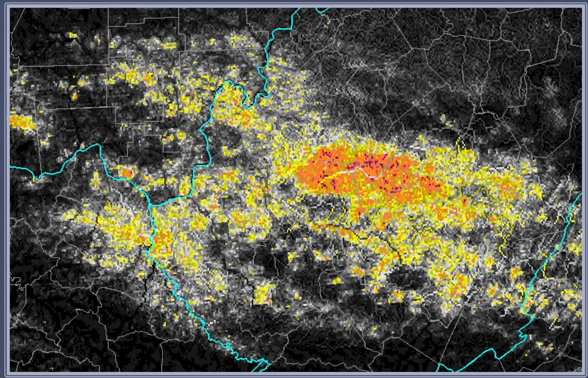
Continental modeling at flash flood scale across the U.S.

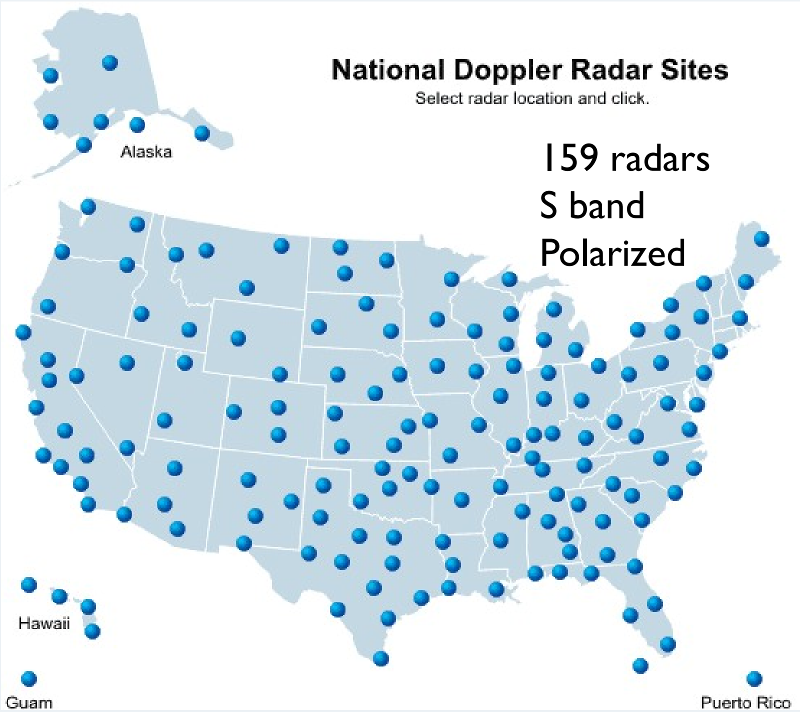


Jonathan J. Gourley

NOAA/National Severe Storms Laboratory, Norman, OK, USA

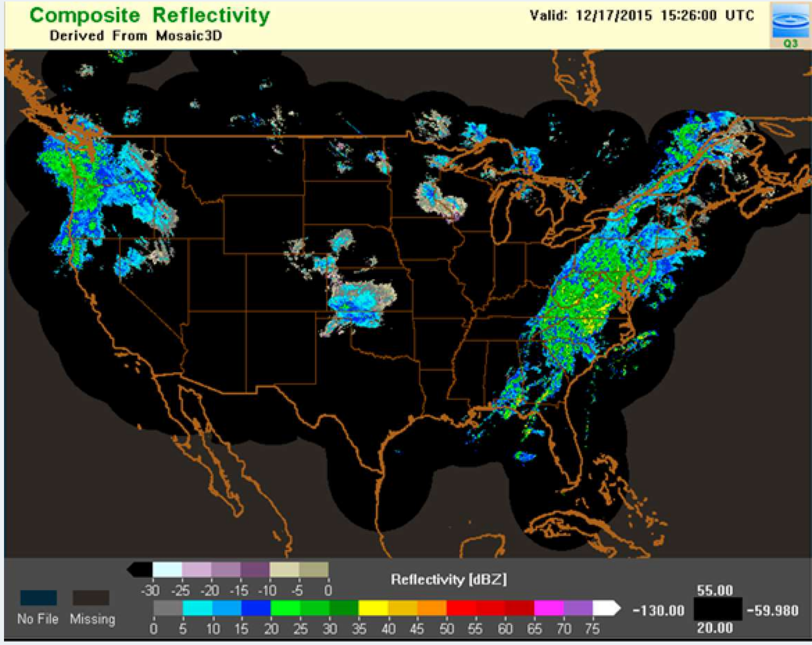
Cooperative Institute for Mesoscale Meteorological Studies

NEXRAD-based Multi-Radar Multi-Sensor System



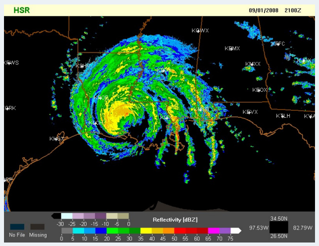
159 radars
S band
Polarized

Mosaic of reflectivity from NEXRAD and Environment Canada radars

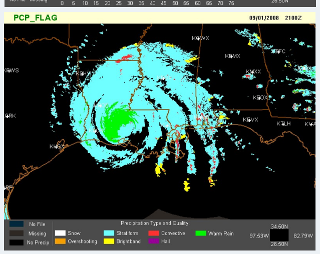


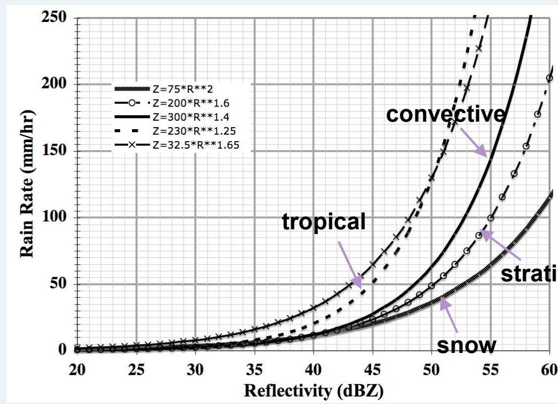
Adaptive Reflectivity-Rainfall (Z-R) Relationships

Radar reflectivity

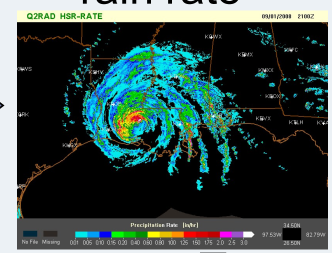


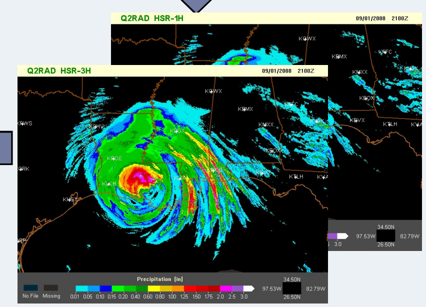
Precipitation type



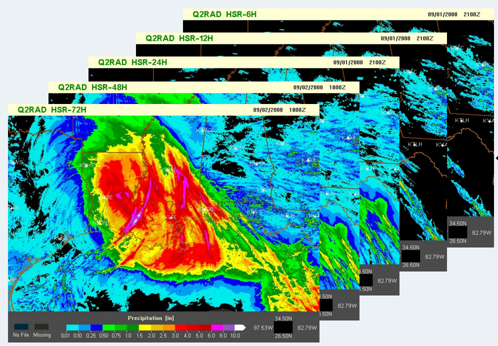


rain rate





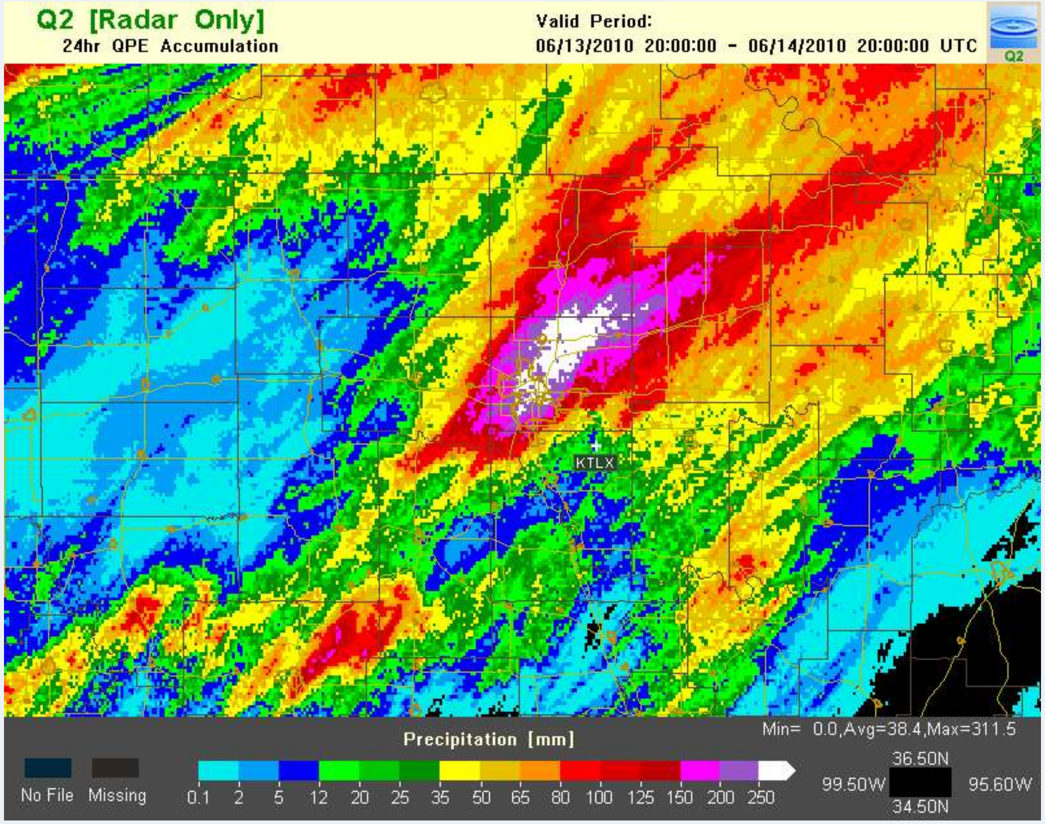
1- and 3-h acc
updated every 5-min



6- to 72-h acc
(updated hourly)

MRMS captures rainfall at flash flood scale

- NEXRAD Radar-only
- 2-min frequency
- 1-km^2 spatial resolution
- Covers continental US



Gauges vs QPE

24hr QPE: Q2 [Radar Only]

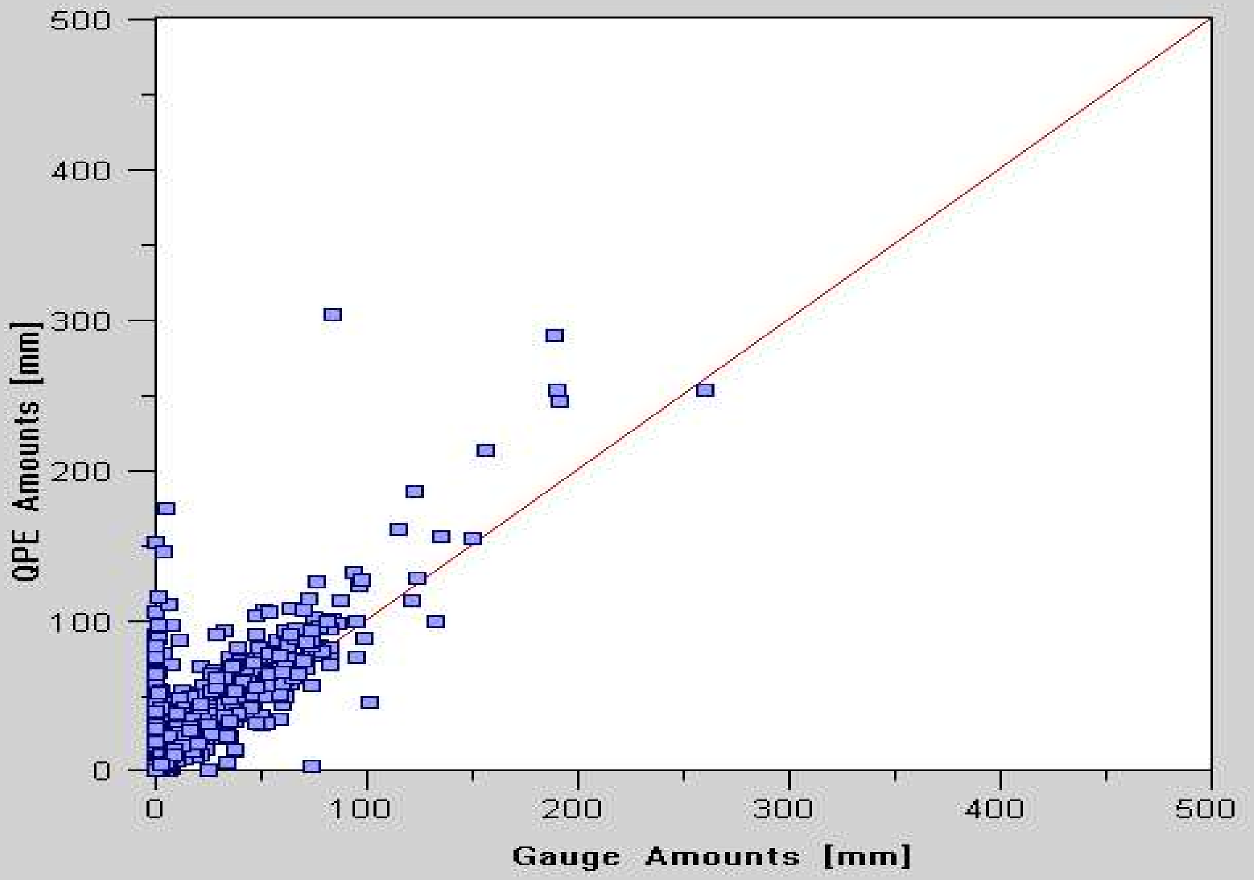
Valid Period: 06/13/2010 20:00 - 06/14/2010 20:00 UTC

Gauge Groups: HADS,OCS

Q2

Scatter Plot:

			Gauge	QPE [mm]
Gauges In Region:	1206	Max:	259.59	302.10
Total With QPE:	1206	Avg:	12.16	19.36
		Min:	0.00	0.00



Contingency Functions:

Not Applicable-No Threshold

Contingency Table:

Yes/No Threshold:

None

Predicted	N	Y	
	0	1206	Y
	0	0	N

Actual

Stats:

	[Y/Y]	[Y/Y+Y/N+N/Y]
Total Bias:	1.59	1.59
Corr Coeff:	0.85	0.85
RMSE [mm]:	19.51	19.51

Region:

40.00N

106.00W 90.31W

32.00N

Mask: none

Verif Mode: 1pt Accum>=0%

Gauges vs QPE

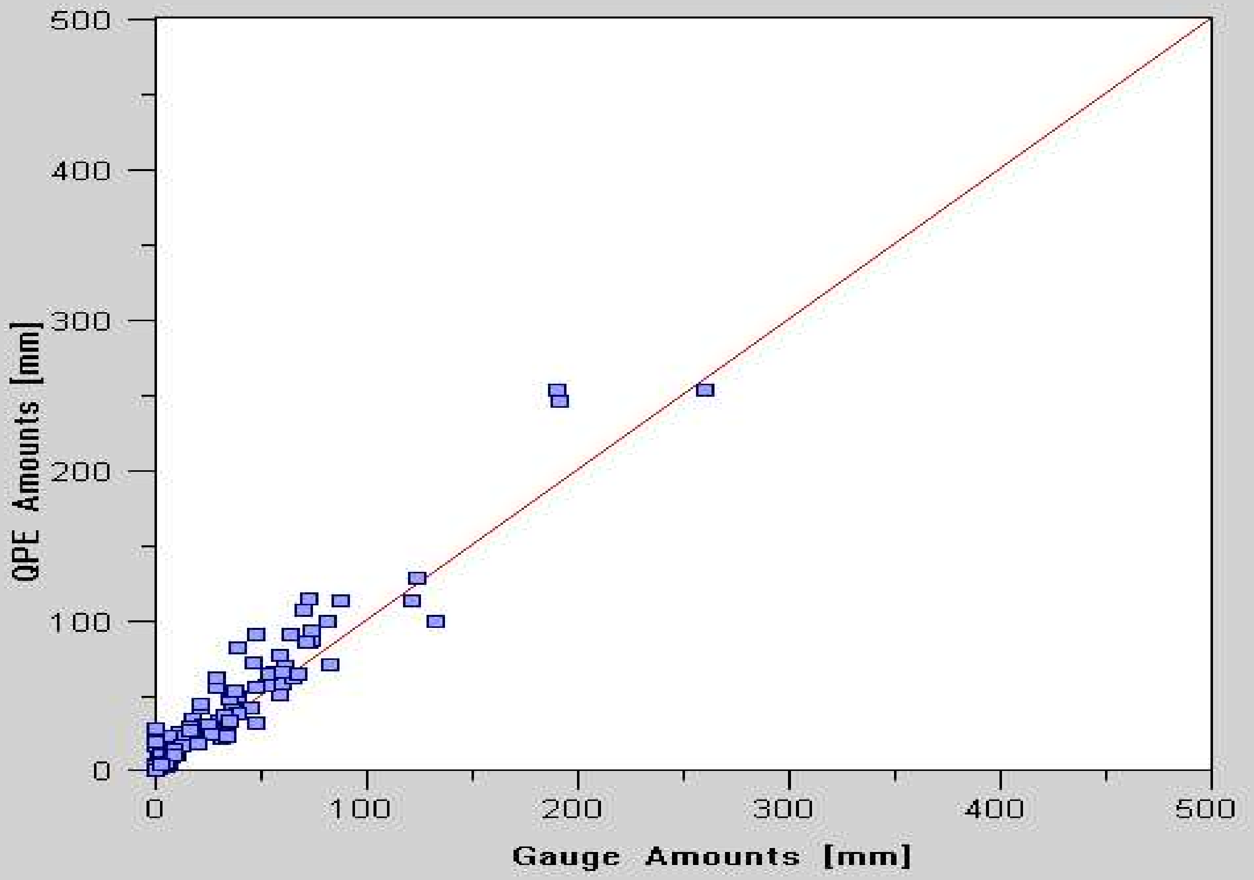
24hr QPE: Q2 [Radar Only]

Valid Period: 06/13/2010 20:00 - 06/14/2010 20:00 UTC

Gauge Groups: OCS

Scatter Plot:

			Gauge	QPE [mm]
Gauges In Region:	116	Max:	259.59	252.30
Total With QPE:	116	Avg:	30.12	36.51
		Min:	0.00	0.00



Contingency Functions:

Not Applicable-No Threshold

Contingency Table:

Yes/No Threshold:

None

Predicted \ Actual	N	Y
Y	0	116
N	0	0

Stats:

	[Y/Y]	[Y/Y+Y/N+N/Y]
Total Bias:	1.21	1.21
Corr Coeff:	0.96	0.96
RMSE [mm]:	14.80	14.80

Region:

40.00N

106.00W 90.31W

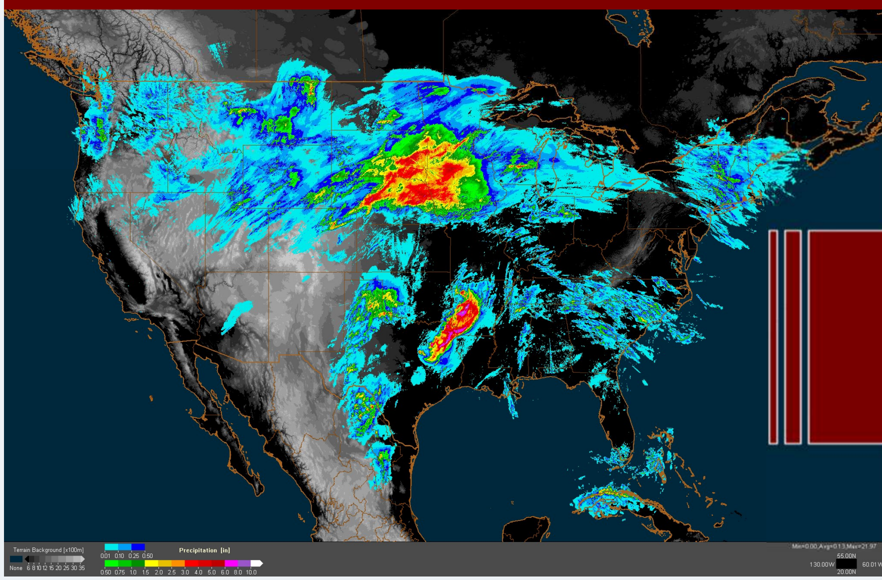
32.00N

Mask: none

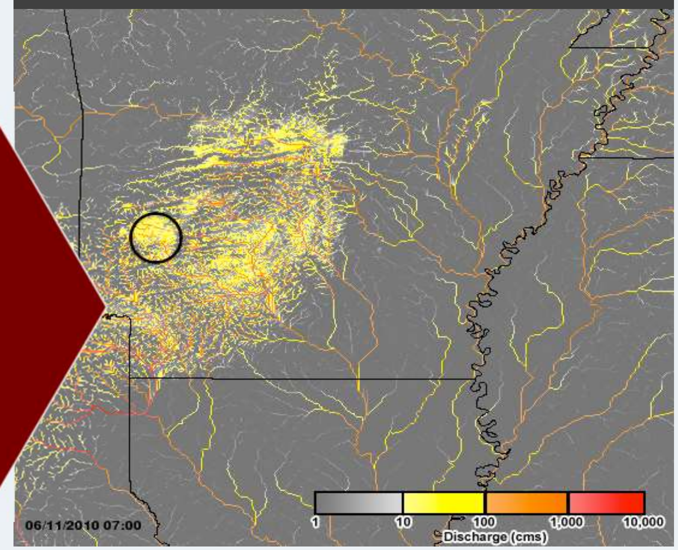
Verif Mode: 1pt Accum>=0%

Continental-scale Flash Flood Modeling

NEXRAD-based rainfall estimates from the Multi-Radar Multi-Sensor system



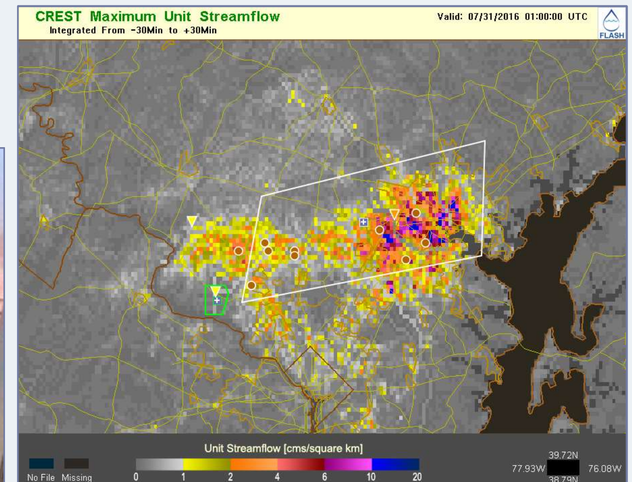
Hydrologic forecasts of flash floods downstream from the causative rainfall



FLASH – Flooded Locations And Simulated Hydrographs

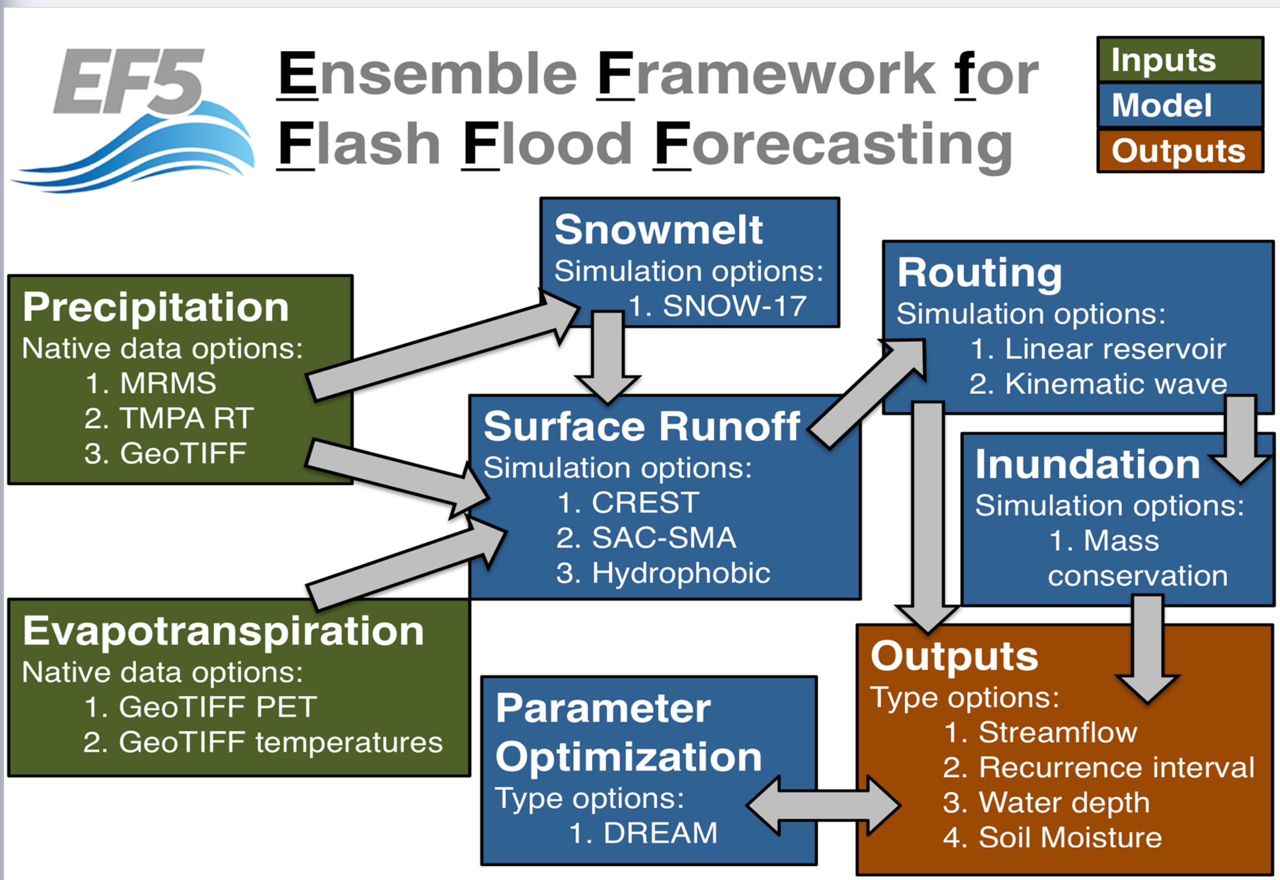
- First distributed hydrologic modeling framework to operate at flash flood scale in real-time across the continental United States (Gourley et al. 2017)
- Capability to provide forecasts at all grid points covered by radars without the requirement of model calibration
- Supported by Sandy Suppl. to improve the forecasters' toolbox in the NWS (12 pubs, 7 PhDs, 1 MS, successful R2O)

FLASH
Flooded Locations and Simulated Hydrographs Project



Ellicott City, MD
July 30, 2016

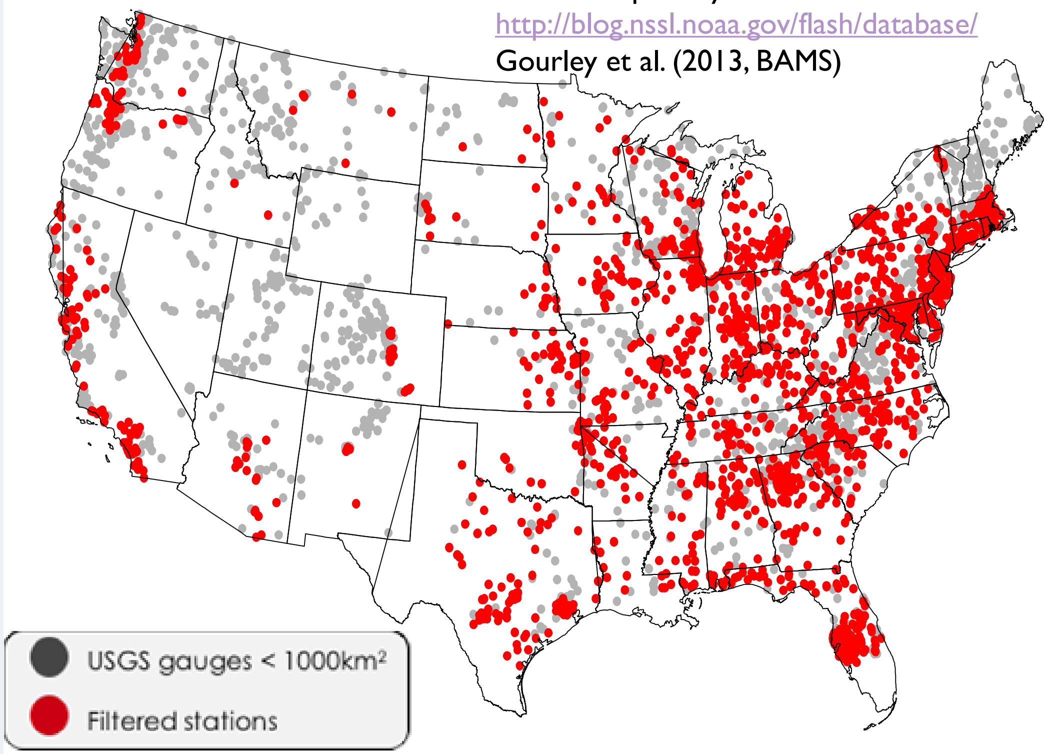
Distributed Hydrologic Modeling Framework



http://ef5.ou.edu

*Wang, J., Y. Hong, L. Li, J. J. Gourley, S. I. Khan, K. K. Yilmaz, R. F. Adler, F. S. Policelli, S. Habib, D. Irwin, A. S. Limaye, T. Korme, and L. Okello, 2011: The coupled routing and excess storage (CREST) distributed hydrological model. *Hydrol. Sci. Journal,* **56,** 84-98.

Objective Streamflow Evaluation

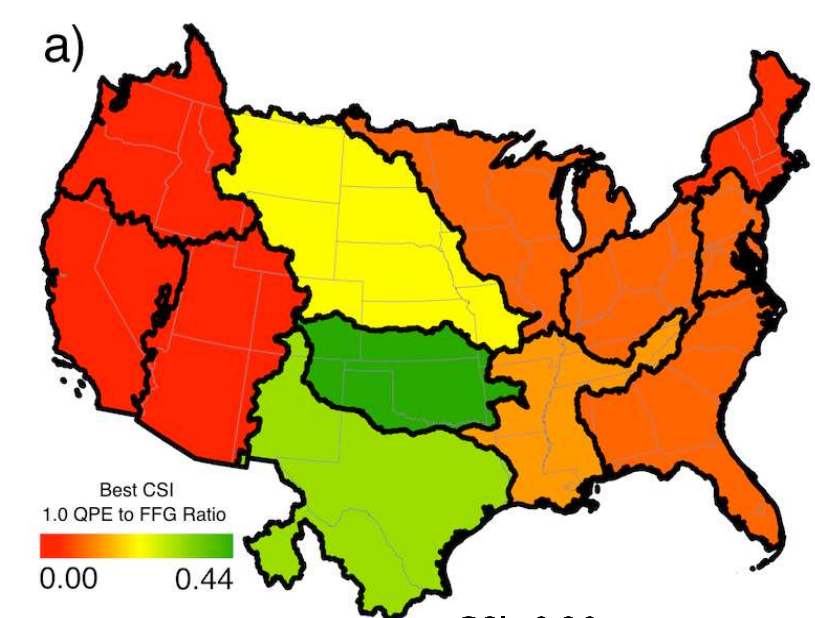


*Database publicly available at:
http://blog.nssl.noaa.gov/flash/database/
Gourley et al. (2013, BAMS)

- 1837 unregulated basins
- Drainage < 1000 km^2
- Oct **2002** to Sep. **2011**
- 5 min/1 km hindcast with MRMS radar-based forcing
- > 80% of basin area with 1km radar coverage
- Snow contribution < 30% of annual precip
- **88,241** significant flow events

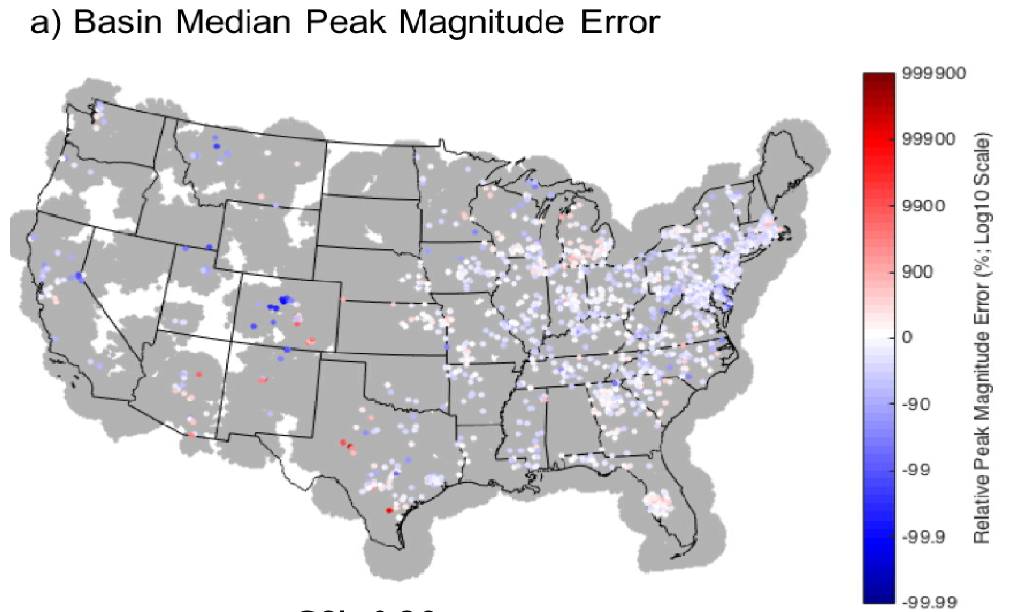
Comparison to Flash Flood Guidance

Flash Flood Guidance



CSI=0.20

CREST



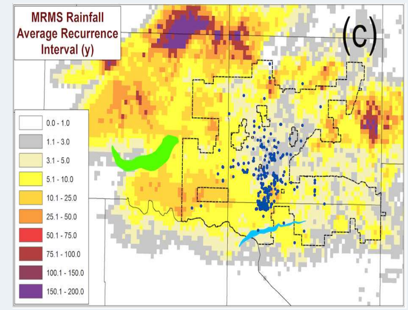
CSI=0.38

Clark, R. A., J. J. Gourley, Z. L. Flamig, Y. Hong, and E. Clark, 2014: CONUS-wide evaluation of National Weather Service flash flood guidance products, *Wea. Forecasting*, **29,** 377-392. doi:10.1175/WAF-D-12-00124.1.

Summary of FLASH Product Suite

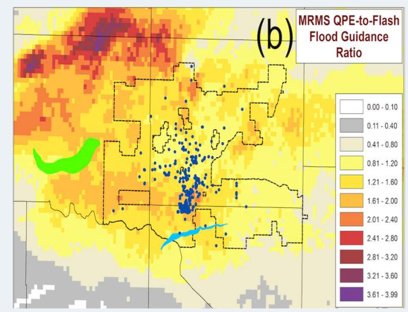
- **Rainfall Average Recurrence Intervals (ARI)**: Comparison of MRMS QPE to static thresholds

1 km/2 min



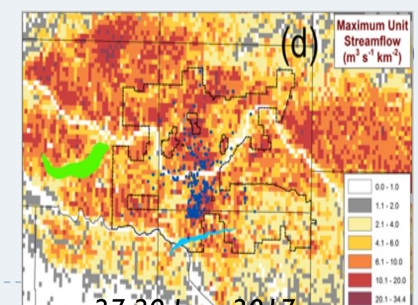
- **QPE-to-Flash Flood Guidance Ratios:** Comparison of MRMS QPE to dynamic thresholds

1 km/2 min

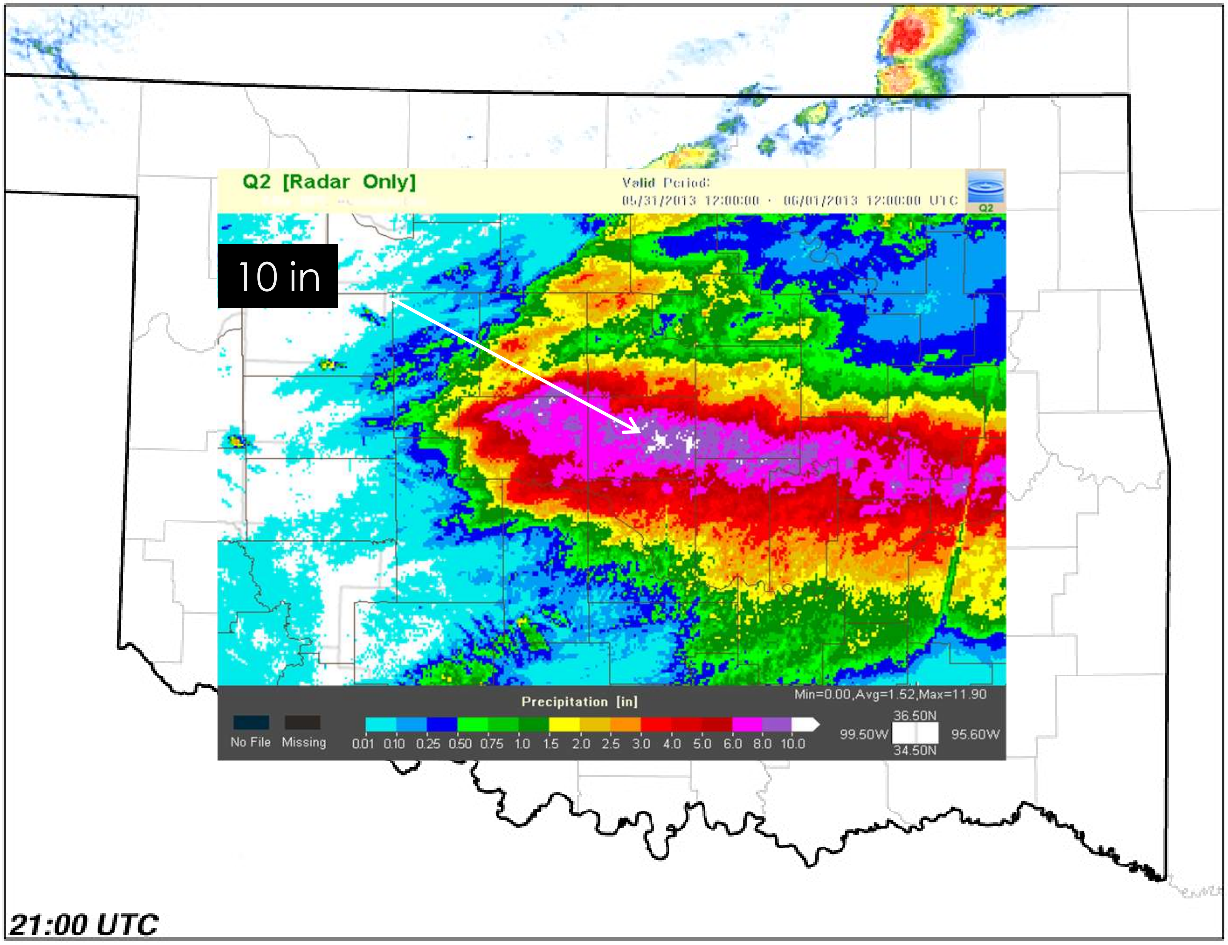


- **Distributed hydrologic model forecasts**: 0-12 hr forecasts of discharge, unit discharge, soil saturation

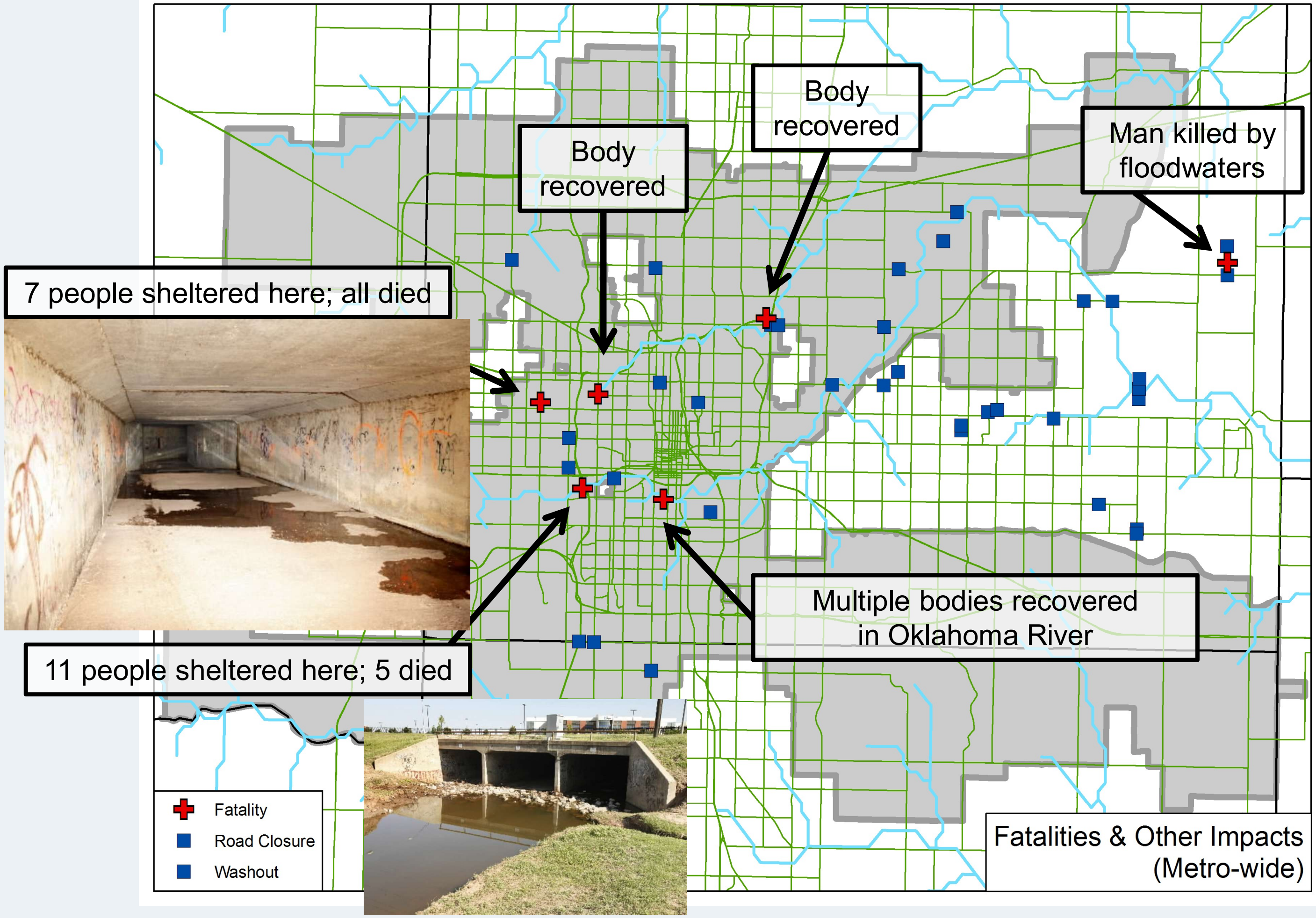
1 km/10 min



May 31, 2013 OKC Flash Flood: Rainfall



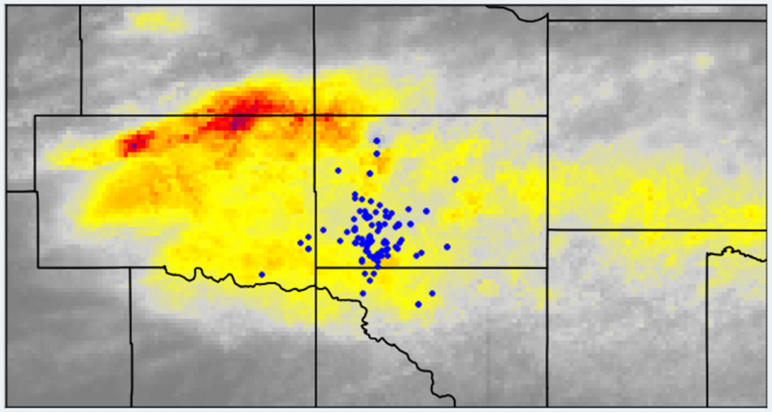
- Composite reflectivity animation
- Supercell storm with quasi-stationary core over Oklahoma City metro area

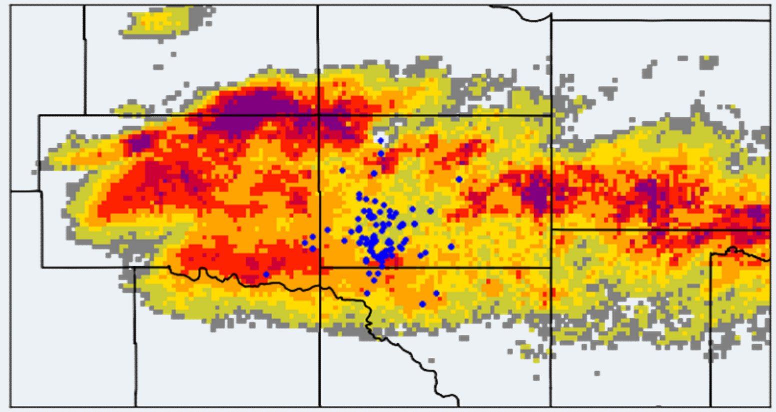


During the storms, 23 people lost their lives (12 from flooding in OKC).
This is the deadliest flood in OKC history & the worst in the state since 1984

Reports from Twitter, Facebook, KFOR-TV, KOCO-TV, News9, and The *Oklahoman*; Photos from The *Oklahoman*

FLASH Rainfall Threshold Products



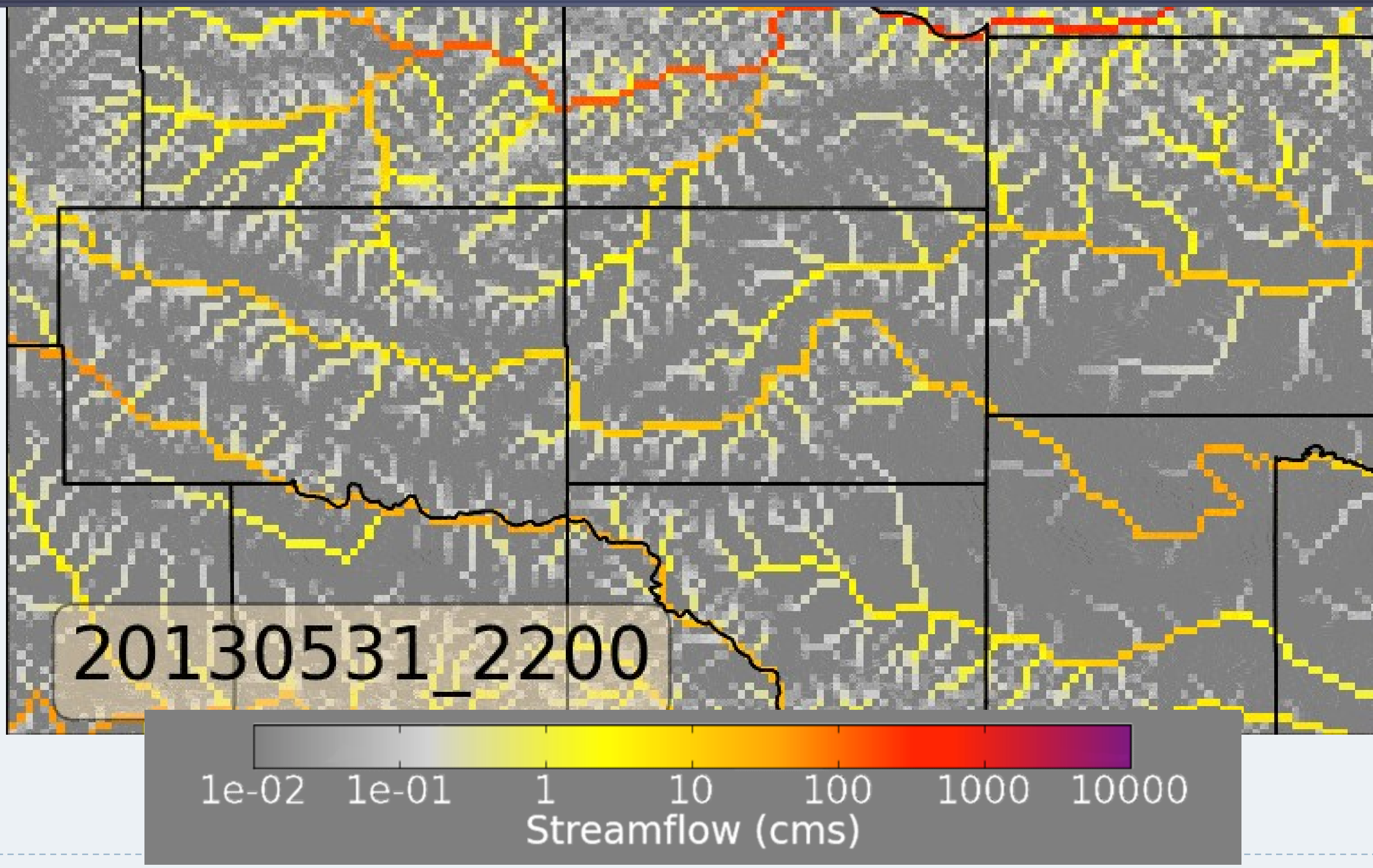


MRMS/Flash Flood Guidance (FFG)

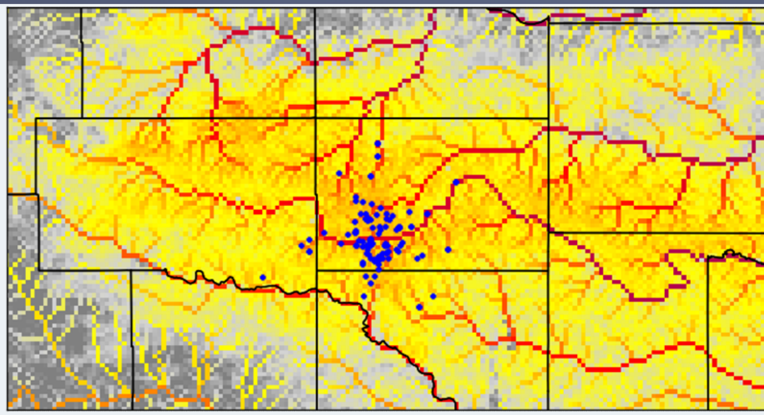
MRMS Rainfall Average Recurrence Interval (Return Period)

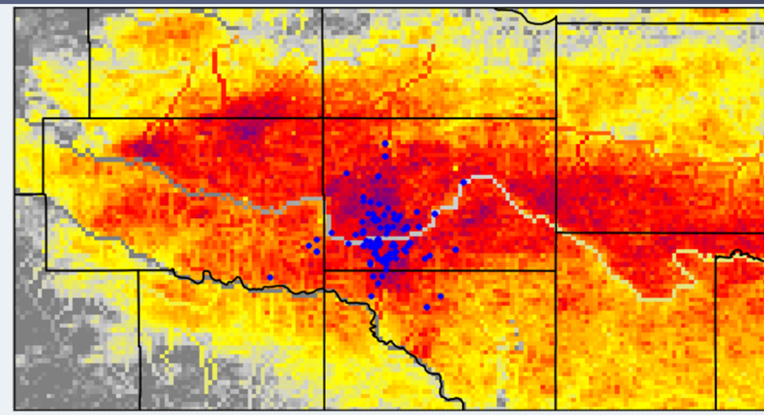
- Both products indicate greatest threat is to the northwest of the region that was most heavily impacted
- All blue dots correspond to known flooding reports collected from City of Oklahoma City, media, social media (rescues, water in homes, street closures, fatalities)

May 31, 2013 OKC Flash Flood: Forecast Streamflow



FLASH Distributed Hydrologic Model Products





Maximum Streamflow (m^3/s)

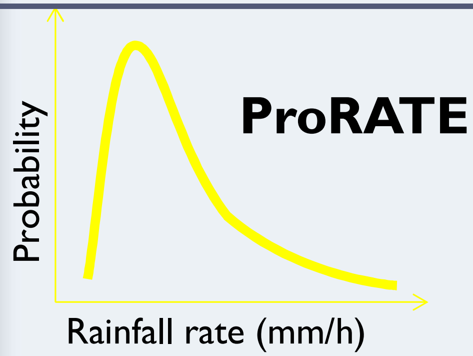
Maximum Unit Streamflow ($m^3/s/km^2$)

Streamflow forecasts from EF5 distributed hydrologic modeling framework correctly highlight the metropolitan area due to:

1. Routing
2. Modeling of impervious surfaces

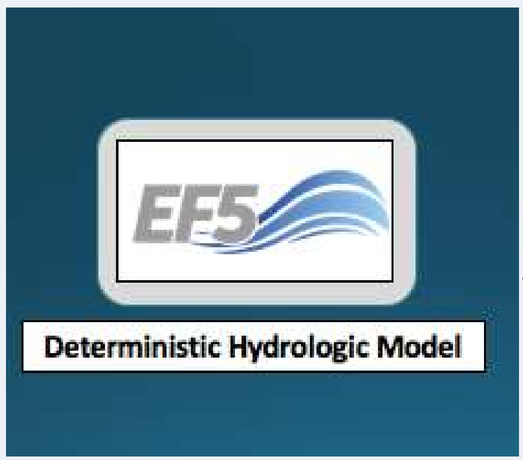
From deterministic FLASH to "ProFLASH"

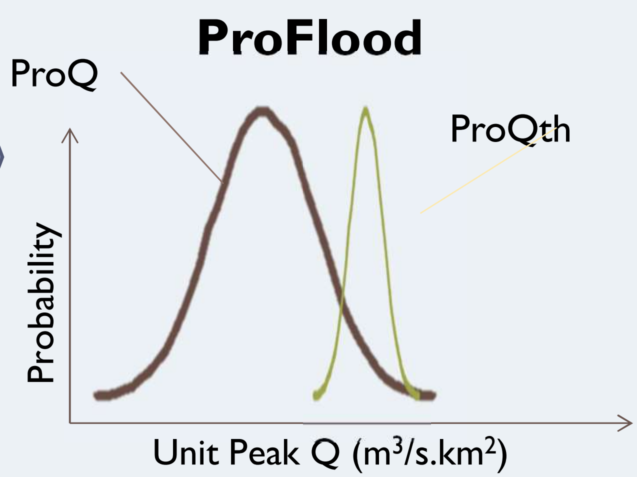
- Probabilistic forecasts
- Increased lead-time through Warn-On-Forecast ensembles



Probabilistic QPE using Radar Observations of Rate And Typology Estimates (Kirstetter et al. 2015)

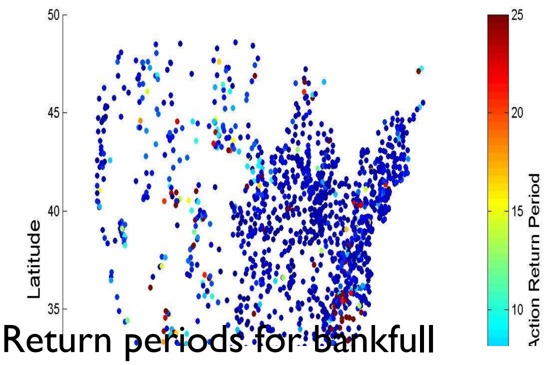
<u>Warn-on-Forecast</u>
50 members
3 km/15 min
0-3 hr forecasts





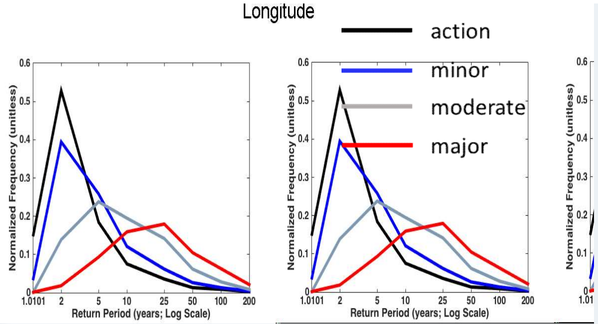
Challenge of knowing flood stages in ungauged basins

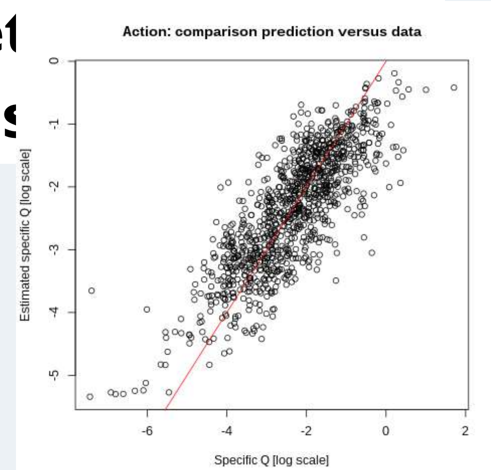
Variable	P-value
River Length (km)	< 0.000001
Annual Precipitation (mm)	< 0.000001
Shape Factor	< 0.000001
Slope Index	<

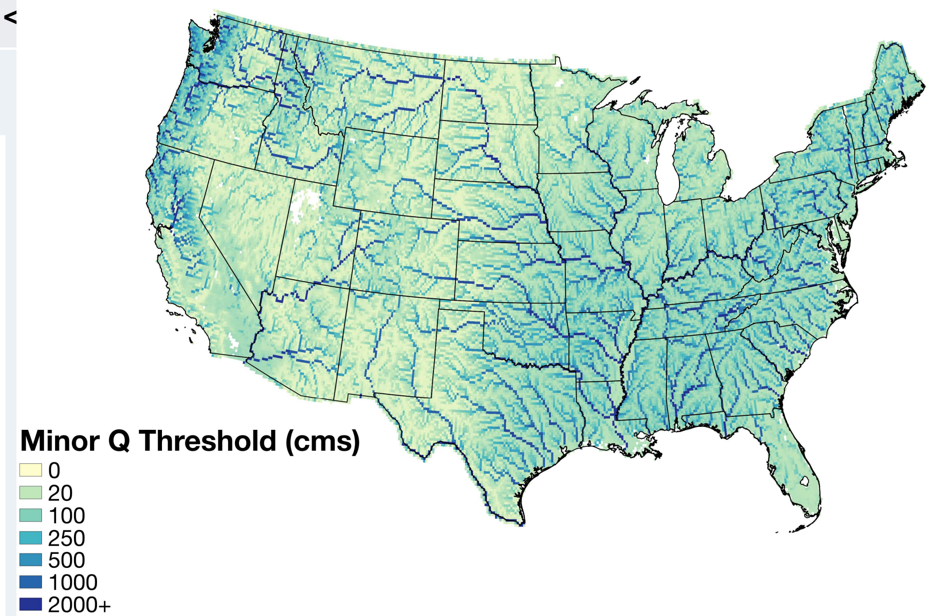


Return periods for bankfull

Large spread of ret
with a given flood s







Considerations for flash flood modeling at continental or global scale

- Quantitative precipitation forecasts offer lead time but rarely resolve storm-scale rainfall that drive flash floods
- Some countries (e.g., US, Canada, Europe, China, Japan, S. Korea) have invested in radar networks that can provide scale-relevant rainfall estimates
- Satellite-based rainfall show potential but have latency on the order of several hours and often do not perform well with extreme rainfall
- Hydrologic models don't necessarily need to be too terribly sophisticated; fluxes are generally 1-way
- Parsimonious hydrologic models can run efficiently and take advantage of high frequency inputs from radars or storm-scale NWP ensembles

Contact Information:

Jonathan J. Gourley jj.gourley@noaa.gov

References:

Clark, R. A., J. J. Gourley, Z. L. Flamig, Y. Hong, and E. Clark, 2014: CONUS-wide evaluation of National Weather Service flash flood guidance products. *Wea. Forecasting*, **29**, 377–392. doi: 10.1175/WAF-D-12-00124.1.

Gourley, J. J., Z. Flamig, H. Vergara, P. Kirstetter, R. Clark III, E. Argyle, A. Arthur, S. Martinaitis, G. Terti, J. Erlingis, Y. Hong, and K. Howard, 2017: The Flooded Locations And Simulated Hydrographs (FLASH) project: improving the tools for flash flood monitoring and prediction across the United States, Bull. Amer. Meteor. Soc., 98, 361-372. http://dx.doi.org/10.1175/BAMS-D-15-00247.1.

Martinaitis, S. M., J. J. Gourley, Z. L. Flamig, E. M. Argyle, R. A. Clark, A. Arthur, B. R. Smith, J. M. Erlingis, S. Perfater, B. Albright, 2017: The HMT Multi-Radar Multi-Sensor Hydro Experiment, Bull. Amer. Meteor. Soc., 98, 347–359. http://dx.doi.org/10.1175/BAMS-D-15-00283.1

Wang, J., Y. Hong, L. Li, J. J. Gourley, S. I. Khan, K. K. Yilmaz, R. F. Adler, F. S. Policelli, S. Habib, D. Irwin, A. S. Limaye, T. Korme, and L. Okello, 2011: The coupled routing and excess storage (CREST) distributed hydrological model. *Hydrol. Sci. Journal,* **56,** 84–98. doi: 10.1080/02626667.2010.543087.

Thank You