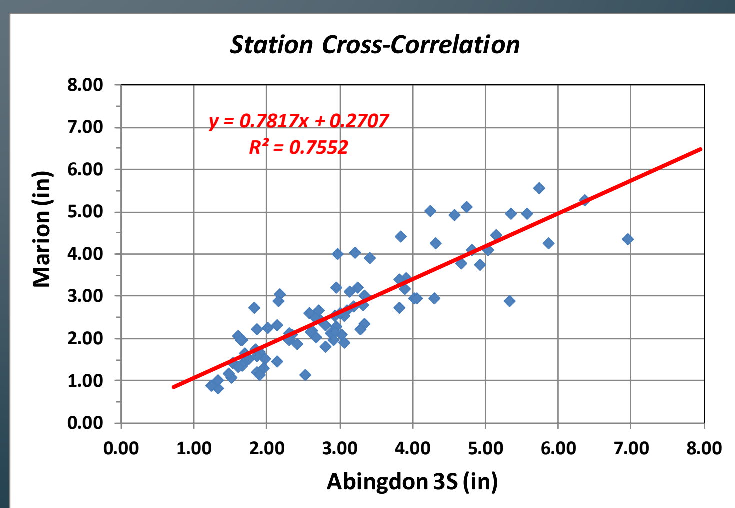
Spatial and Temporal Storm Analyses

Spatial

Storm Structure

Cross-Correlation

Relationships



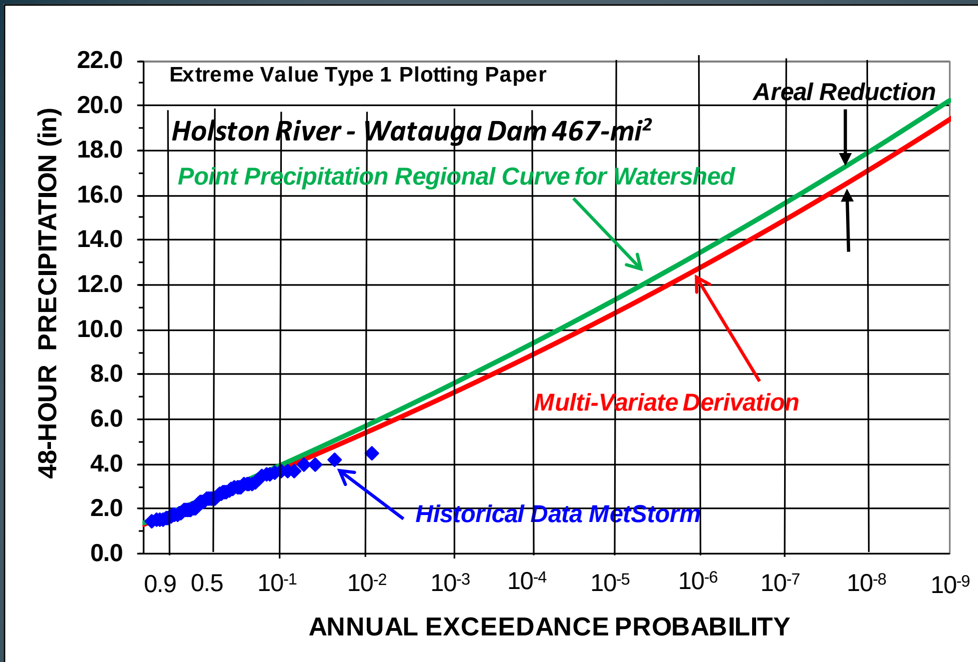
Uncertainty

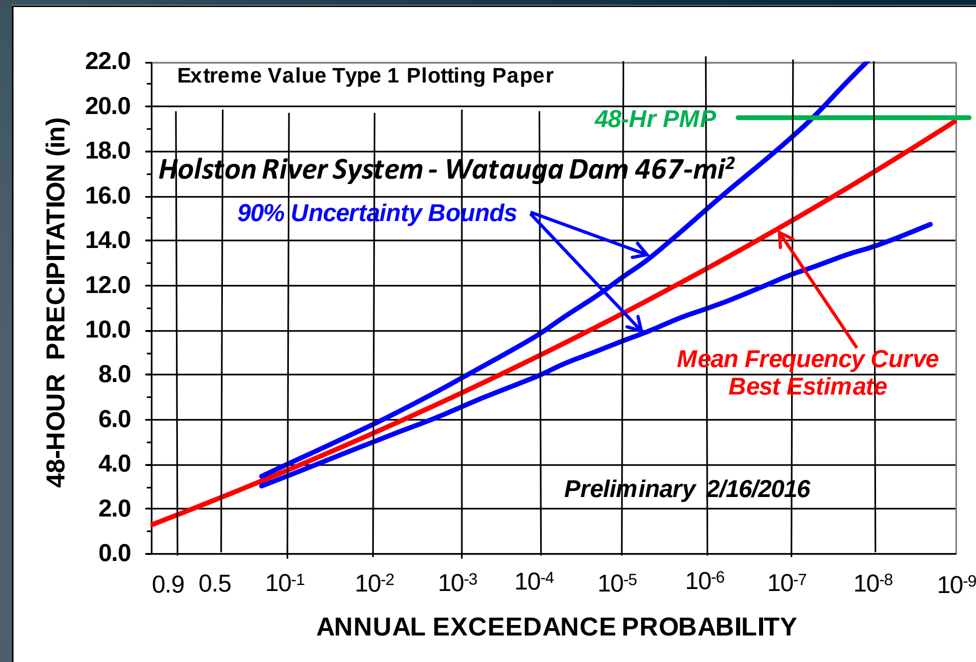
Characterizations of

Contributing Parameters

Watershed Precipitation-Frequency Curves

Mid-Latitude Cyclone (MLC) Storm Type



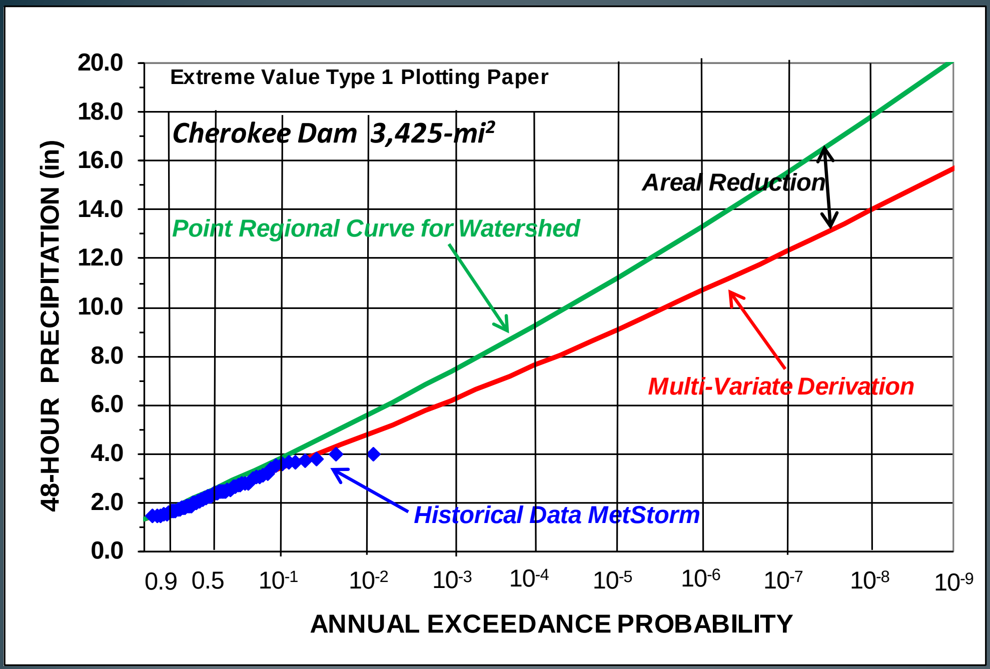


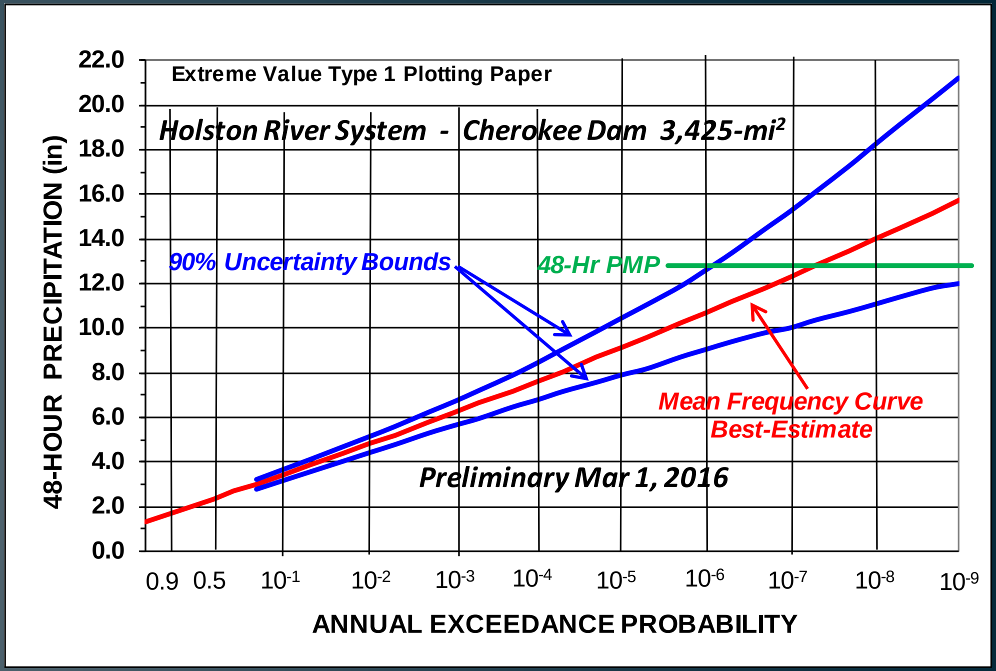
Watauga Dam Watershed

Small Areal Reduction Factor
from Point Precipitation-Frequency
to Watershed Precipitation-Frequency
for Small Watershed Relative to Scale of MLC Storms

Watershed Precipitation-Frequency Curves

Mid-Latitude Cyclone (MLC) Storm Type





Cherokee Dam Watershed

Greater Areal Reduction Factors for Larger Watershed

Watershed Precipitation-Frequency Relationship is One of the Key Inputs for Stochastic Flood Modeling and Development of Hydrologic Hazard Curves

Conclusions

Storm Typing is a Big Deal

Provides the Ability to Develop
Watershed Precipitation-Frequency Relationships
for Specific Storm Types

Allows Separate Stochastic Flood Modeling
to be Conducted for Each Storm/Flood Type

End-of-Slides

Regional Precipitation-Frequency Analyses
for Mid-Latitude Cyclones,
Mesoscale Storms with Embedded Convection,
Local Storms and Tropical Storm Remnant
Storm Types in the Tennessee Valley Watershed

\+ PowerPoint Presentation

MGS Engineering Consultants website
http://www.mgsengr.com

Navigate to the L-RAP page