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

National Hydrologic Warning Council
Dallas Texas
October 23, 2003

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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

Better Rainfall Estimates than either system alone

Rain Gauge

Radar
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.
Classifying hydrologic models

Deterministic
- Hydrodynamics
- Black Box (Neural Nets)
- Conceptual
  - Distributed
    - Fully Distributed Grid/Unit
    - Semi-Distributed Subareas

Stochastic
- Models that benefit from using radar inputs and geospatial data
  - Statistical Distribution

Distributed Hydrologic Modeling

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

\[\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} = R - I\]
Vflo™
Distributed Hydrologic Analysis and Prediction

www.vieuxinc.com
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
Discharge - Blue River Basin
Uncalibrated, No Rating Curves, No Mod Puls Routing
Initial Saturation of 30%

Date (UTC)

Observed  Simulated
Blue River
March 25, 1997

Discharge - Blue River Basin
Uncalibrated, No Rating Curves, No Mod Puls Routing
Initial Saturation of 50%
Blue river volume and peak

Vflo™
RMSE = 9.8 mm
α = 1.0 and β = 1.0.

Vflo™
RMSE = 52.0 m³s
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 + Vflo™

www.floodalert.org
Real-time prediction

Observations  Flood Information  Response
Vflo™ Brays Bayou

Drainage area 260 km²
Model resolution 120 x 120 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 not 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

Main observed-simulation comparison for Aug 15th event, No Boundary, Rainfall up to 7:22 am
Scheme 4 - Channel n 0.4 main-gesner, 0.45 gesner-roark, 0.35 roark-upstream
Overland n 1.2 main-gesner, 1.3 gesner-upstream

Current Time: 7:22 am
Time of Peak: 9:31 am
Load Time: 200

Discharge (cfs)

Date (CDT)
Verification
2\textsuperscript{nd} wave August 15

Main observed-simulation comparison for Aug 15th event, No Boundary, Rainfall up to 3:37 pm
Scheme 4 - Channel n 0.4 main-gessner, 0.45 gessner-roark, 0.35 roark-upstream
Overland n 1.2 main-gessner, 1.3 gessner-upstream
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.
Hydrographs

Greenville

Measured
Simulated

Louisberg

TS Allison
Vflo™ Predicted Inundation Web Display
Hurricane Floyd
Transportation Impacts

Pitt-Greenville Airport (PGV), Pitt County
Photo Courtesy of North Carolina Emergency Management
Stage Sensitivity Summary

Calibration sensitivity

% difference

- Rainfall: 78.9%
- Channel width: 30.7%
- Channel side slope: 15.0%
- Overland slope: 9.1%
- Infiltration: 8.3%
- Channel slope: 7.6%
- Hydraulic roughness: 1.3%
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


Second Edition expected 2004 English and Chinese
Questions?

--Ganges River Distributary, Bangladesh

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