Combined Use of Radar and Gauge Measurements for Flood Forecasting Using a Physics-based Distributed Hydrologic Model

National Hydrologic Warning Council
Dallas Texas
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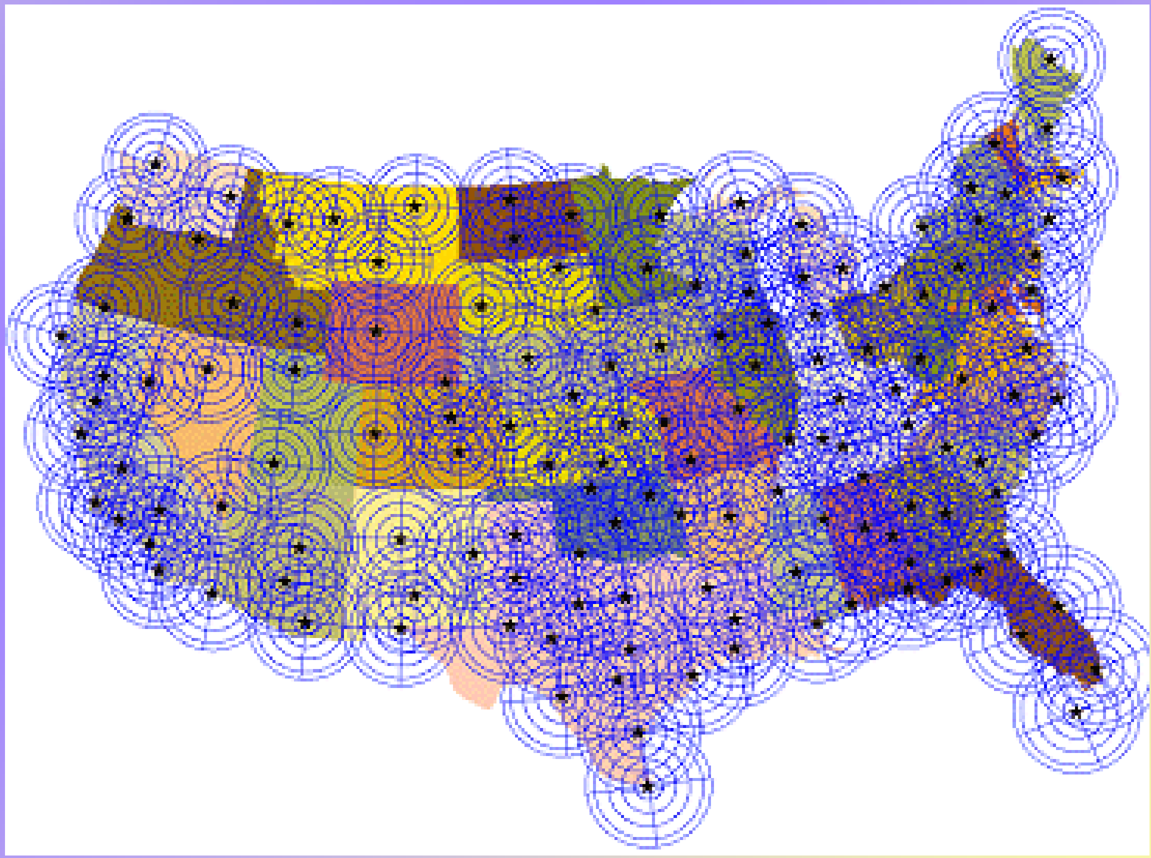
Technological Advances in Rainfall Measurement

- Advances in rainfall measurement technology have made new approaches to hydrologic prediction possible, and with more accuracy than ever before.
- Technological advances in precipitation measurement (radar/satellite/gauge) and hydrologic modeling allow us to better plan, design, and forecast performance of drainage infrastructure in preparation for the next flood.

Distributed Radar Input

NEXRAD 10 cm Doppler Radar—

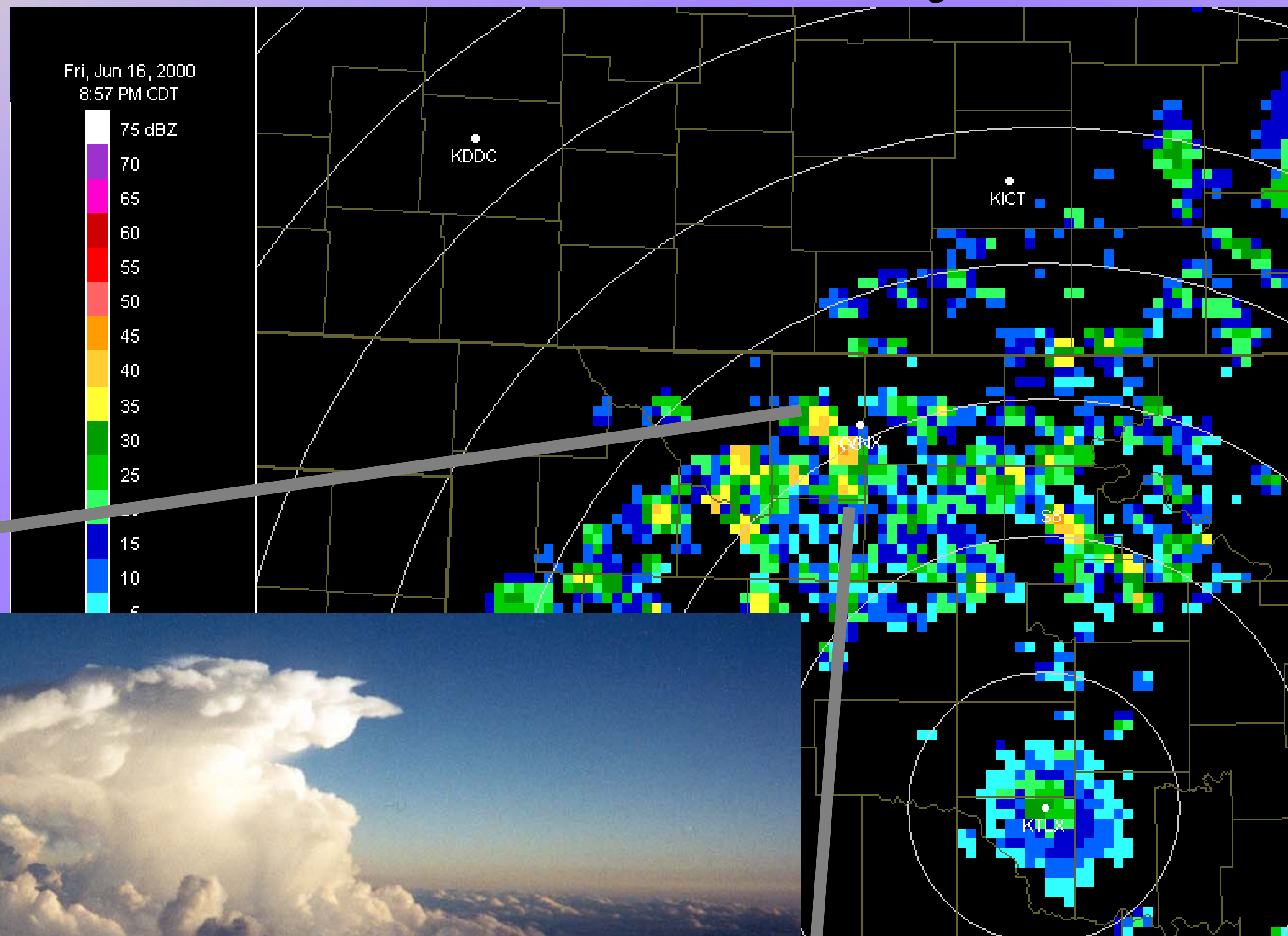
- 160+ installed
- ~130 in US
- Elsewhere internationally

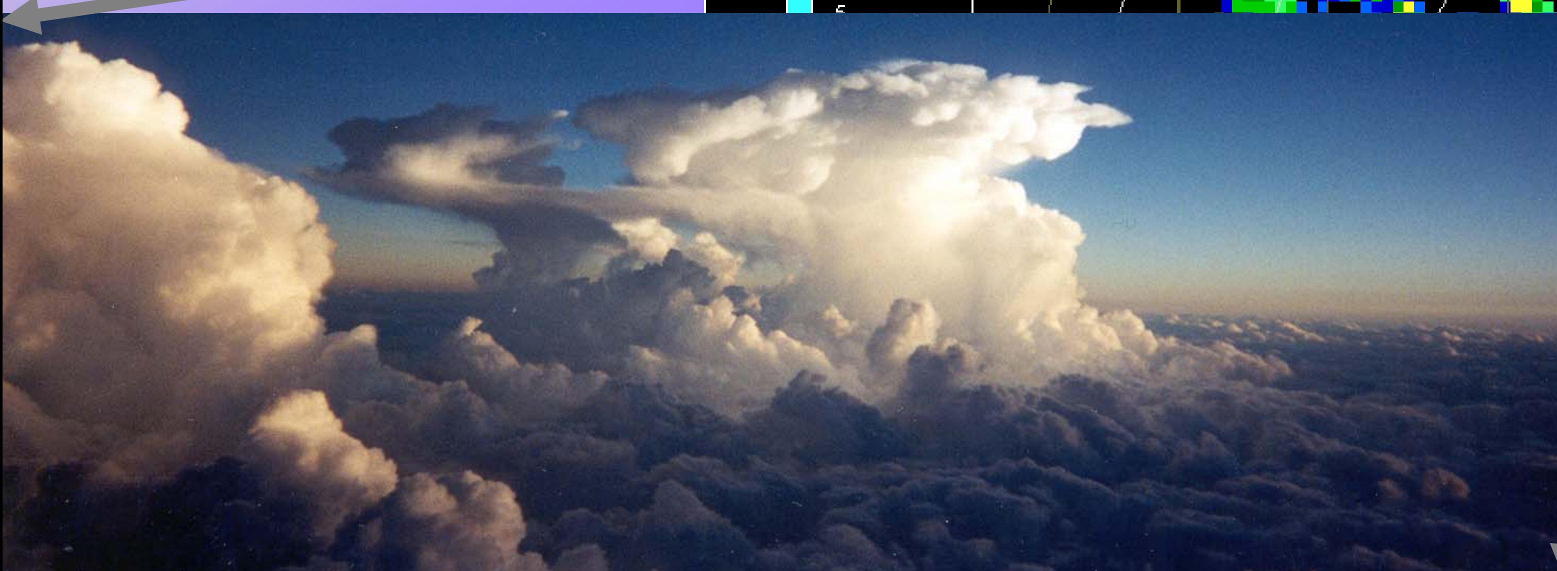


Twin Lakes, Oklahoma

- The first operational WSR-88D
- Installed in May 1990 at Twin Lakes, Oklahoma
- Prototyped at National Severe Storms Laboratory (NSSL), Norman, OK
- Movie ‘Twister’

Radar measures reflectivity



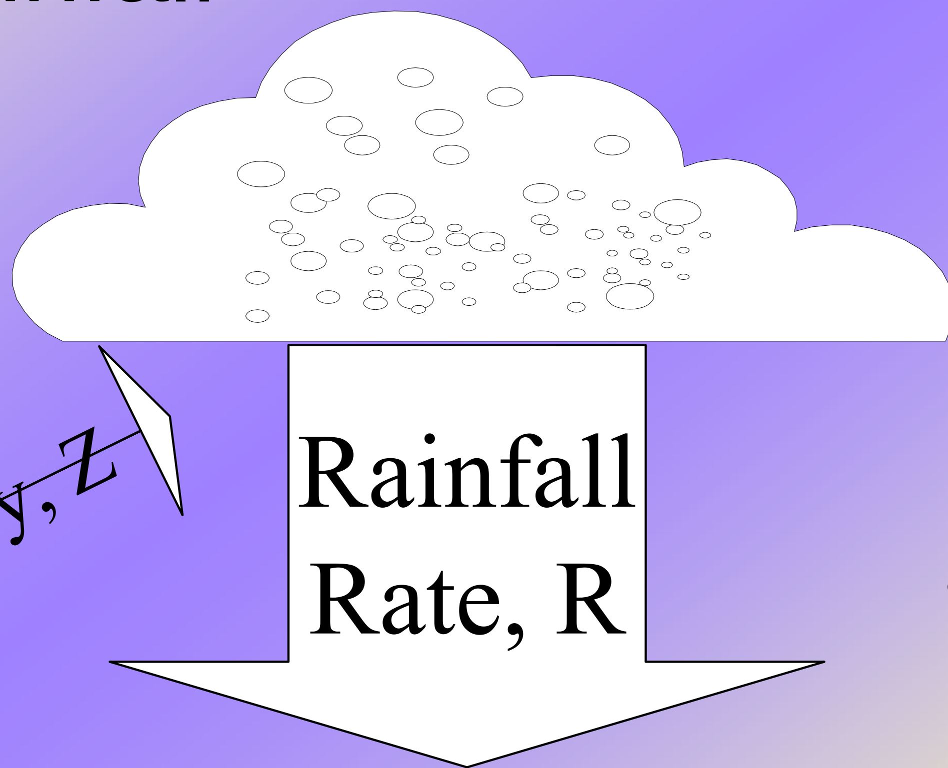


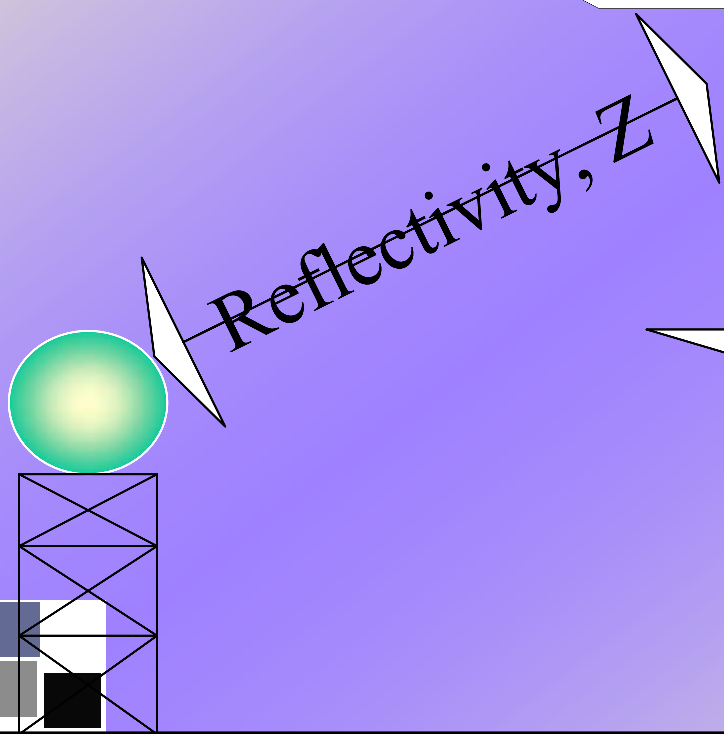
Reflectivity and rainfall rate

Radar rainfall—

$Z=300\ R^{1.4}$

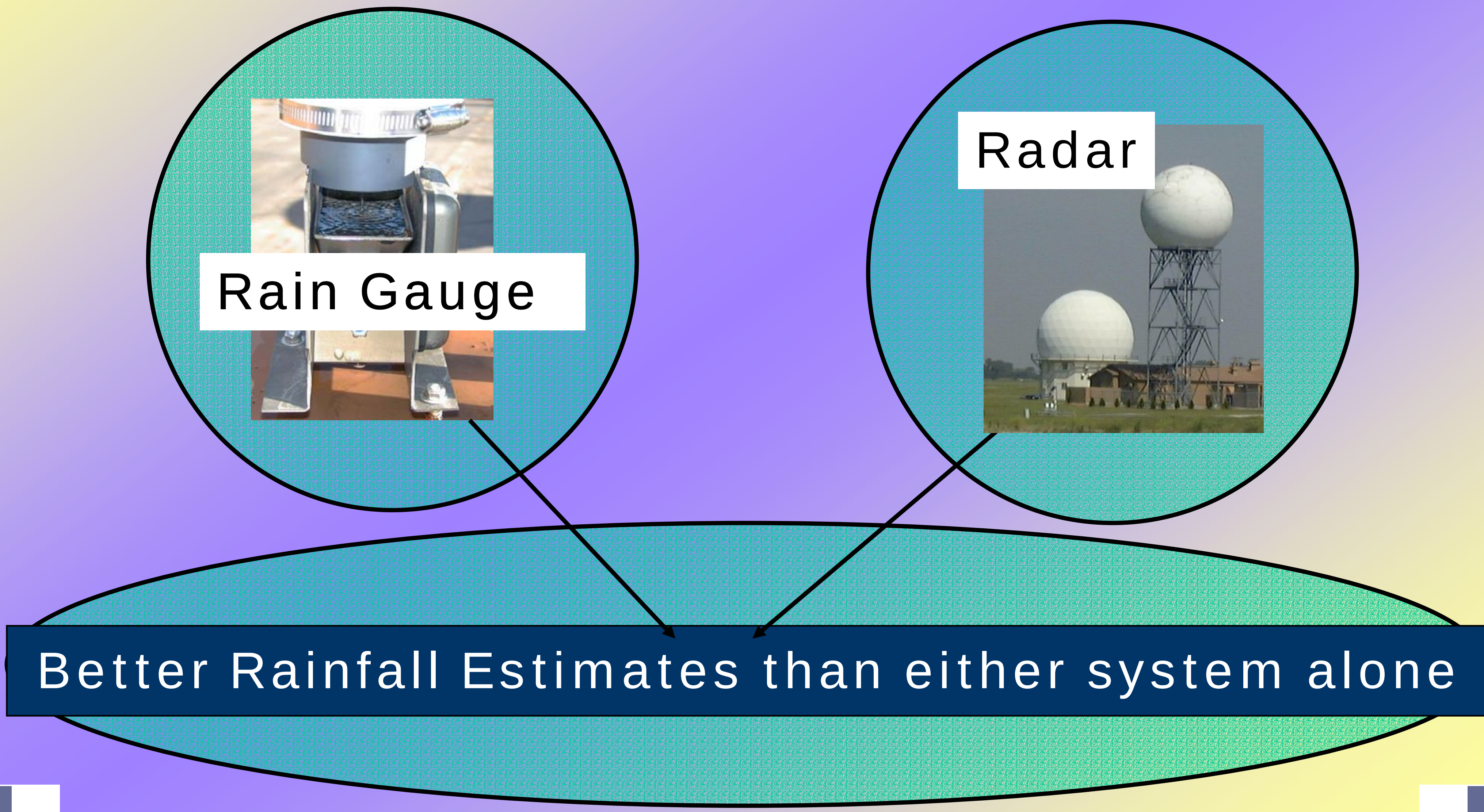
$Z=250\ R^{1.2}$





- Reflectivity depends on drop size distribution
- Rainfall rate depends on drop size distribution

Combining Systems

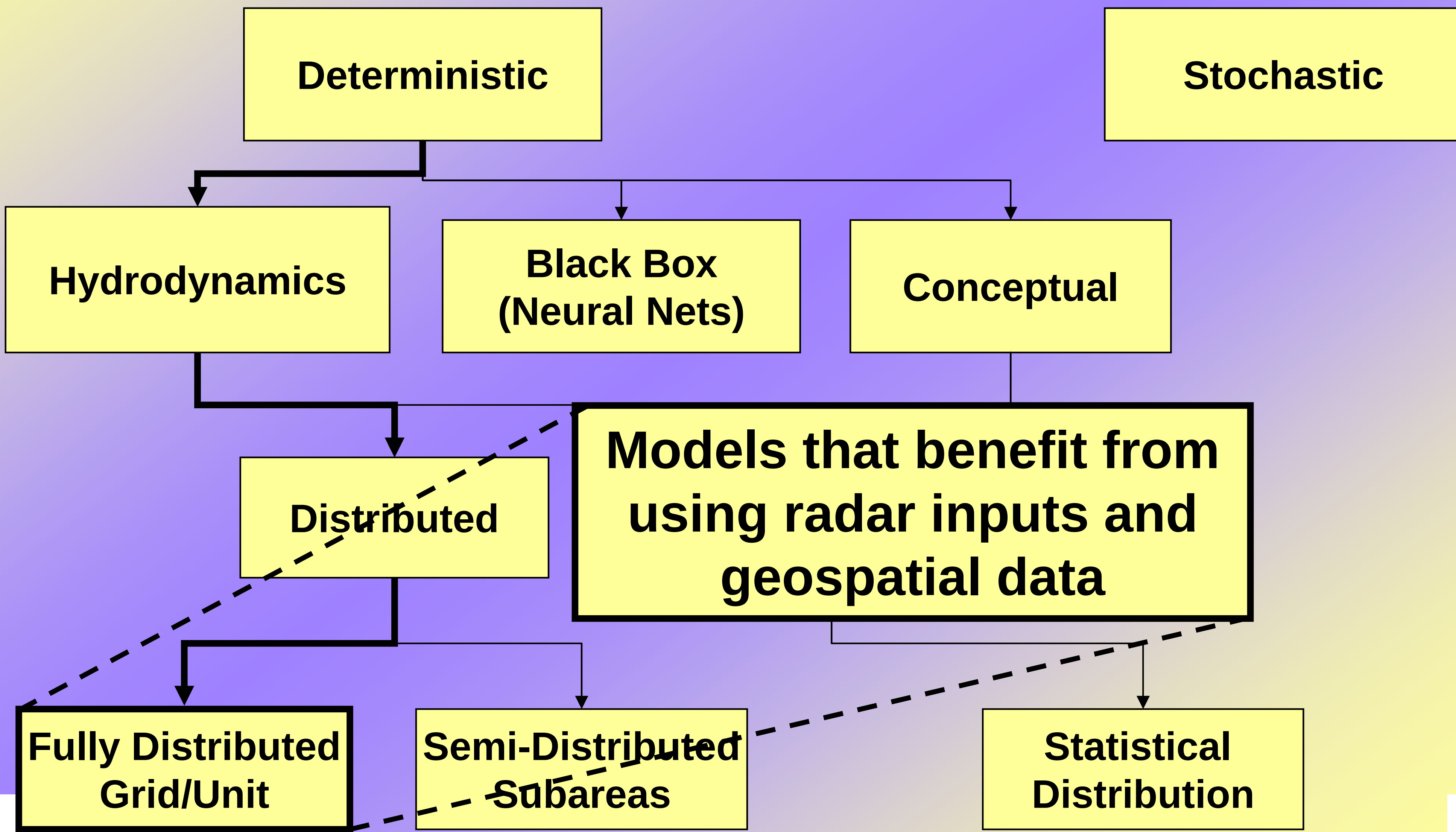


Physics-based distributed modeling

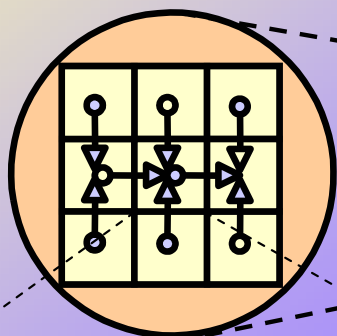
- “Physics-based” means that conservation laws of mass momentum and energy are used to make hydrologic predictions
- Hydrodynamics are used to generate both flow rates and flood stage
- Represents spatial variability of parameters and inputs
- Distributed modeling is accomplished by subdividing the domain of interest
- Fully distributed models use computational elements such as grid cells

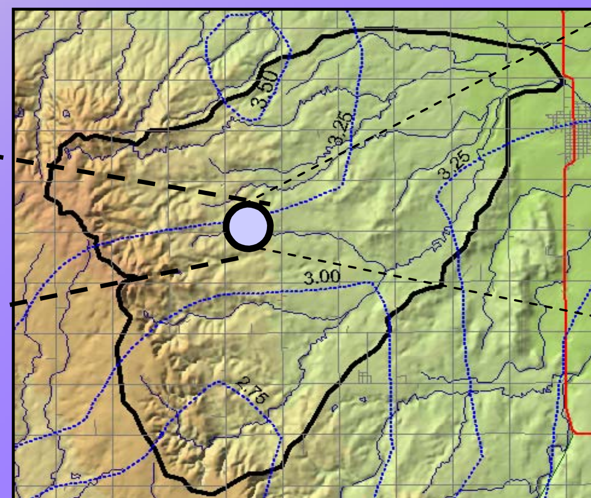
Adapted from—
Rhodda and Rhodda,
Proceedings of the Royal Society, 1999.

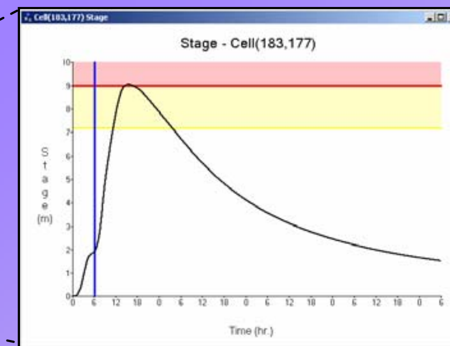
Classifying hydrologic models



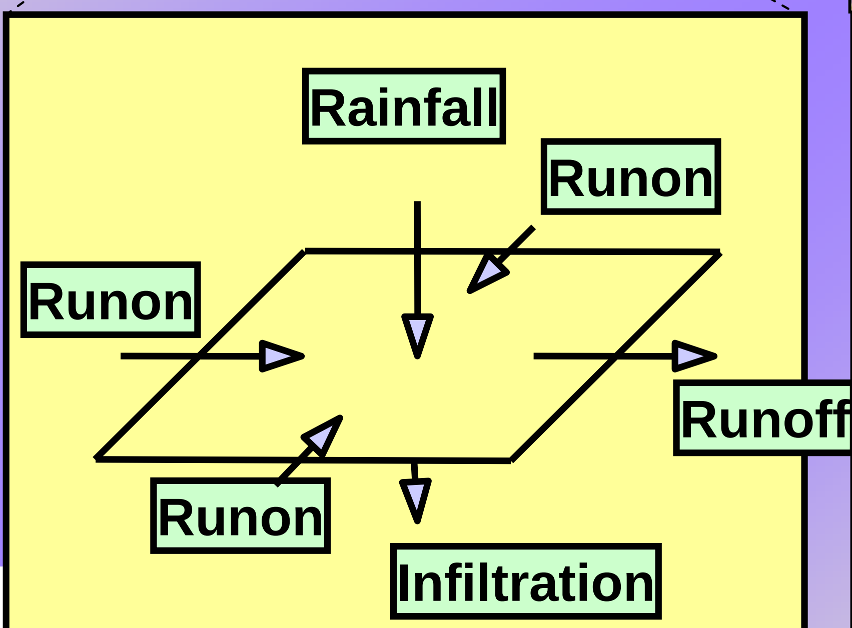
Distributed Hydrologic Modeling







$$\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} = R - I$$



Factors controlling runoff:

1. Rainfall/Snowmelt Input
2. Channel/overland Hydraulics
3. Drainage network
4. Soil Infiltration/Impervious
5. Land Cover
6. Antecedent Moisture
7. Water Control Structures

V*flo*™
Distributed Hydrologic Analysis and Prediction

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Blue River—
Importance of channel hydraulics

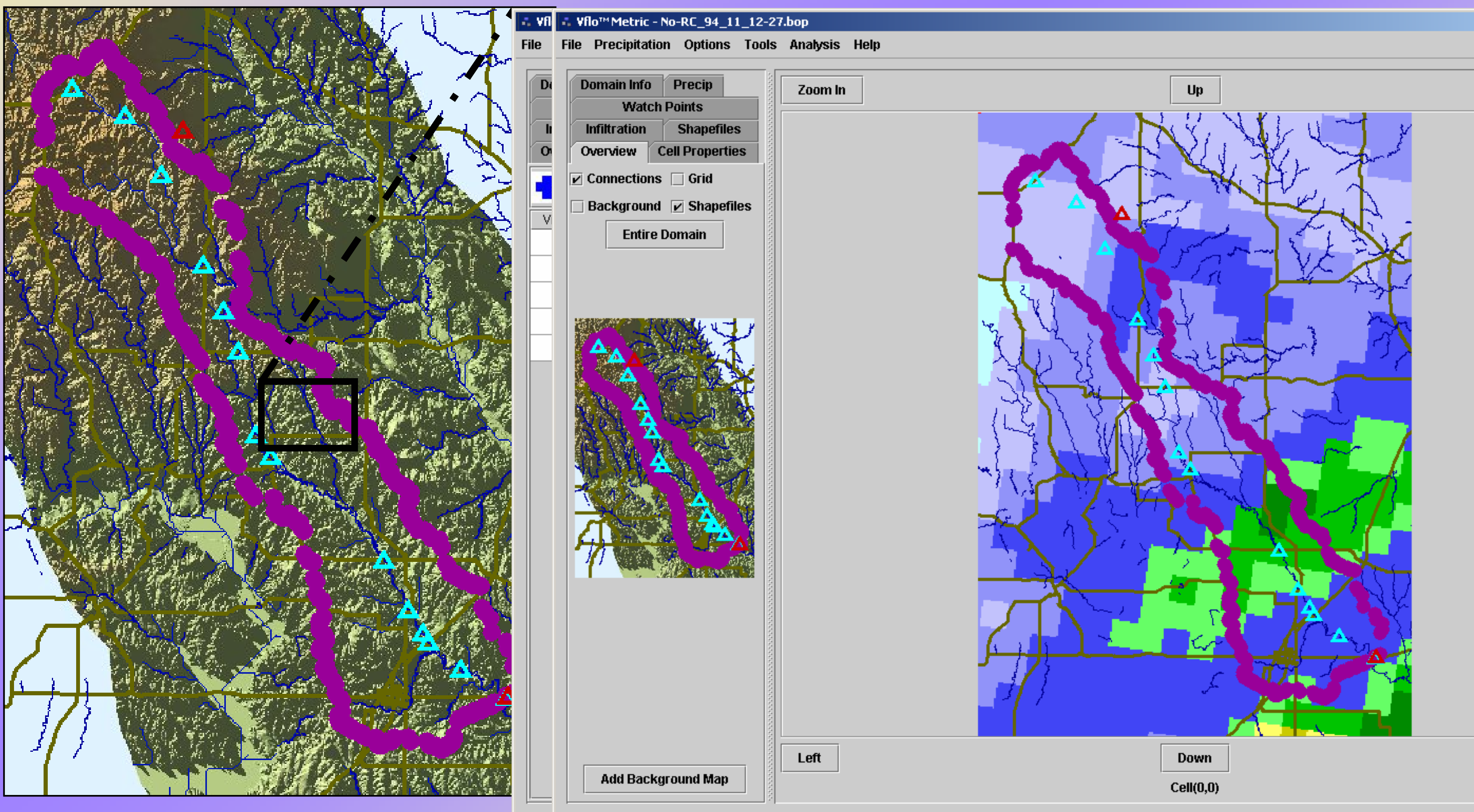
- Basin located in south central Oklahoma.
- Subject of longstanding research and the National Weather Service experiment to compare distributed models (DMIP)
- 1200 km^2 modeled with 270 m resolution
- NWS gauge-adjusted radar (NEXRAD Stage3)
- Model simulations for 23 events (18 calibration and 5 verification)
- Event based simulation initialized by simple soil moisture scheme.

Achievable Accuracy
Case Studies

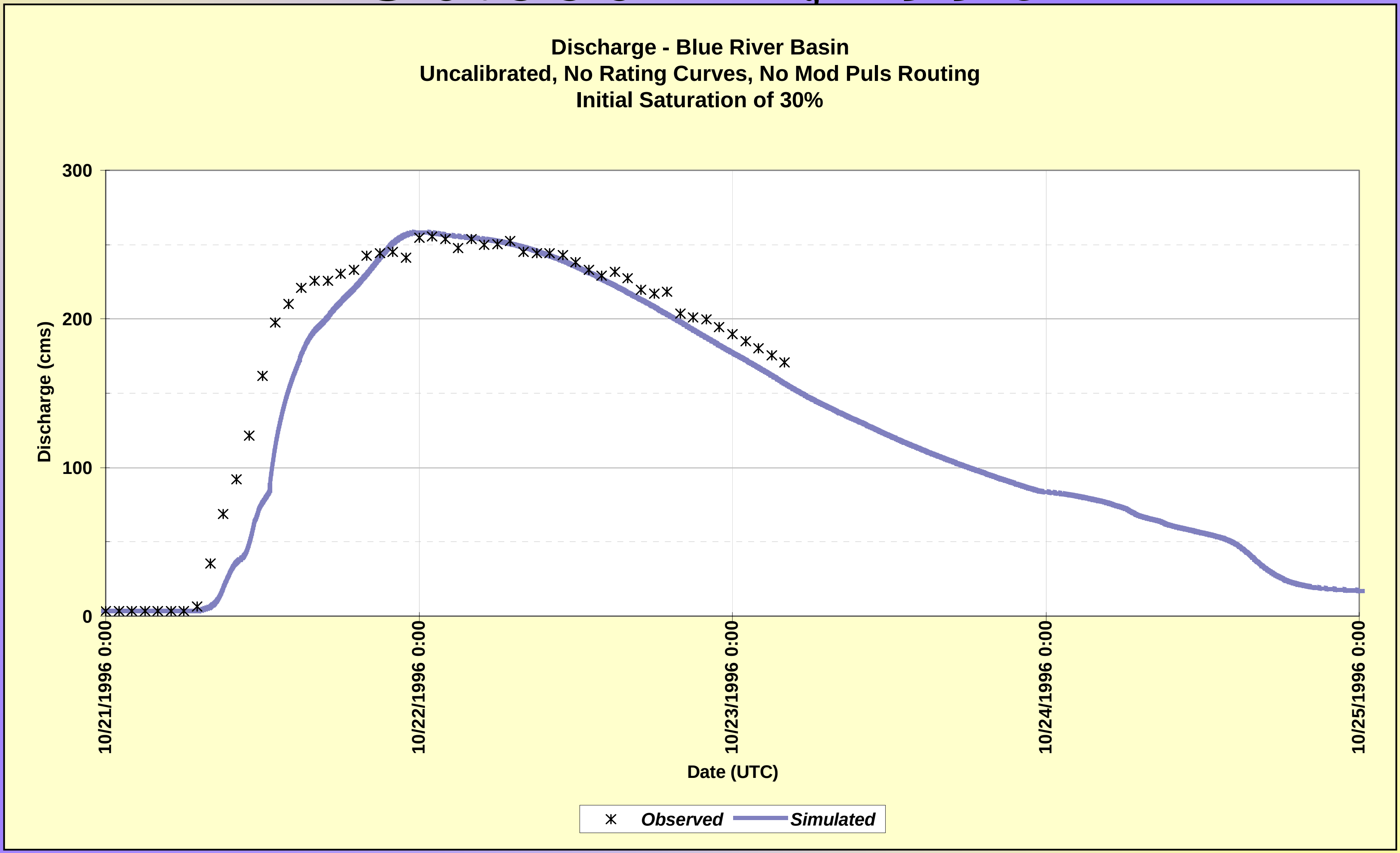
- Within a distributed modeling framework, an important question is:

How accurately can hydrographs be simulated using physics-based hydrologic models and gauge-adjusted radar?

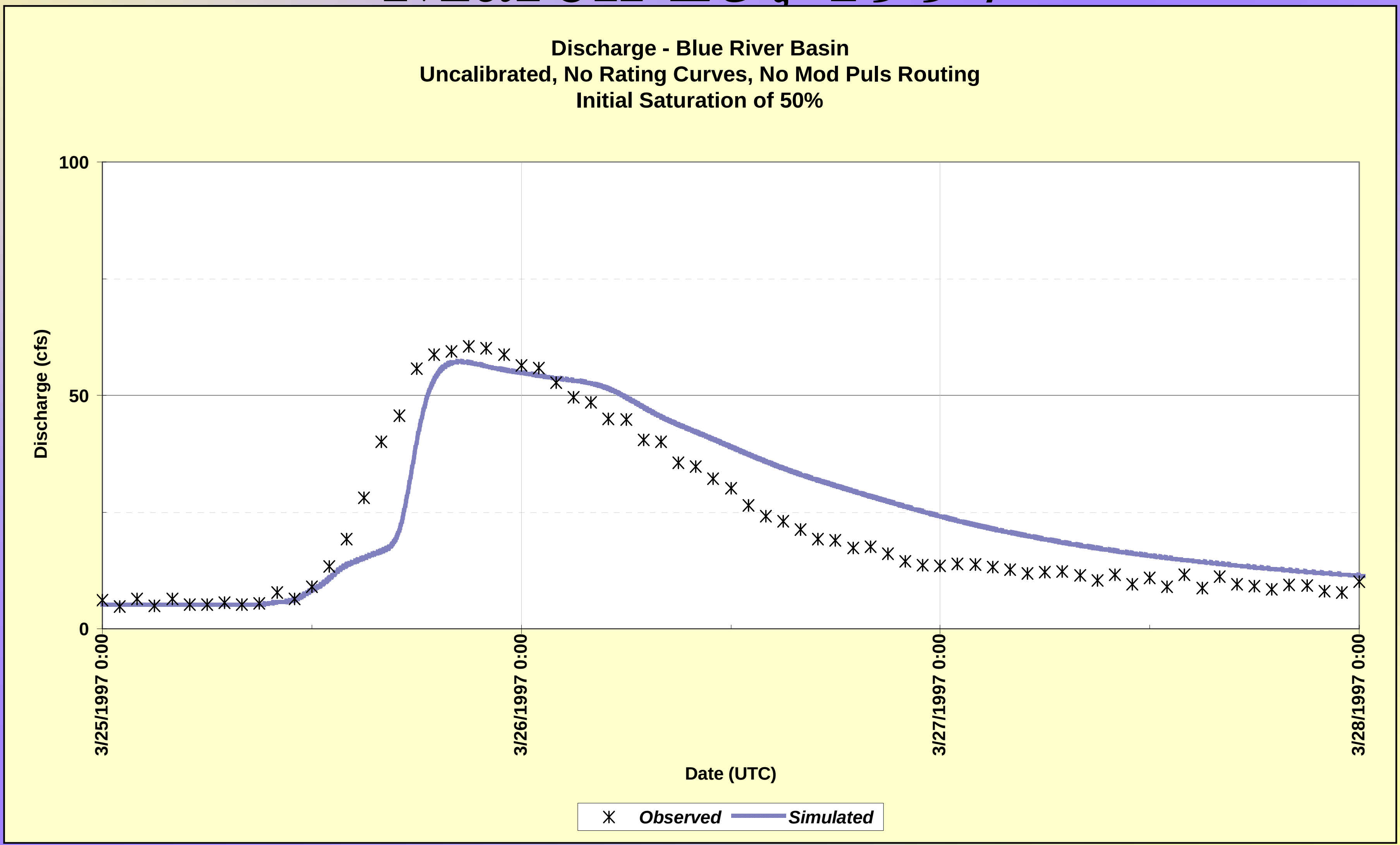
Blue River
Model setup



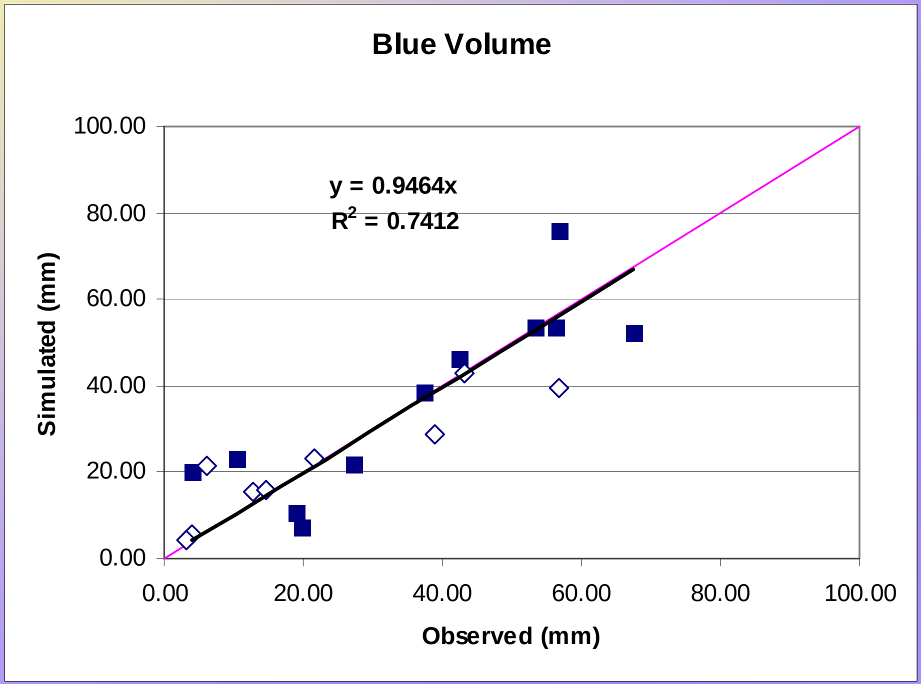
Blue River
October 21, 1996



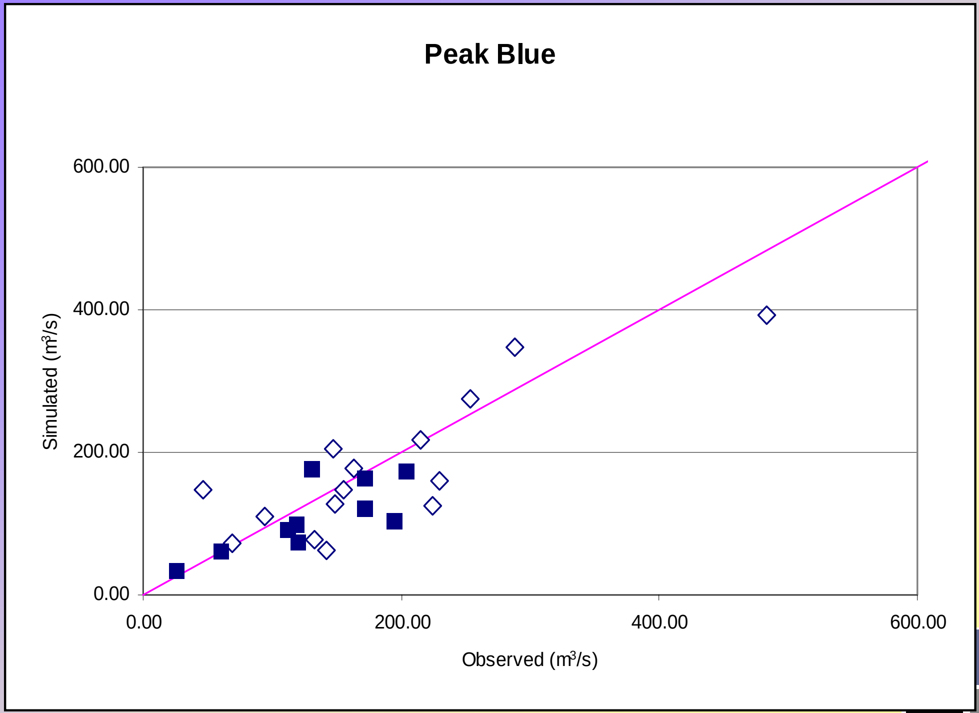
Blue River
March 25, 1997



Blue river volume and peak



V*flo*™
RMSE= 9.8 mm
α=1.0 and β=1.0.



V*flo*™
RMSE= 52.0 m^3s
α=0.75 and β=1.0.

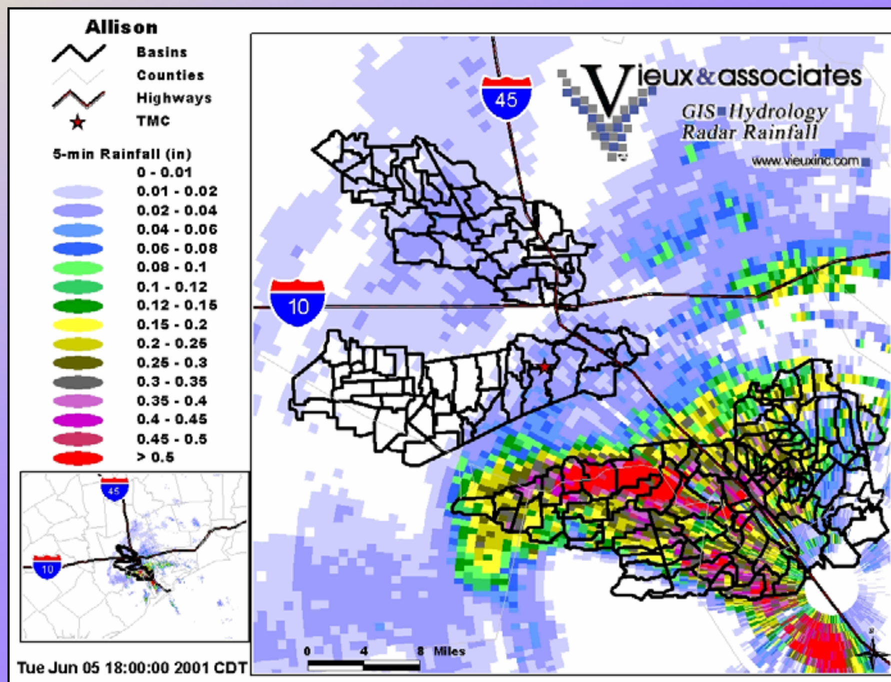
Texas Medical Center/Rice University Flood Alert System

Urban real-time flood forecasting—

- Texas Medical Center relies on an operational distributed model flood forecasting
- Radar + V*flo*™

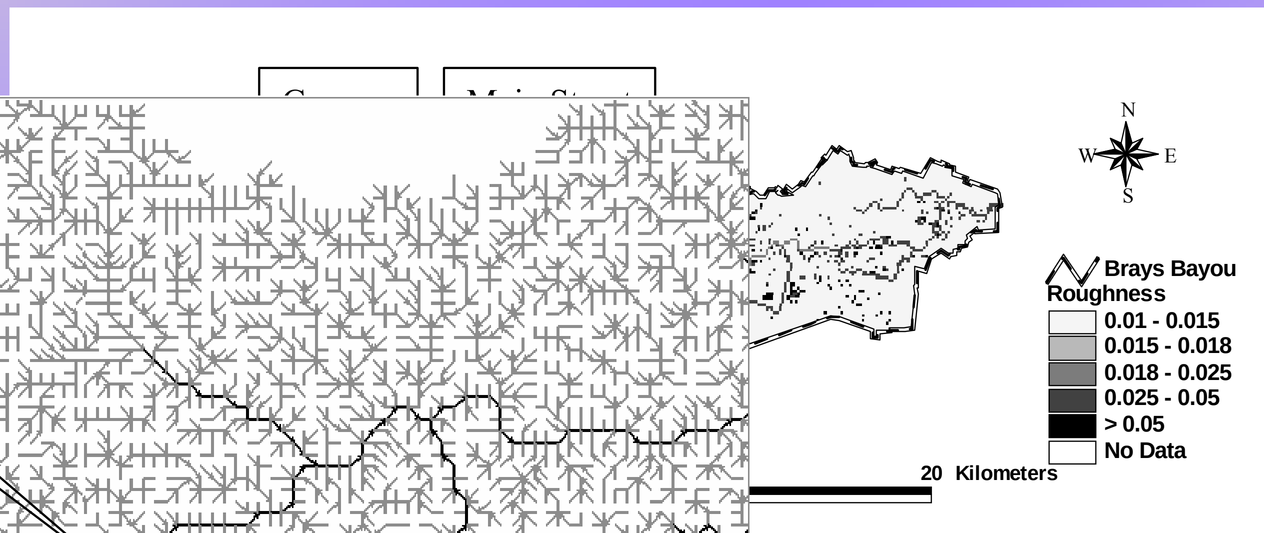
www.floodalert.org

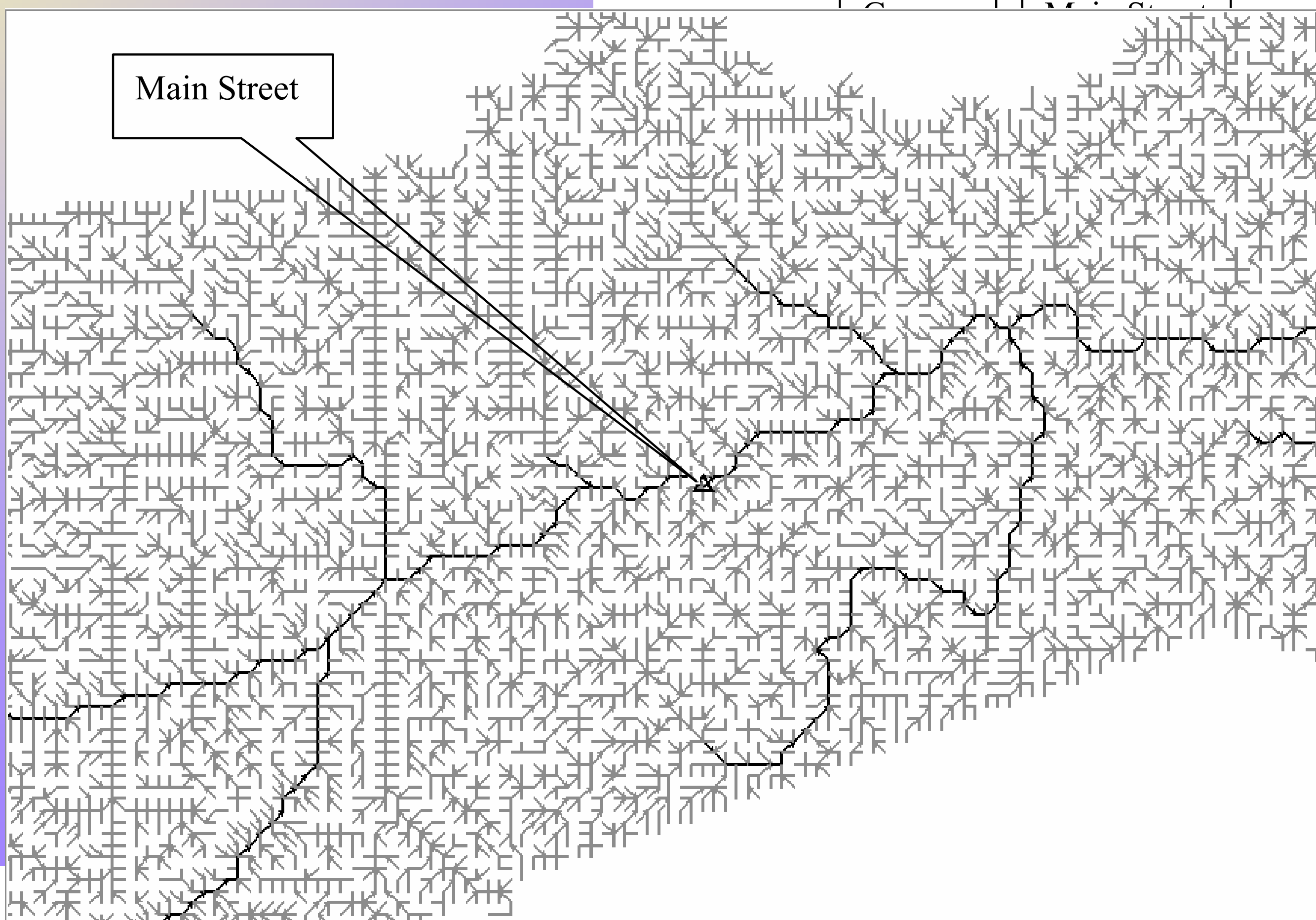
Real-time prediction



Observations → Flood Information → Response

V*flo*™ Brays Bayou





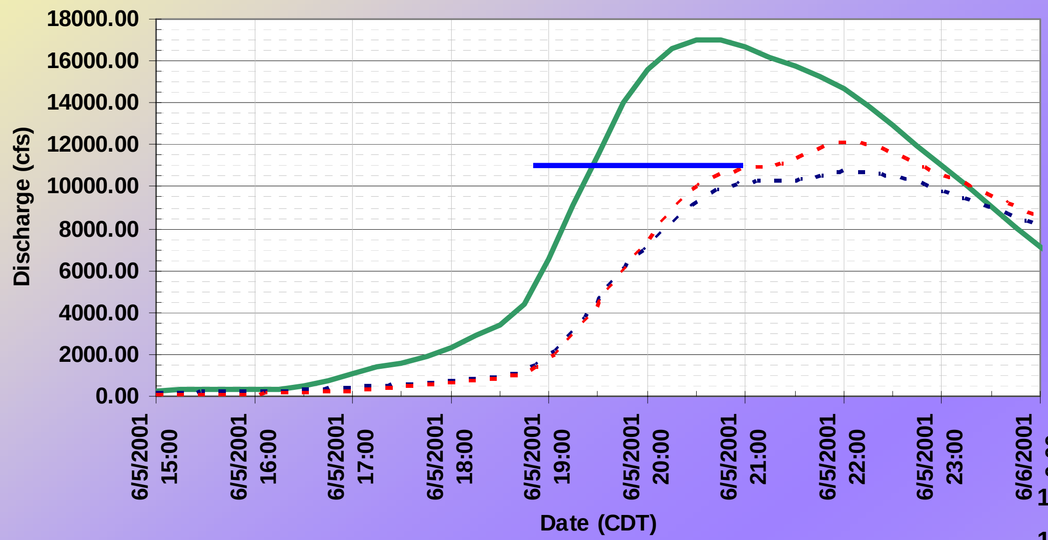
Drainage area
260 km^2

Model resolution
120 x120 m

Testing reliability

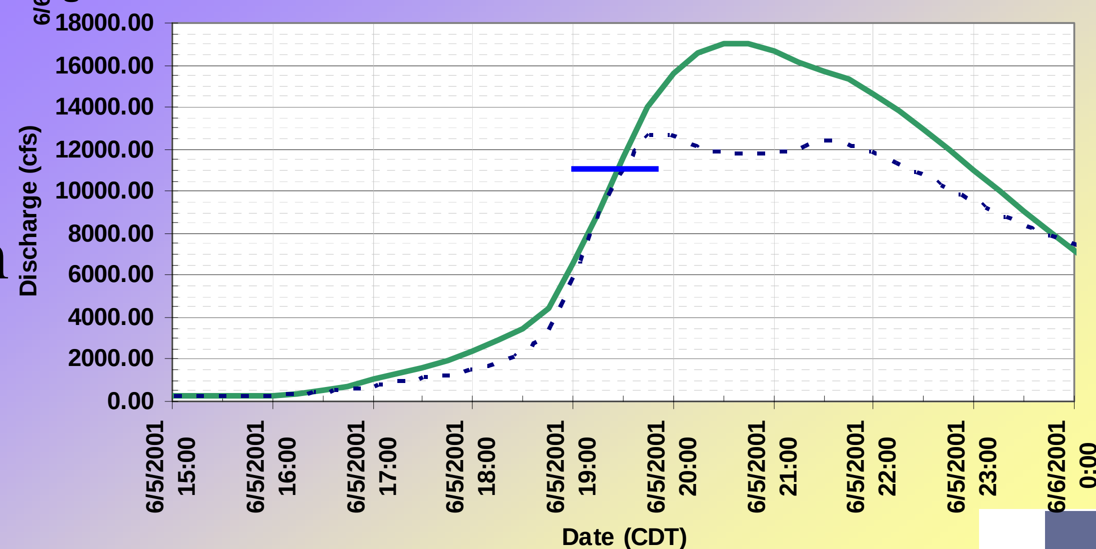
- Optimizing the rising limb—
  Select a threshold and measure observed and simulated time to cross the threshold called time to flood (TTF).
- Adjust parameters to optimize TTF, peak and time to peak for three calibration storms
- Validate performance

Forecasts based on Hydrograph rising limb

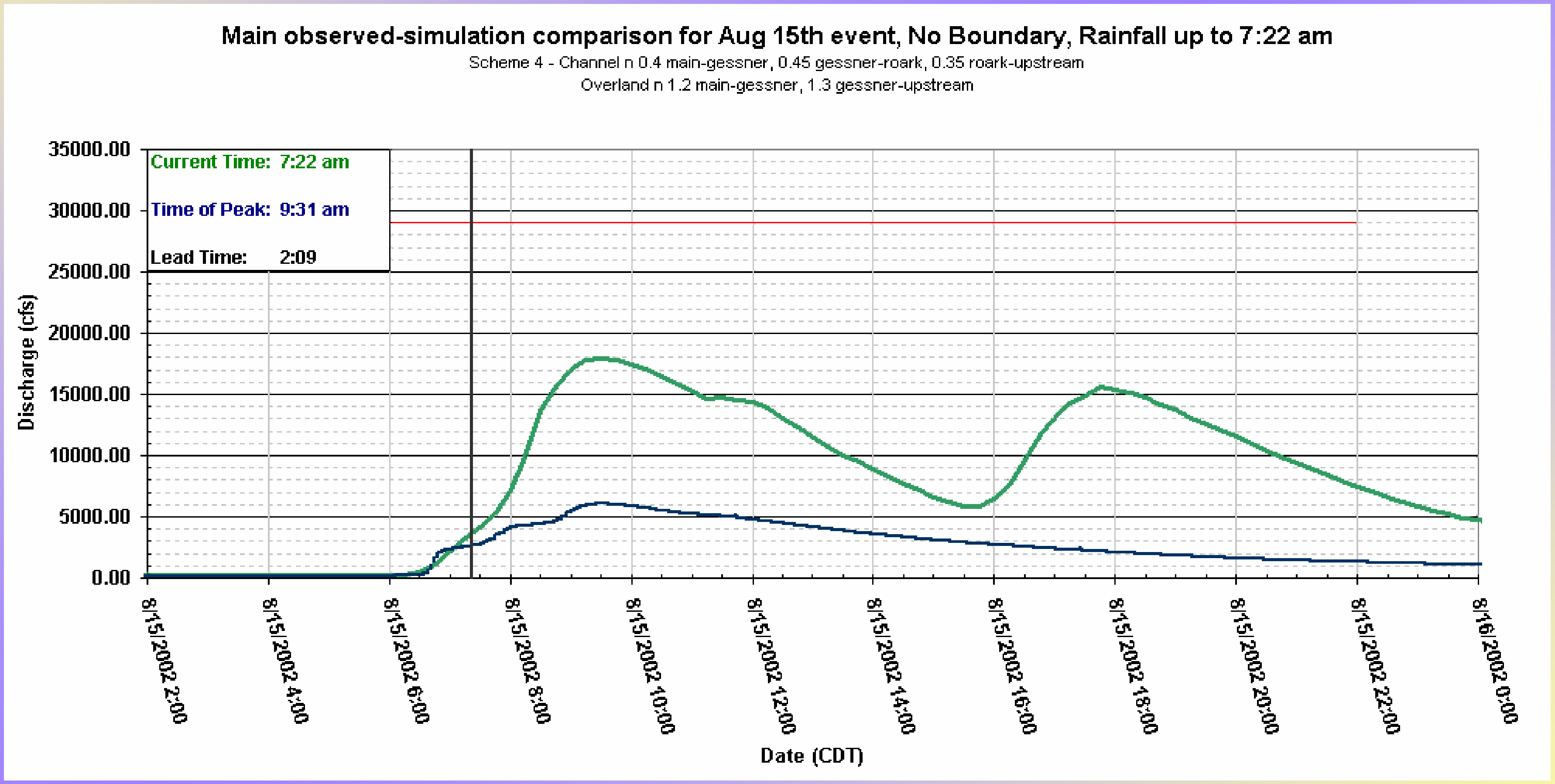


Only optimizing for peak and time to peak does <u>not</u> necessarily match the rising limb making forecast thresholds accurate

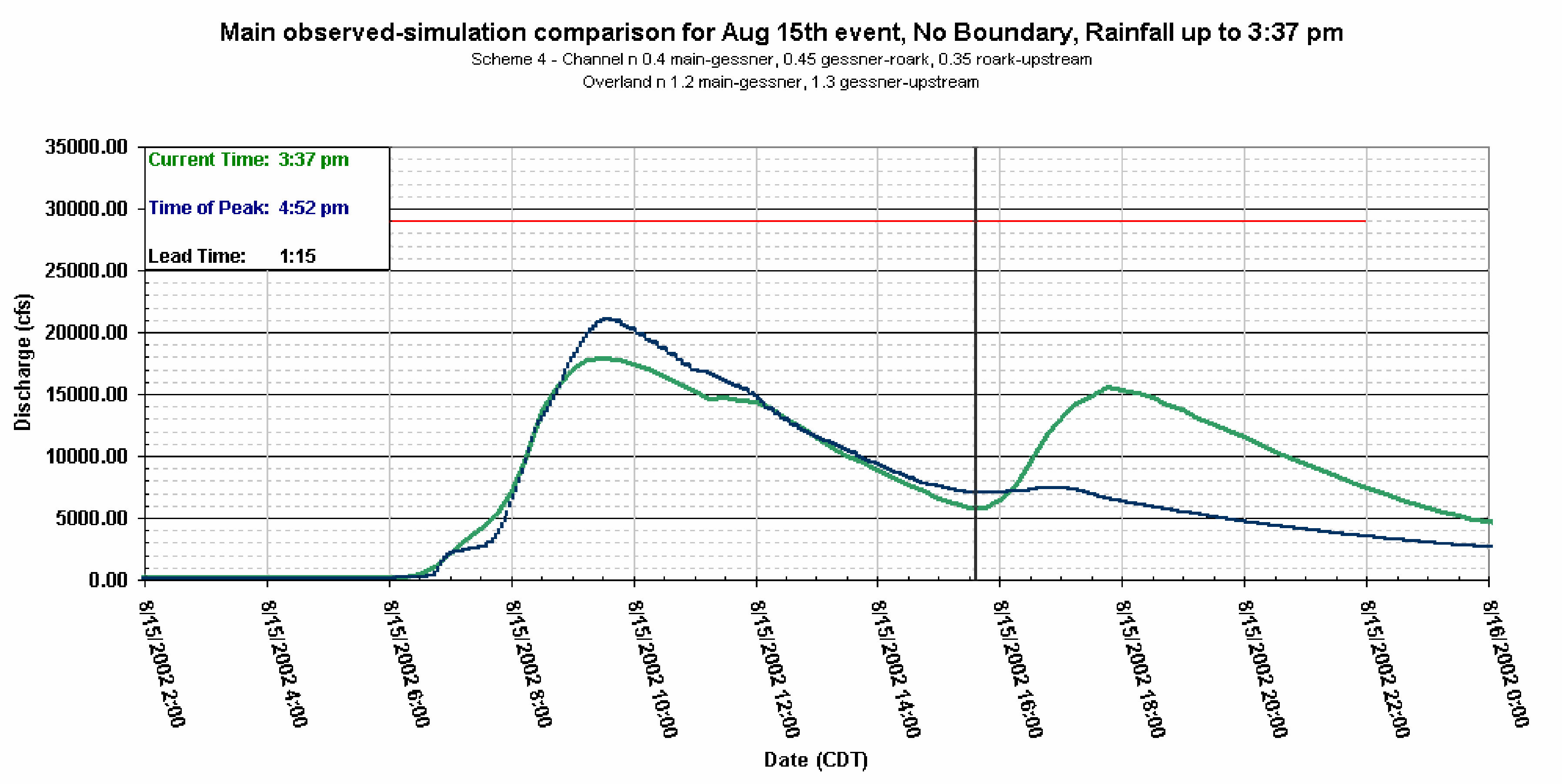
Optimizing for TTF improves rate of rise that will be used in a real-time flood alert system



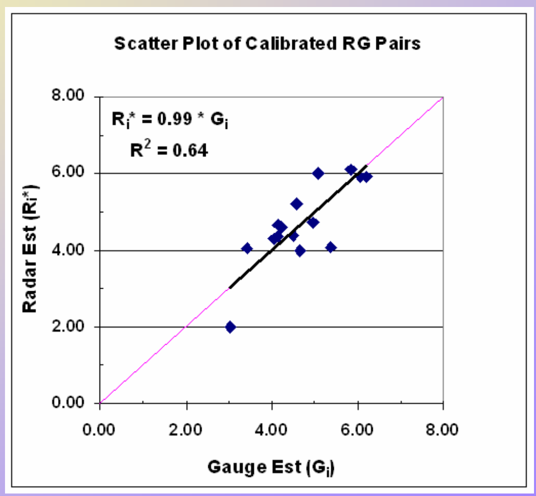
Verification
1st wave August 15

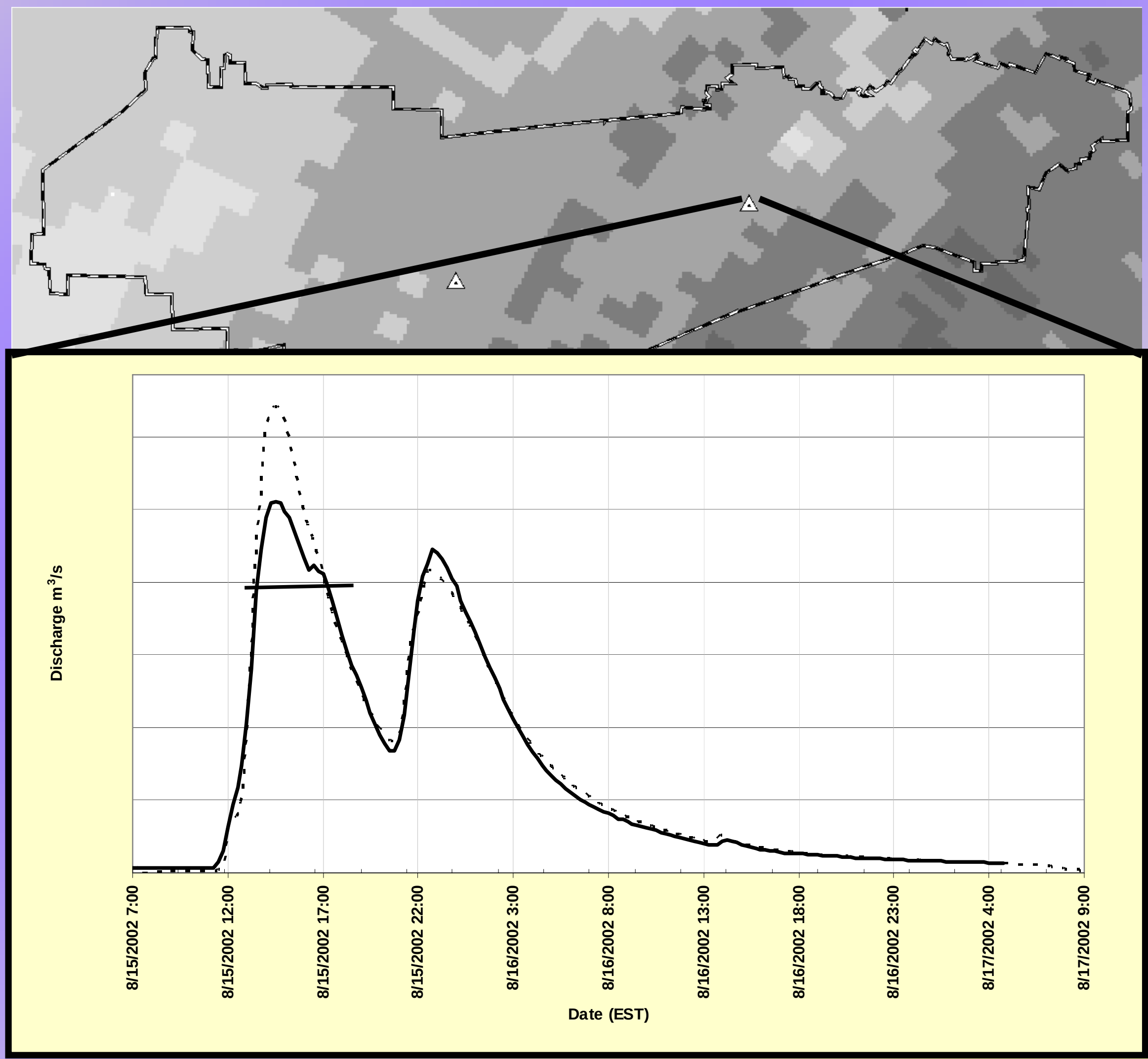


Verification
2nd wave August 15



Main Street
Verification event



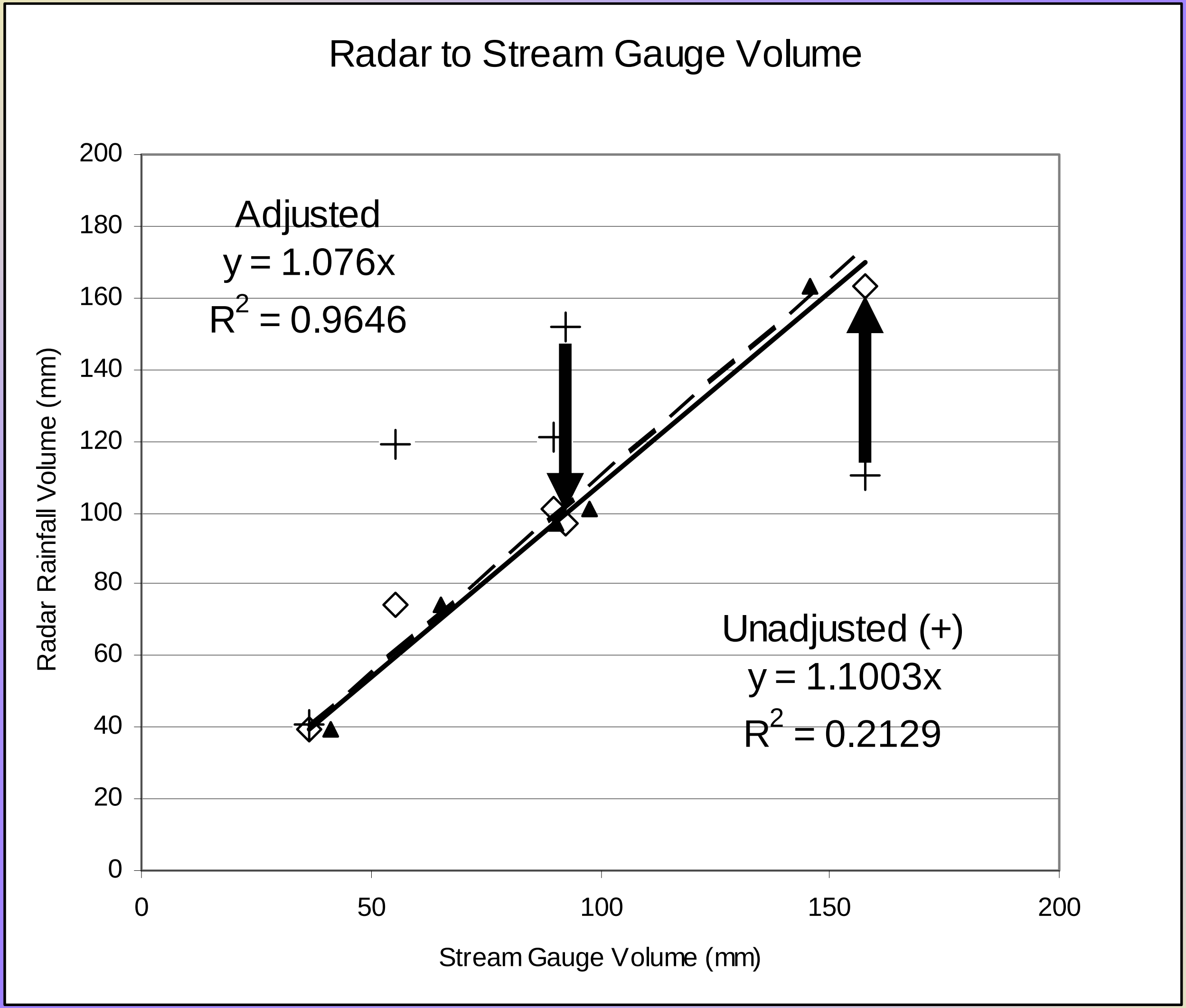


Verification—

Gauge adjusted radar

No model adjustment

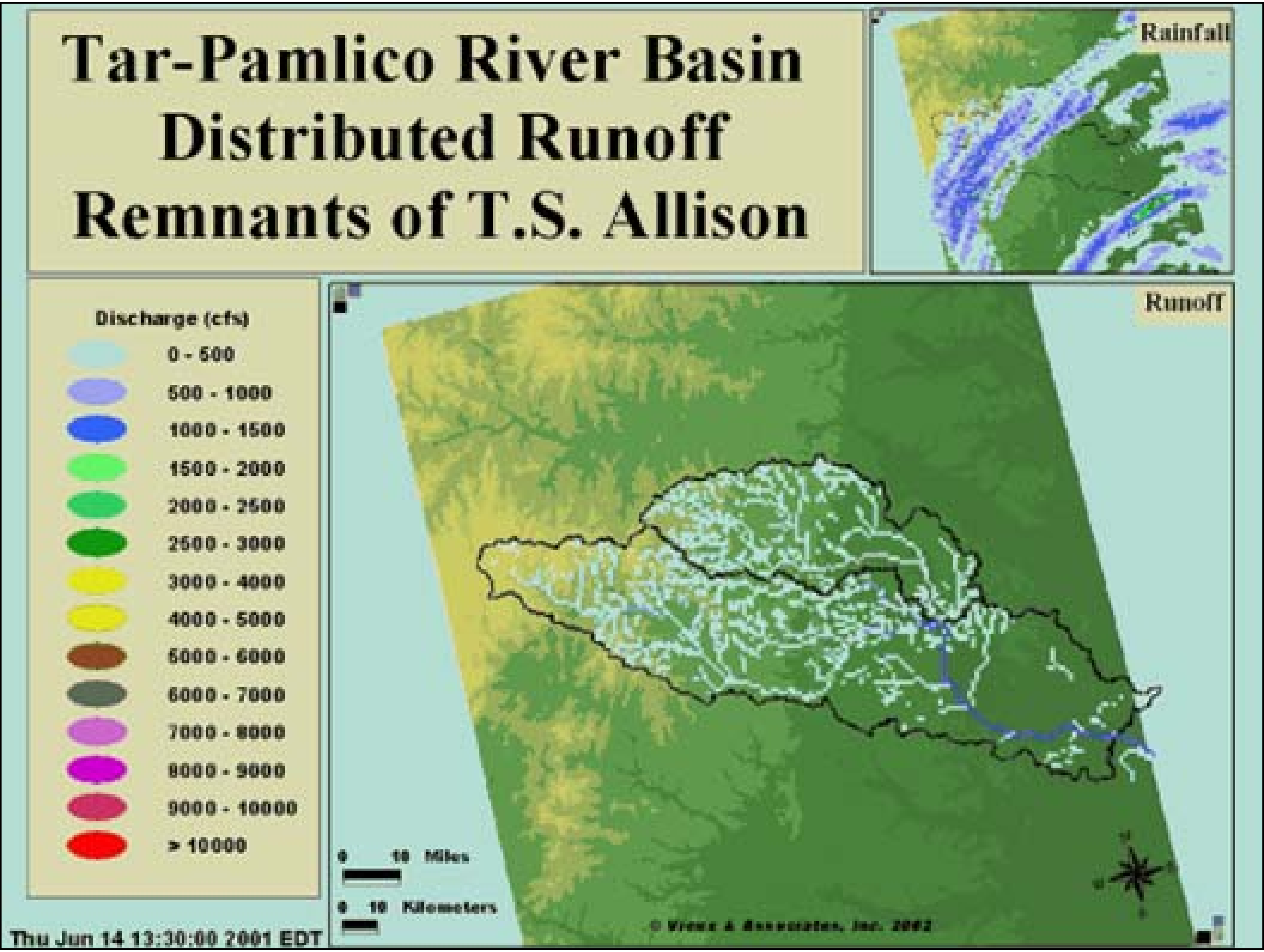
Historic event performance



- Verification of QPE using stream gauge volumes
- Radar adjustment improves efficiency from R^2=0.2129 to R^2=0.9646

Rainfall Runoff Prediction in Real-Time

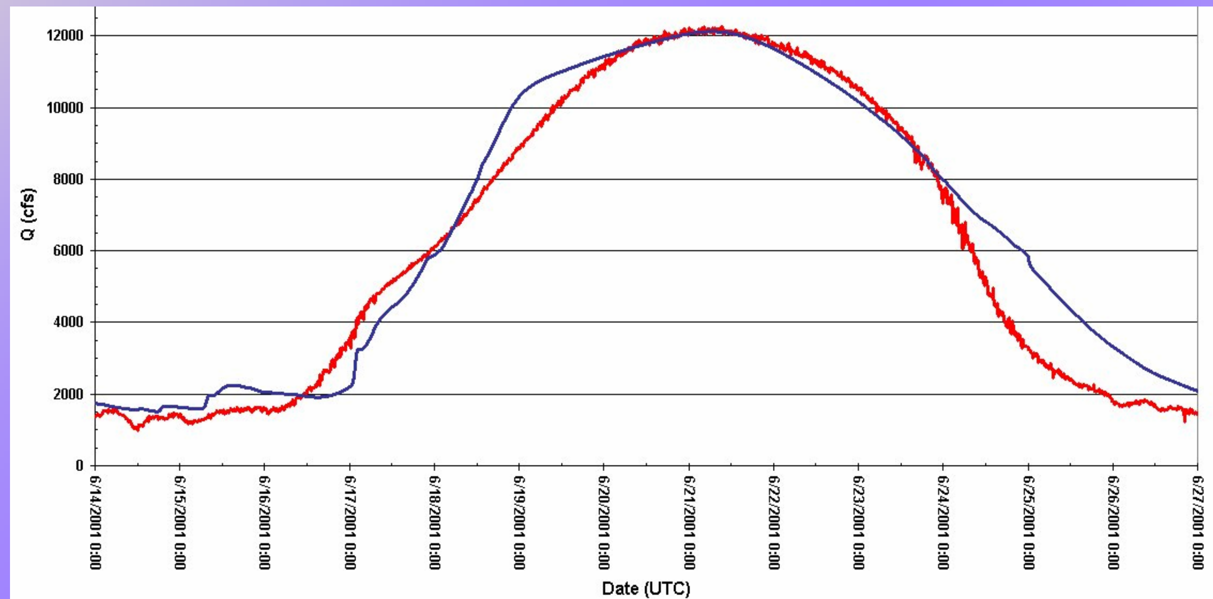
- Rainfall-runoff prediction is particularly important for a variety of applications such as water resources management, flood prediction, emergency management.



Tar-Pamlico River Basin
Distributed Runoff
Remnants of T.S. Allison
Rainfall
Runoff
Discharge (cfs)
0 - 500
500 - 1000
1000 - 1500
1500 - 2000
2000 - 2500
2500 - 3000
3000 - 4000
4000 - 5000
5000 - 6000
6000 - 7000
7000 - 8000
8000 - 9000
9000 - 10000
> 10000
0 10 Miles
0 10 Kilometers
Thu Jun 14 13:30:00 2001 EDT

Hydrographs

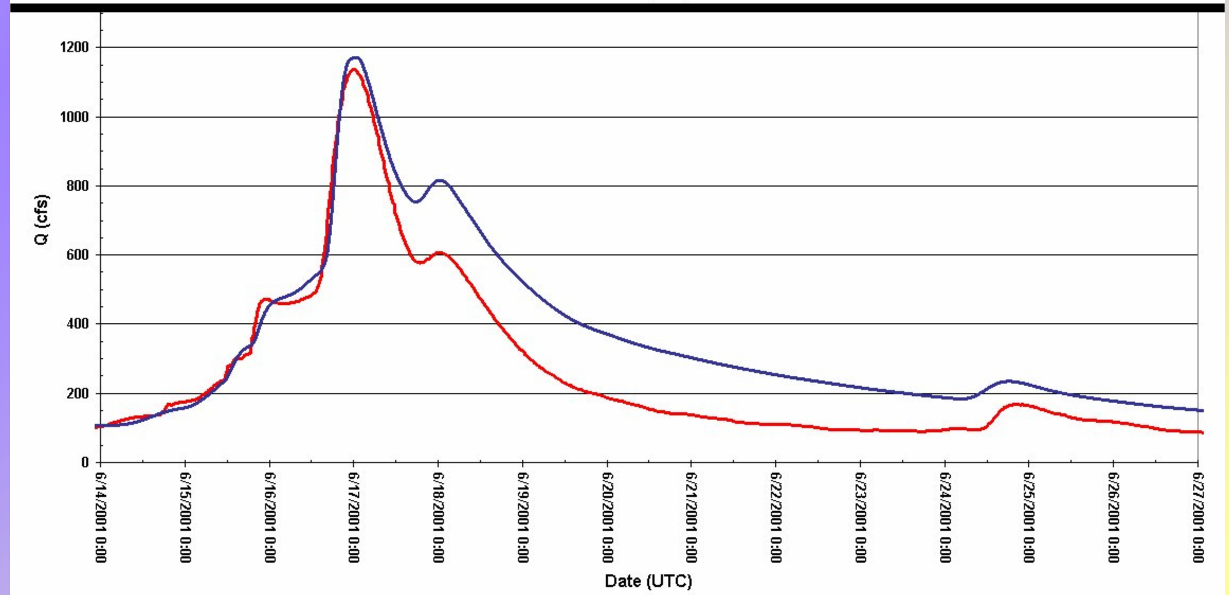
Greenville



Measured

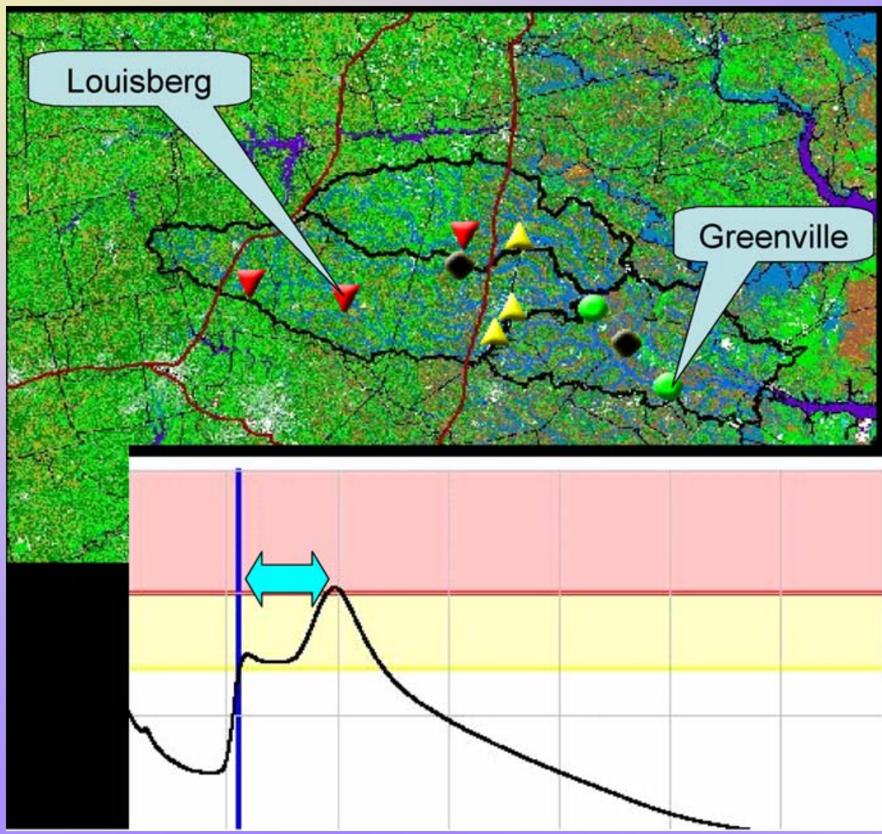
Simulated

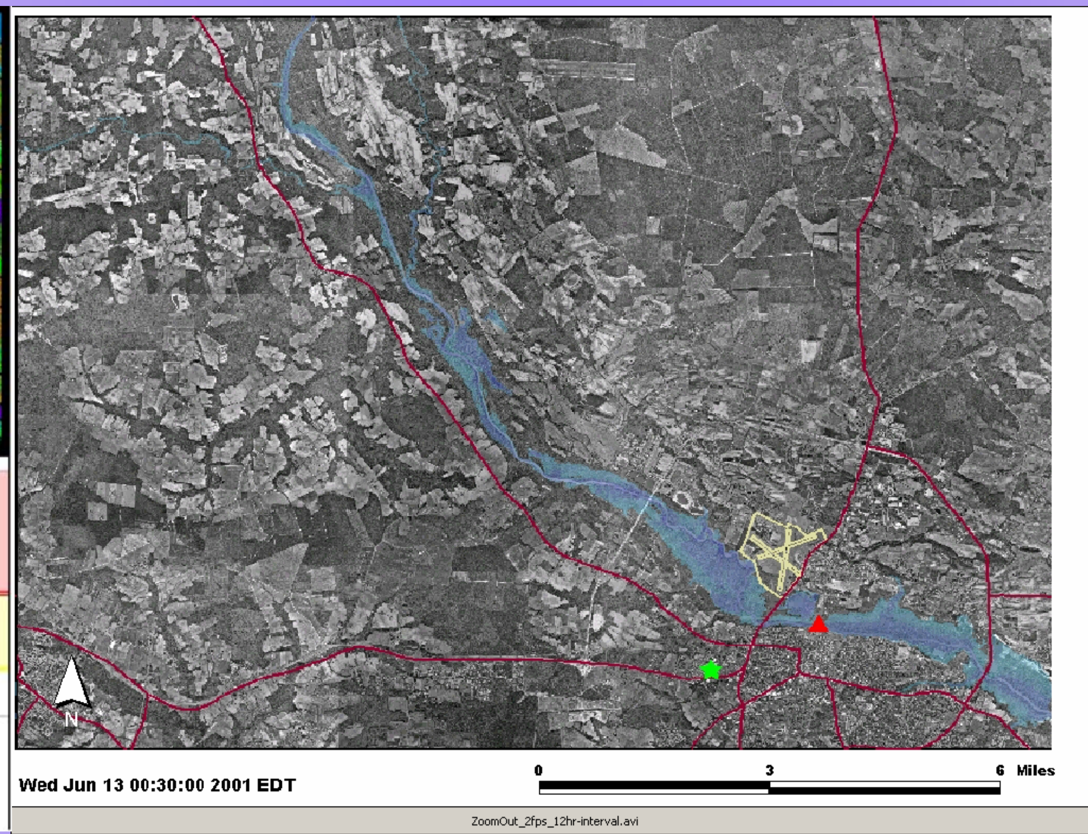
Louisberg



TS Allison

V*flo*™ Predicted Inundation Web Display



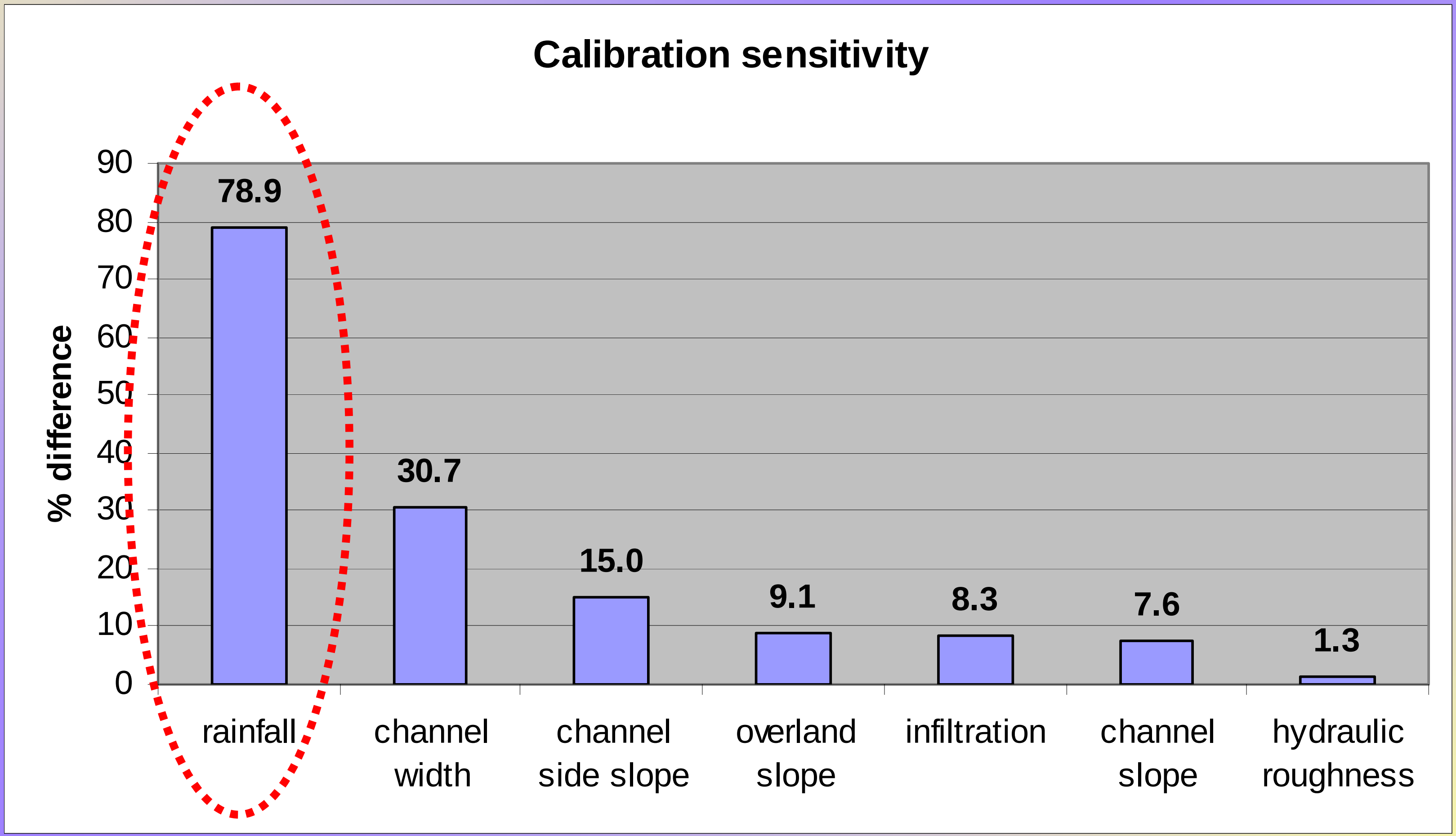


Hurricane Floyd
Transportation Impacts

Pitt-Greenville Airport (PGV), Pitt County

Photo Courtesy of North Carolina Emergency Management

Stage Sensitivity Summary



Summary

1. Physics-based distributed modeling can produce accurate predictions in real-time at any location in a drainage network.
2. Made possible by technological advances in radar rainfall measurement
3. Consistent performance across storm sizes/type
4. Physically realistic parameters from geospatial data
5. High achievable accuracy in peak and rising limb predictions given good channel hydraulic data
6. Event reconstruction tests reliability of operational flood forecasting systems

Further information

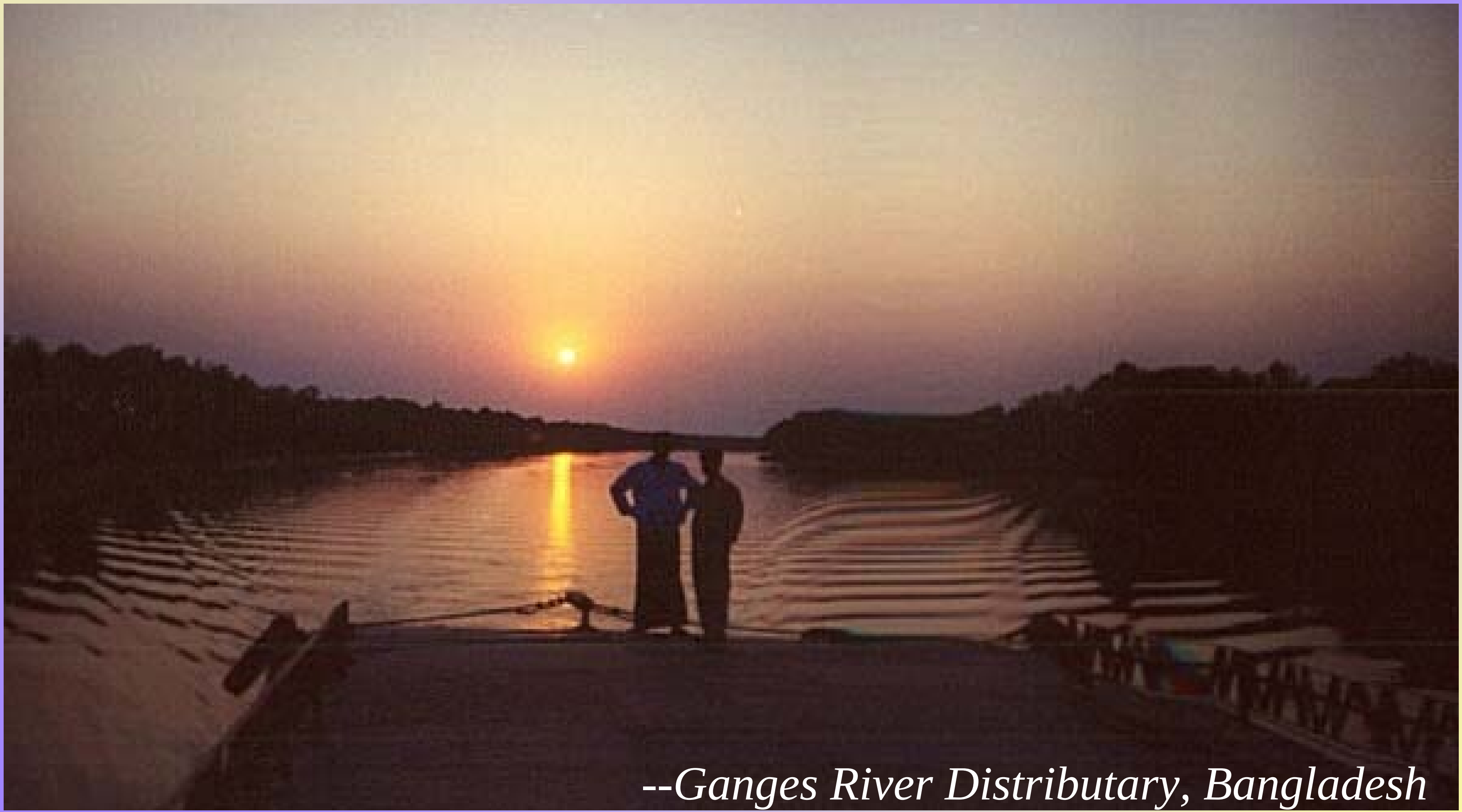
Vieux B.E. 2002. "Predictability of Flash Floods Using Distributed Parameter Physics-Based Models." *Report of a Workshop on Predictability & Limits-To-Prediction in Hydrologic Systems*, Committee on Hydrologic Science, Water Science and Technology Board, Board on Atmospheric Sciences and Climate, National Research Council, ISBN 0-309-08347-8. pp. 77-82.

Vieux, B.E., and F.G. Moreda, (2003). Ordered Physics-Based Parameter Adjustment of a Distributed Model. Chapter 20 in *Advances in Calibration of Watershed Models*, Edited by Q. Duan, S. Sorooshian, H.V. Gupta, A.N. Rousseau, R. Turcotte, Water Science and Application Series, **6**, American Geophysical Union, ISBN 0-87590-355-X pp. 267-281.

Vieux. B.E., (2001) *Distributed Hydrologic Modeling Using GIS*, ISBN 0-7923-7002-3, Kluwer Academic Publishers, Norwell, Massachusetts, Water Science Technology Series, Vol. 38. p. 293.

Second Edition expected 2004 English and Chinese

Questions?



--Ganges River Distributary, Bangladesh

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