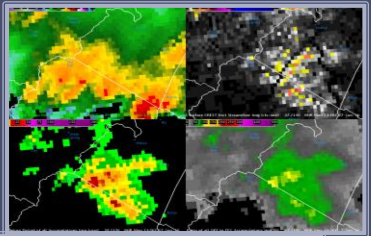
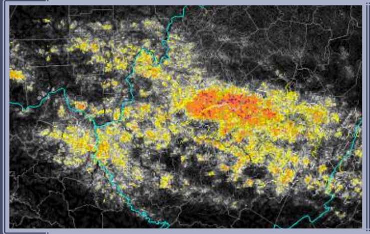
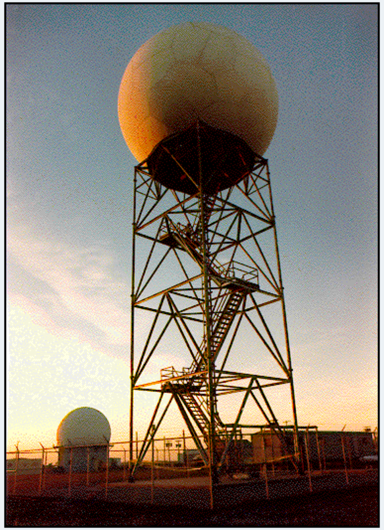
Radar-Based Tools for Flash Flood Forecasting in the National Weather Service (USA)

Jonathan J. Gourley, Ph.D.

Research Hydrometeorologist

NOAA, Office of Oceanic and Atmospheric Research
National Severe Storms Laboratory, Norman, OK



- NOAA/National Severe Storms Laboratory
- NOAA/National Weather Service
- NOAA/Storm Prediction Center
- NOAA/Radar Operations Center
- NOAA/Warning Decision Training Branch
- Oklahoma Climatological Survey (OK Mesonet)
- University of Oklahoma School of Meteorology
- College of Atmospheric and Geographic Science

HYMEX-SOPI
The Field Campaign Dedicated to Heavy Precipitation and Flash Flooding in the Northwestern Mediterranean

BY VERONIQUE DUCROCQ, ISABELLE BRAUD, SILVIO DAVOLIO, ROSSELLA FERRETTI, CYRILLE FLAMANT, AGUSTIN JANSA, NORBERT KALTHOFF, EVELYNE RICHARD, ISABELLE TAUPIER-LETAGE, PIERRE-ALAIN AYRAL, SOPHIE BELAMARI, ALEXIS BERNE, MARCO BORGA, BRICE BOUDEVILLAIN, OLIVIER BOCK, JEAN-LUC BOICHARD, MARIE-NOËLLE BOUIN, OLIVIER BOUSQUET, CHRISTOPHE BOUVIER, JACOPO CHIGGIATO, DOMENICO CIMINI, ULRICH CORSMEIER, LAURENT COPPOLA, PHILIPPE COCQUEREZ, ERIC DEFER, JULIEN DELANOË, PAOLO DI GIROLAMO, ALEXIS DOERENBECHER, PHILIPPE DROBINSKI, YANN DUFOURNET, NADIA FOURRIÉ, JONATHAN J. GOURLEY, LAURENT LABATUT, DOMINIQUE LAMBERT, JÉRÔME LE COZ, FRANK S. MARZANO, GILLES MOLINIÉ, ANDREA MONTANI, GUILLAUME NORD, MATHIEU NURET, KARIM RAMAGE, WILLIAM RISON, ODILE ROUSSOT, FRÉDÉRIQUE SAID, ALFONS SCHWARZENBOECK, PIERRE TESTOR, JOËL VAN BAELEN, BÉATRICE VINCENDON, MONTSERRAT ARAN, AND JORGE TAMAYO

Effects of Radar Beam Shielding on Rainfall Estimation for the Polarimetric C-Band Radar

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MeteoSvizzera, Locarno, Switzerland

JONATHAN J. GOURLEY
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PIERRE TABARY
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(Manuscript received 25 July 2006, in final form 5 February 2007)

Absolute Calibration of Radar Reflectivity Using Redundancy of the Polarization Observations and Implied Constraints on Drop Shapes

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ANTHONY J. ILLINGWORTH
University of Reading, Reading, United Kingdom

PIERRE TABARY
Direction des Systèmes d'Observation, Météo-France, Trappes, France

A SITUATION-BASED ANALYSIS OF FLASH FLOOD FATALITIES IN THE UNITED STATES

GALATEIA TERTI, ISABELLE RUIN, SANDRINE ANQUETIN, AND JONATHAN J. GOURLEY

Risk Analysis, Vol. 39, No. 1, 2019 DOI: 10.1111/risa.12921

Toward Probabilistic Prediction of Flash Flood Human Impacts

Galateia Terti,[1,*] Isabelle Ruin,[1] Jonathan J. Gourley,[2] Pierre Kirstetter,[3] Zachary Flamig,[3] Juliette Blanchet,[1] Ami Arthur,[4] and Sandrine Anquetin[1]

Data Quality of the Meteo-France C-Band Polarimetric Radar

JONATHAN J. GOURLEY, PIERRE TABARY, AND JACQUES PARENT DU CHATELET
Direction des Systemes d'Observation, Meteo-France, Trappes, France

(Manuscript received 24 August 2005, in final form 2 February 2006)

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Analysis of flash flood parameters and human impacts in the US from 2006 to 2012

Maruša Špitalar[a,b], Jonathan J. Gourley[c,*], Celine Lutoff[d,b], Pierre-Emmanuel Kirstetter[e,c], Mitja Brilly[a], Nicholas Carr[e]

Unusually High Differential Attenuation at C Band: Results from a Two-Year Analysis of the French Trappes Polarimetric Radar Data

PIERRE TABARY AND GIANFRANCO VULPIANI
Direction des Systèmes d'Observation, Météo France, Toulouse, France

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A Fuzzy Logic Algorithm for the Separation of Precipitating from Nonprecipitating Echoes Using Polarimetric Radar Observations

JONATHAN J. GOURLEY,* PIERRE TABARY, AND JACQUES PARENT DU CHATELET
Météo-France, Direction des Systèmes d'Observation, Trappes, France

Natural Hazards
December 2015, Volume 79, Issue 3, pp 1481–1497 | Cite as

Dynamic vulnerability factors for impact-based flash flood prediction

Authors Authors and affiliations
Galateia Terti, Isabelle Ruin, Sandrine Anquetin, Jonathan J. Gourley

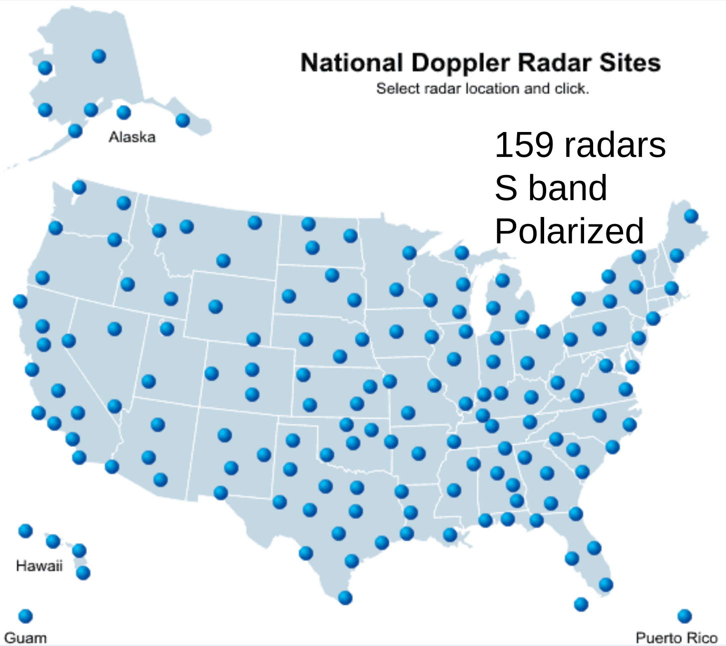
Empirical Estimation of Attenuation from Differential Propagation Phase Measurements at C Band

JONATHAN J. GOURLEY,* PIERRE TABARY, AND JACQUES PARENT DU CHATELET
Direction des Systèmes d'Observation, Météo-France, Trappes, France

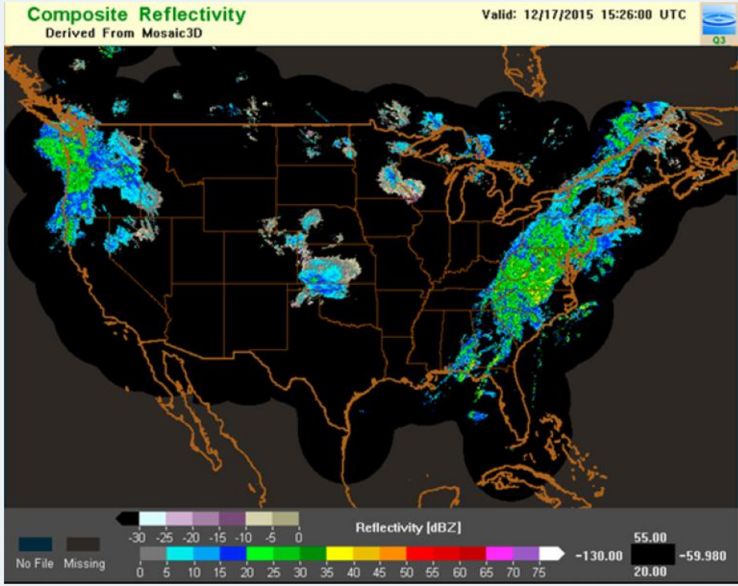
TOWARD A SPACE–TIME FRAMEWORK FOR INTEGRATED WATER AND SOCIETY STUDIES

BY I. RUIN, C. LUTOFF, L. CRETON-CAZANAVE, S. ANQUETIN, M. BORGA, S. CHARDONNEL, J.-D. CREUTIN, J. GOURLEY, E. GRUNTFEST, S. NOBERT, AND J. THIELEN

NEXRAD-based Multi-Radar Multi-Sensor (MRMS) System

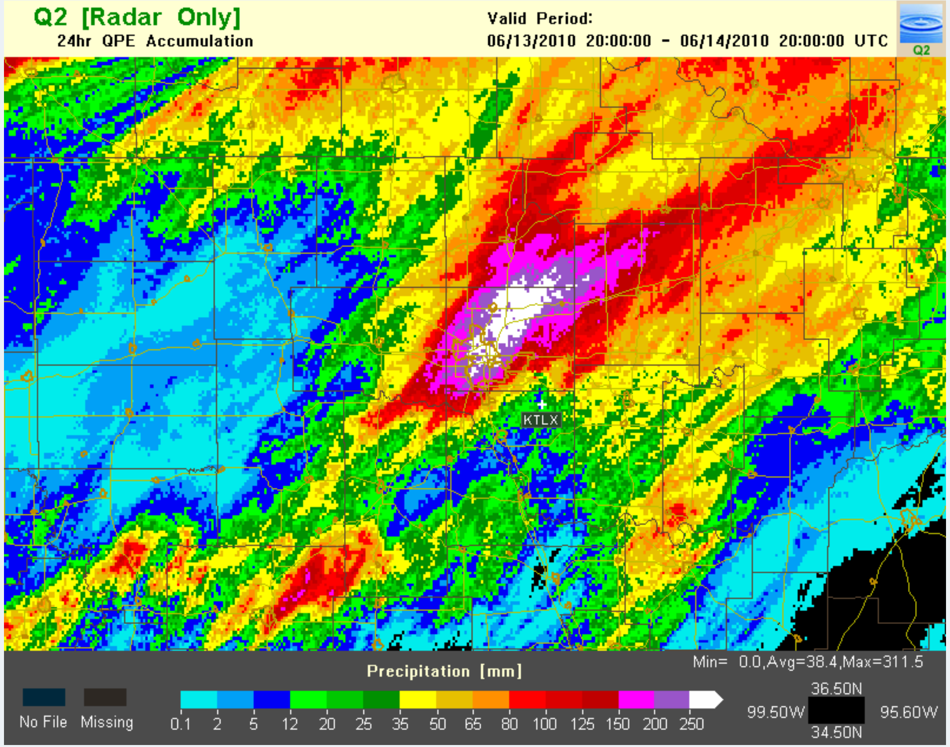


Mosaic of reflectivity from NEXRAD and Environment Canada radars



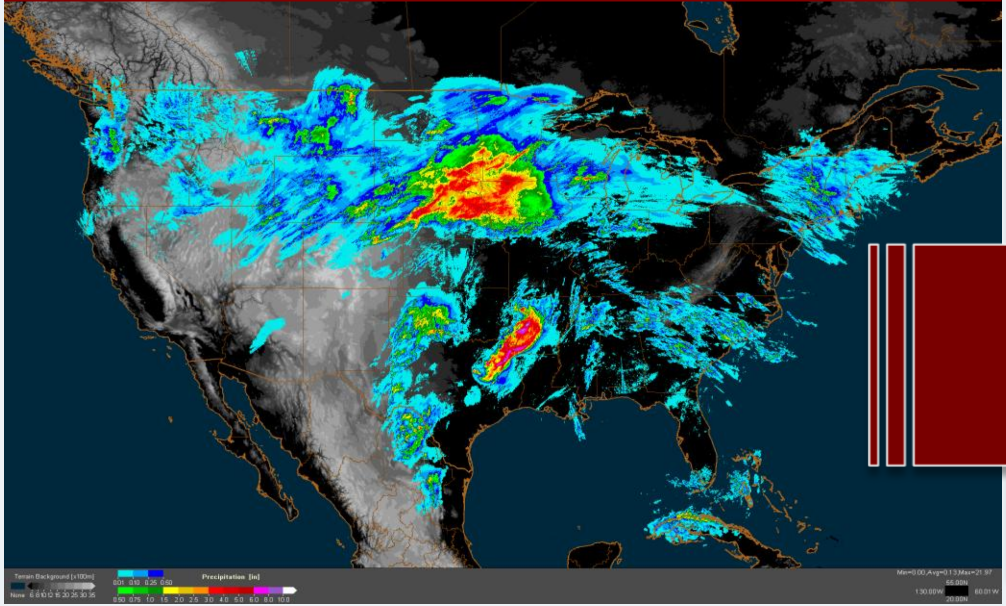
MRMS captures rainfall at flash flood scale

- NEXRAD Radar-only
- 2-min frequency
- 1-km^2 spatial resolution
- Covers continental US (for the most part)

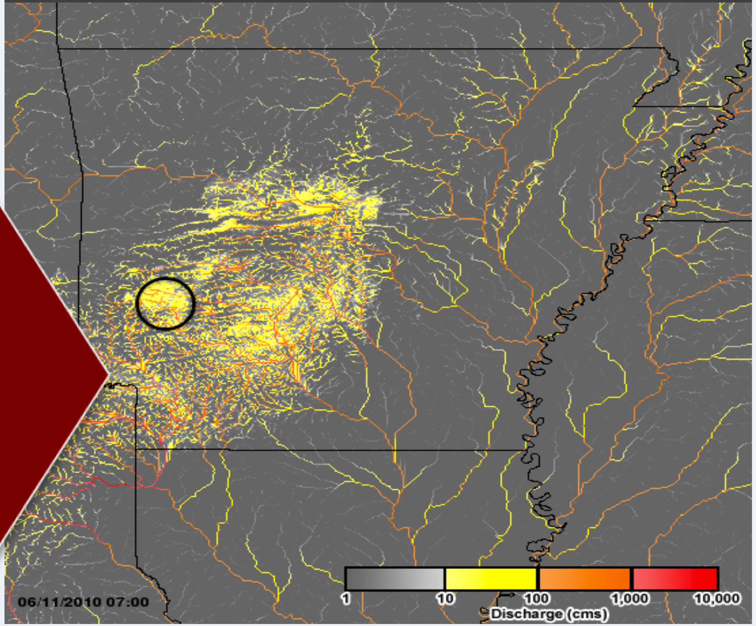


Continental-scale Flash Flood Modeling

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

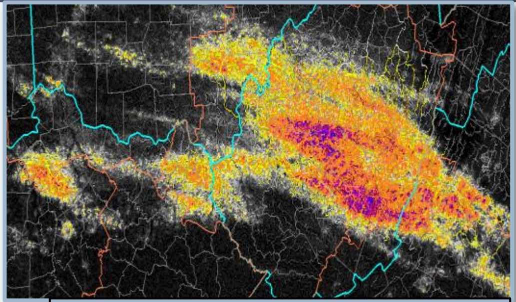


Hydrologic forecasts of flash floods downstream from the causative rainfall

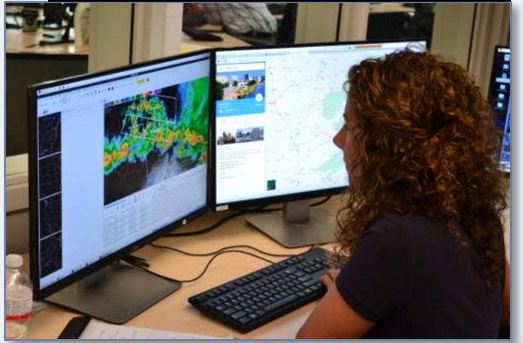


New system in the National Weather Service for predicting flash floods

- Project funded under Public Law 113–2: Disaster Relief Appropriations Act, 2013
- The Flooded Locations and Simulated Hydrographs Project (FLASH) was launched for monitoring and predicting flash floods: Gourley et al. (2017) DOI: 10.1175/BAMS-D-15-00247.1
- Provides forecasts across the US with updates every 2-10 min using 10.8 million grid points
- Transitioned to the National Weather Service in November 2016; rapidly evolved tools for flash flood prediction



FLASH outputs for the Richwood, WV flooding event on June 23, 2016



A National Weather Service forecaster tests FLASH system during Hydrometeorological Testbed Experiment in 2016

Summary of FLASH products

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

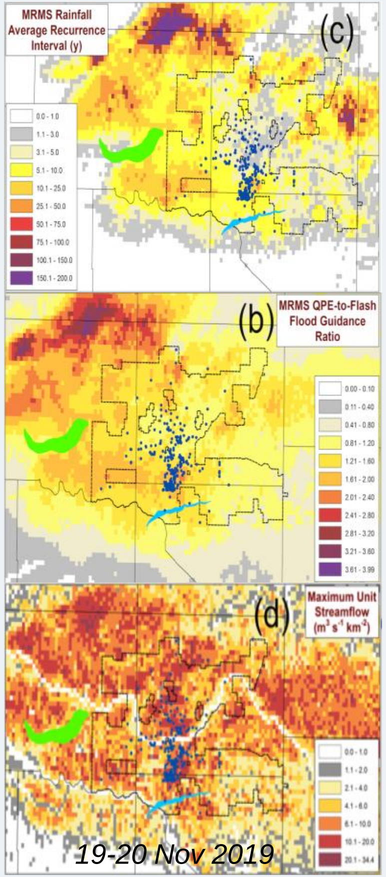
1 km/2 min

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

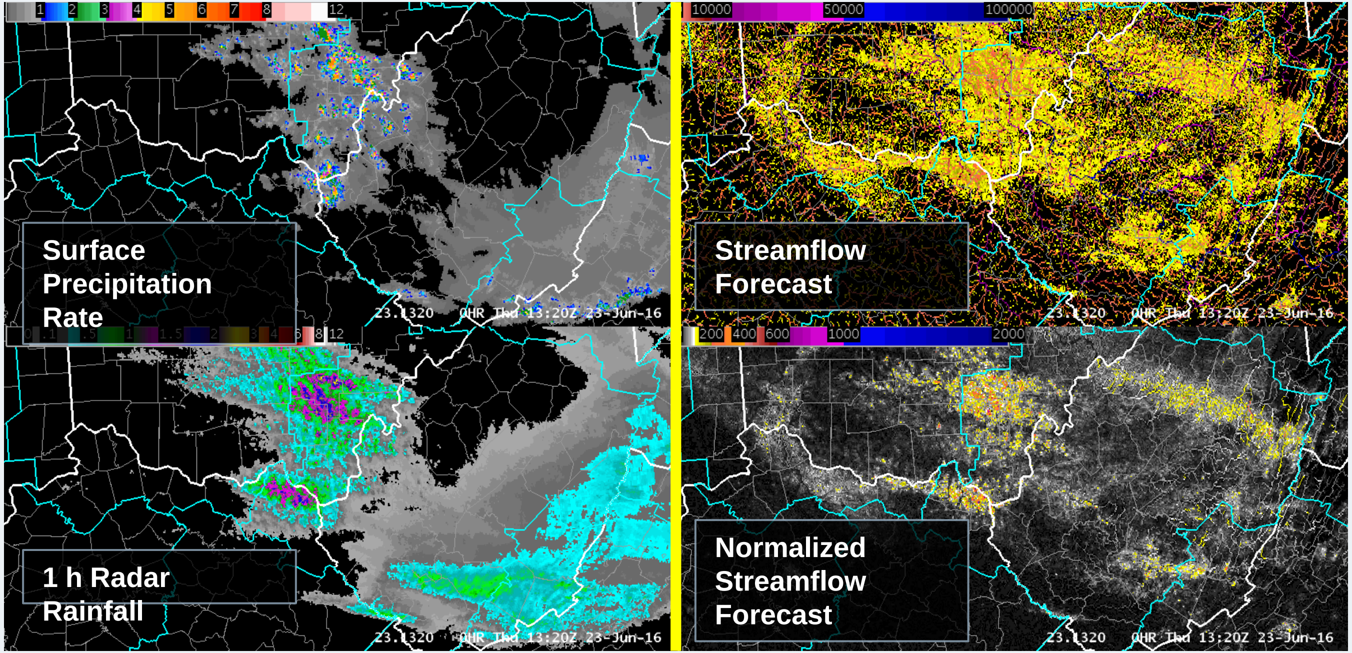
1 km/2 min

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

1 km/10 min



Modeling: What is Flooded Locations and Simulated Hydrographs project (FLASH)?

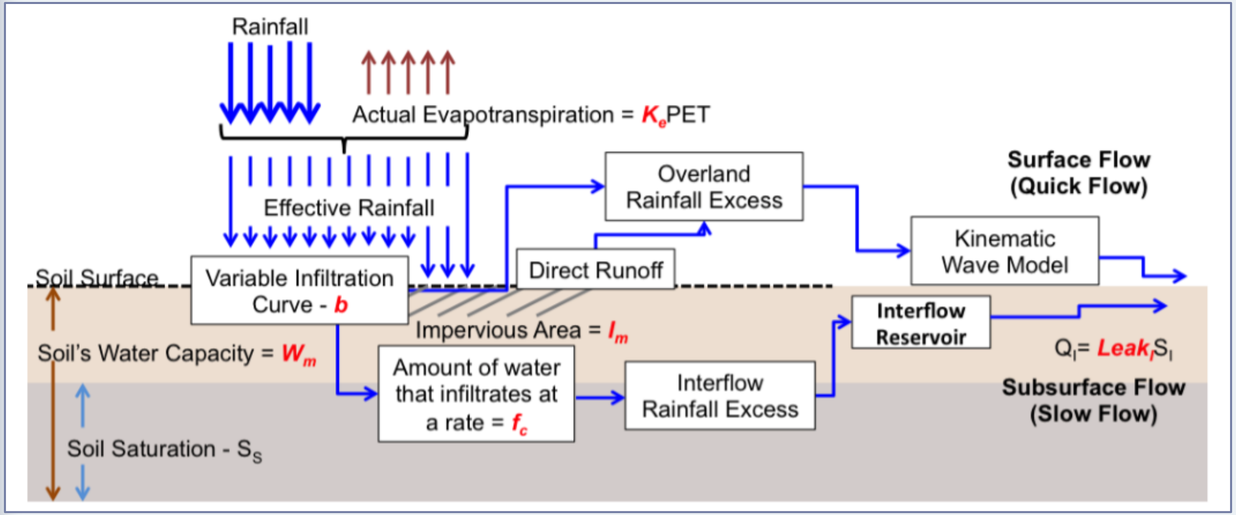


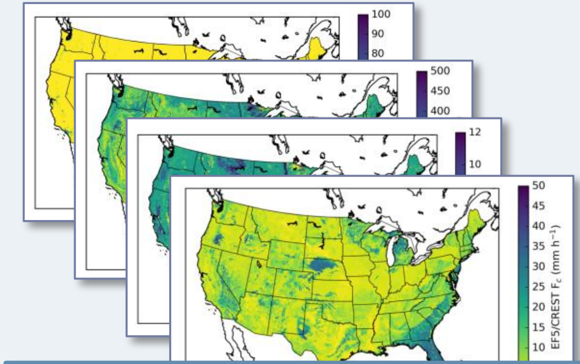
High resolution rainfall (1 km, 2 min) from 158 NEXRAD radars

0-12 hour forecast of surface water flows (1 km, 10 min)

CREST Hydrologic Modeling

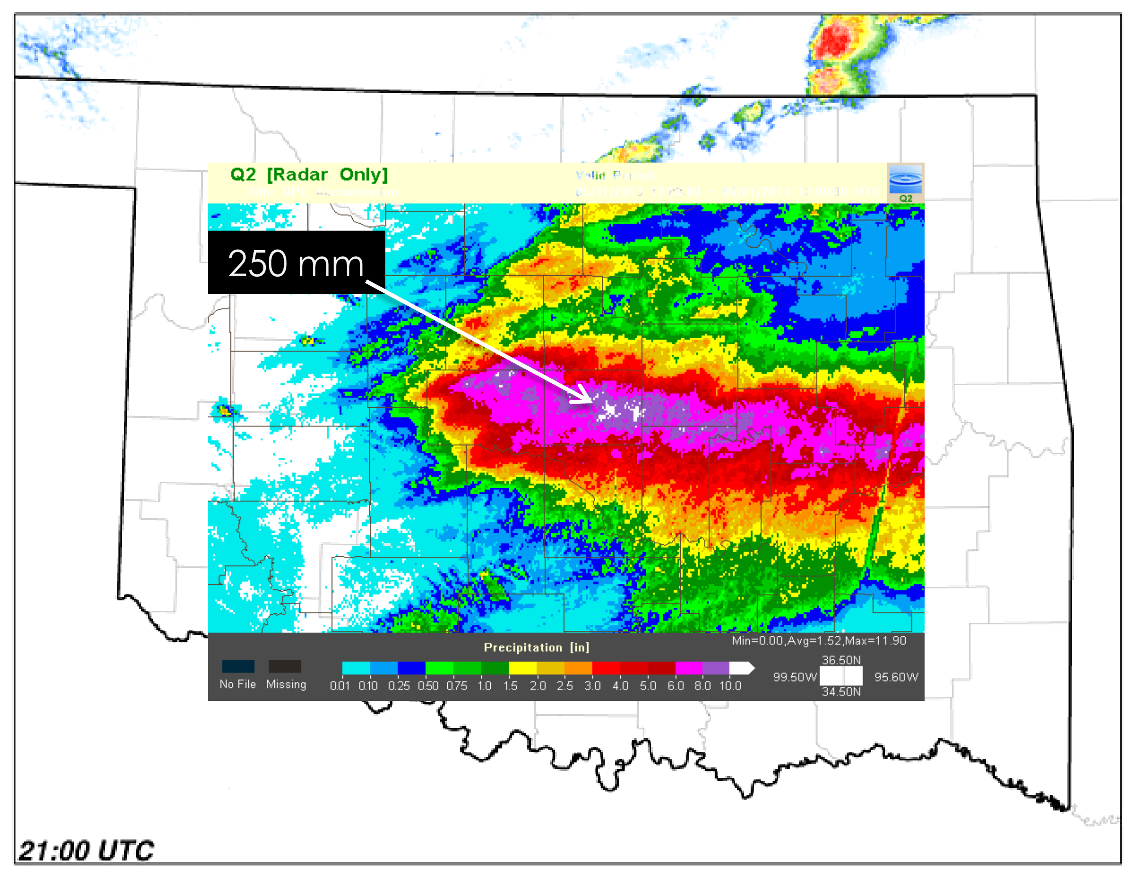
- Utilizes the Ensemble Framework for Flash Flood Forecasting (EF5) to develop Coupled Routing and Excess Storage (CREST) model (Wang et al. 2011)
- Mass balance and kinematic wave routing



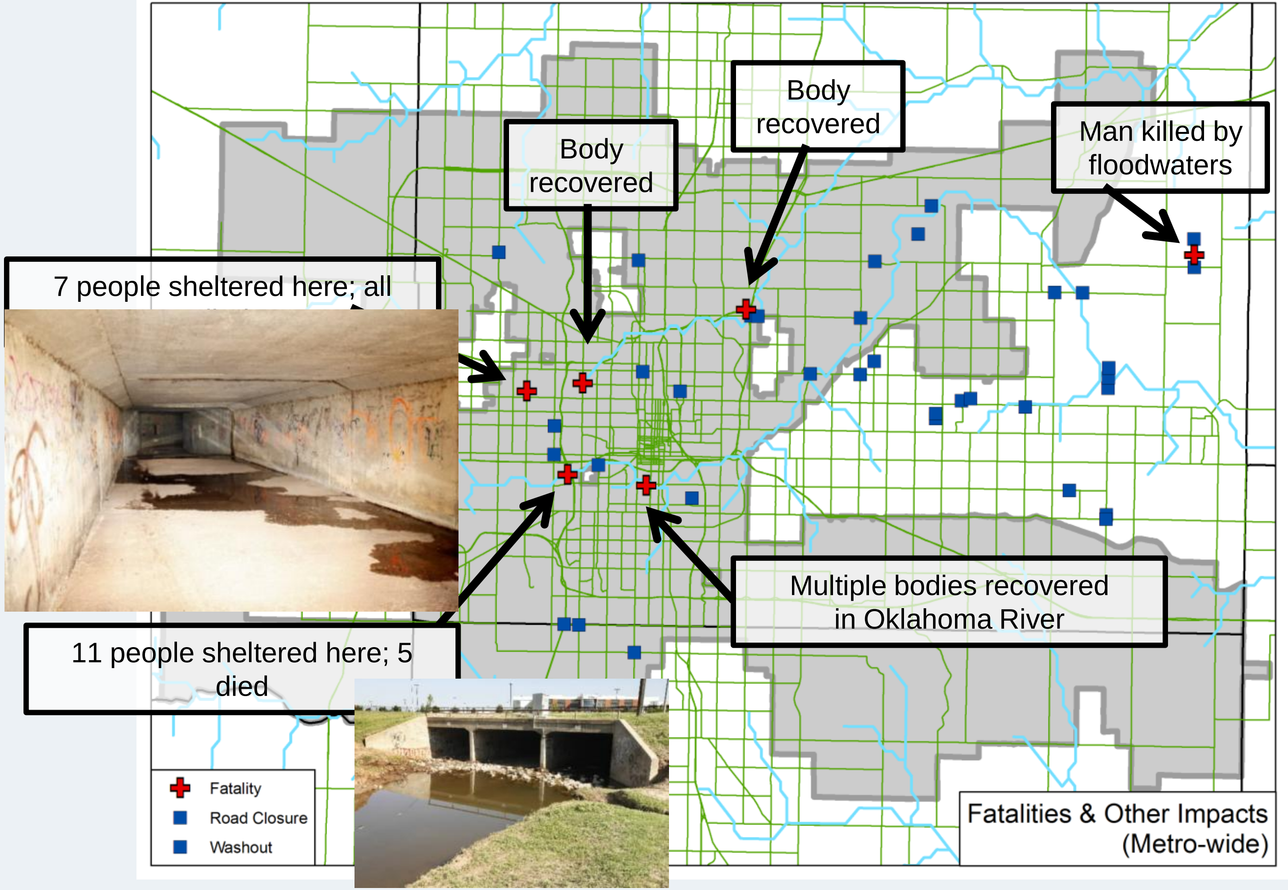


<u>Model Parameters</u>: Impervious area, available water capacity, soil texture & depth, saturated hydraulic conductivity, etc.

May 31, 2013 OKC Flash Flood: Rainfall



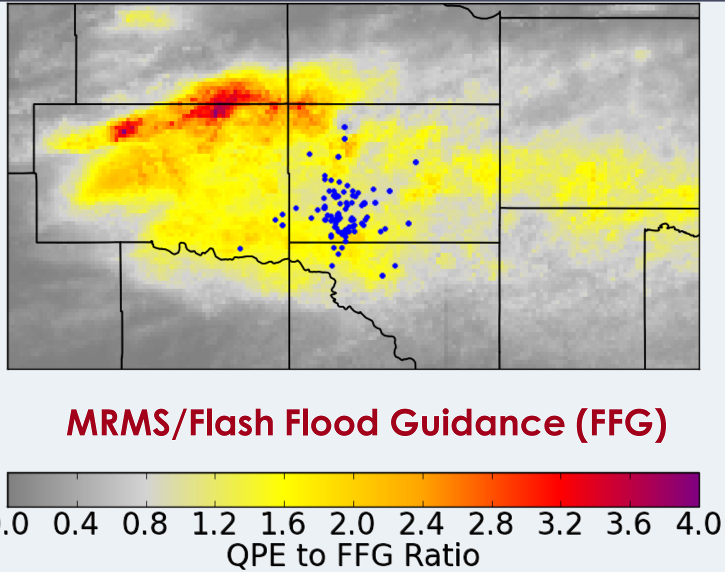
- Composite reflectivity animation
- Supercell storm with quasi-stationary core over Oklahoma City metro area



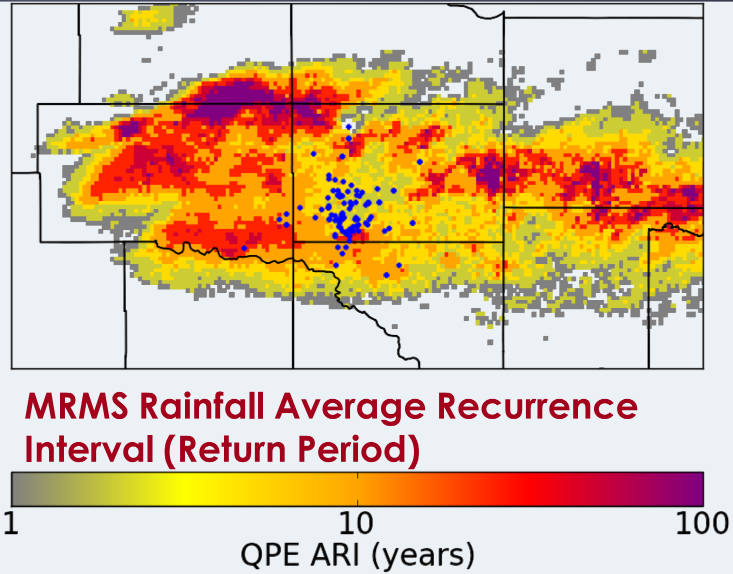
During the storms, 23 people lost their lives (12 from flooding in OKC).
This is the deadliest flood in OKC history & the worst in the state since 1984

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

FLASH Rainfall Threshold Products



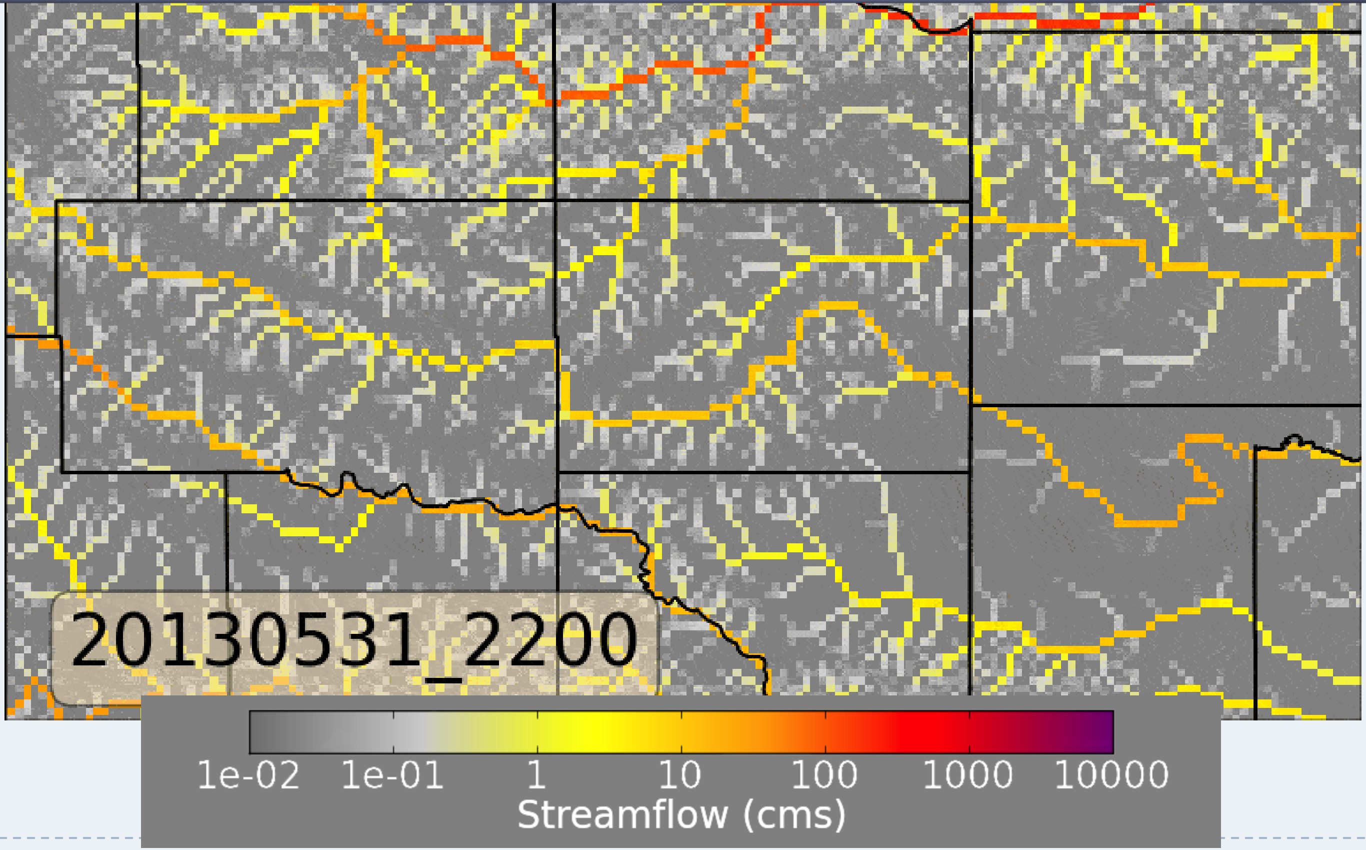
MRMS/Flash Flood Guidance (FFG)



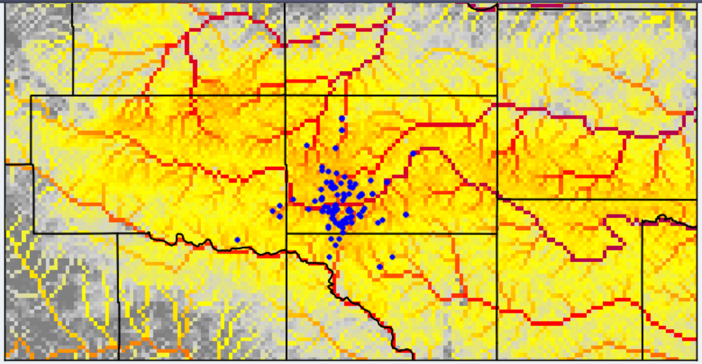
MRMS Rainfall Average Recurrence Interval (Return Period)

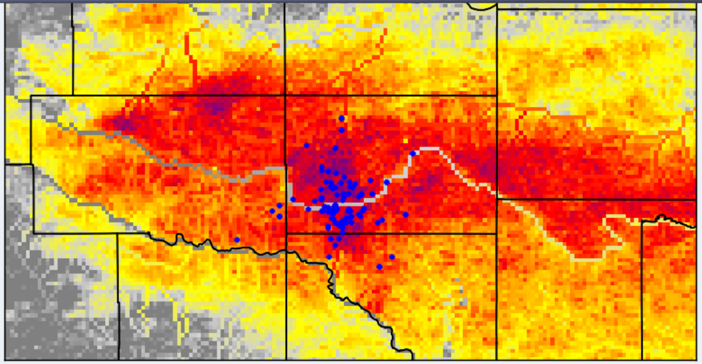
- Both products indicate greatest threat is to the northwest of the region that was most heavily impacted
- All blue dots correspond to known flooding reports collected from City of Oklahoma City, media, social media (rescues, water in homes, street closures, fatalities)

FLASH Forecast Streamflow

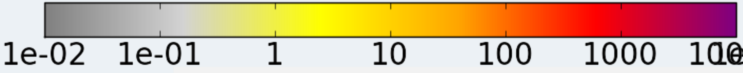


FLASH Streamflow-based Products





Maximum Streamflow (m^3/s)

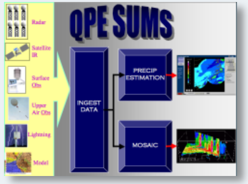


Maximum Unit Streamflow ($m^3/s/km^2$)

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

1. Routing
2. Modeling of impervious surfaces

History of successful research to NWS operations



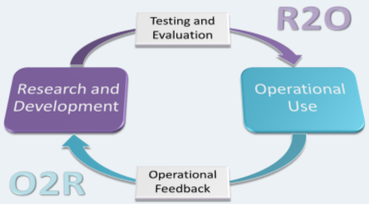
- First demo of multisensor QPE using NEXRAD mosaic

FLASH
Flooded Locations and Simulated Hydrographs Project

- Project launched following funding from Public Law 113-6, the FY2013 Disaster Assistance Supplemental

Postdoc at Météo-France

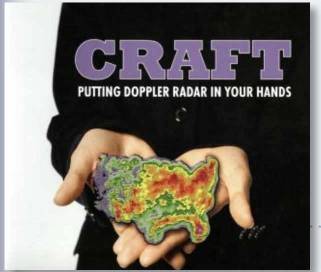
- HMT-Hydro experiments



97 98 04 05 06 13 14 15 16 18 19

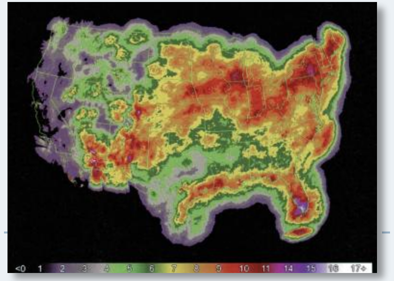
CRAFT

- Transfer of real-time radar data on internet



NMQ/Q2

- QPE produced in real-time across



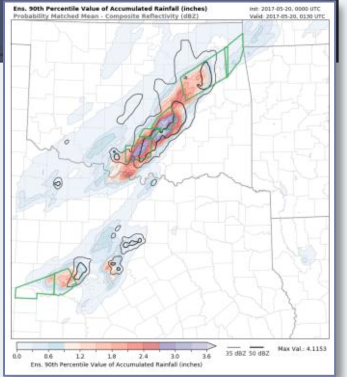
MRMS/Q3

- QPE and severe weather products transitioned for operational use in the NWS

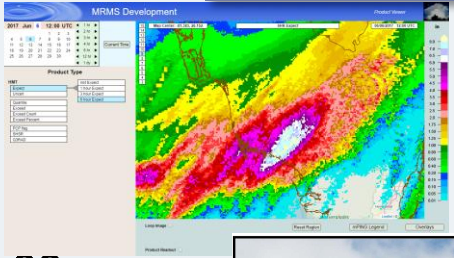
FLASH

- Flash flooding software transitioned for operational use in the NWS

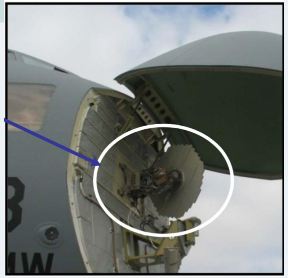

Future of forcings from a flash flood forecasting perspective



- Use of QPFs from NSSL's Experimental Warn-on-forecast System using Ensembles (NEWS-e)
  - Potential to increase lead time
  - Accommodates change in paradigm to probabilistic forcings and products

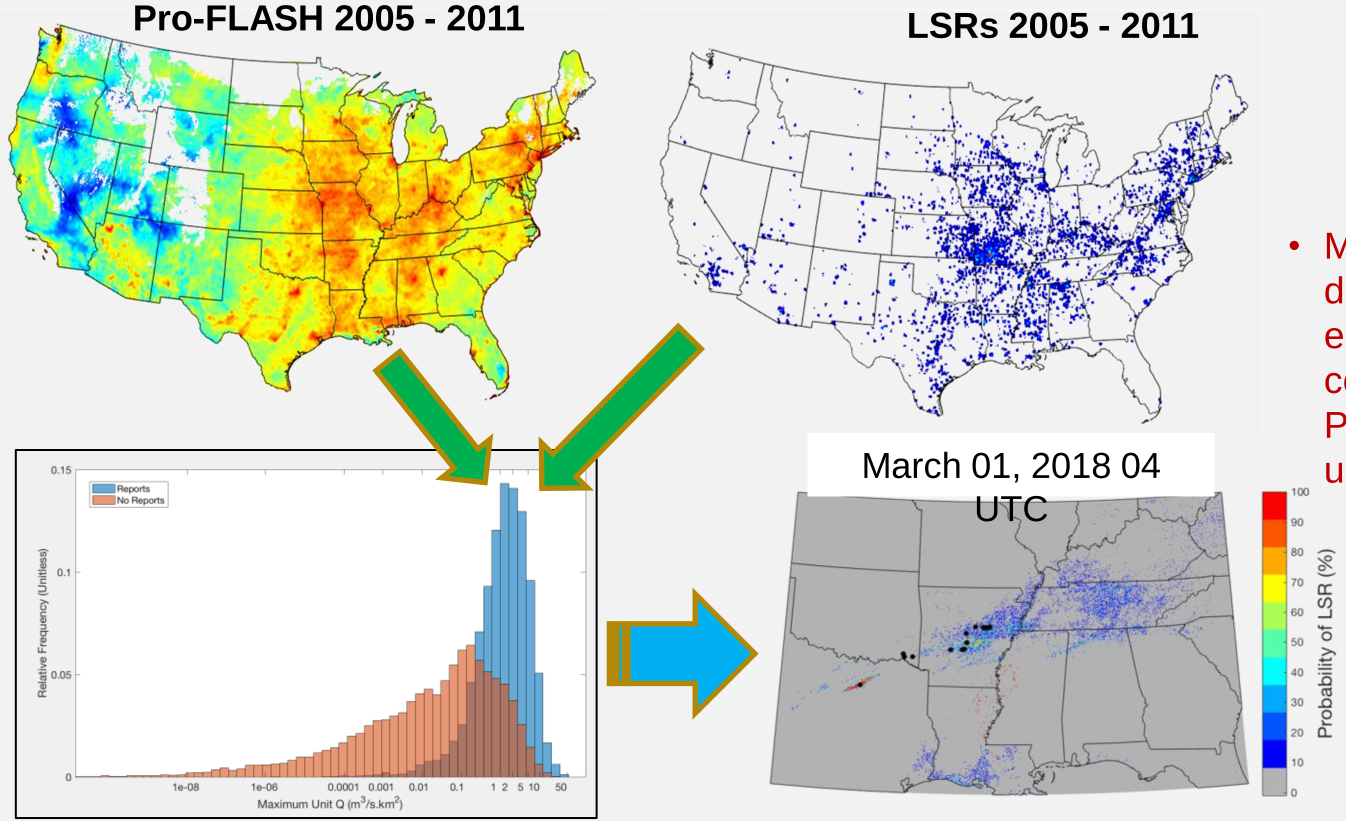


- Use or Probabilistic QPEs (Kirstetter et al. 2015, *WRR*)
  - Acknowledges uncertainty in radar-based QPE
  - Inherent bias correction
  - Provides moments of distribution at every grid point such as quantiles, expected value, % exceedance



- Incorporation of radar data from non-NEXRAD sources

FLASH v20: Transitioning from deterministic to probabilistic products



- Marginal distributions enable the computation of Prob(flood | unitQ)

Example of real-time outputs during Washington DC flash flood emergency (08 July 2019)

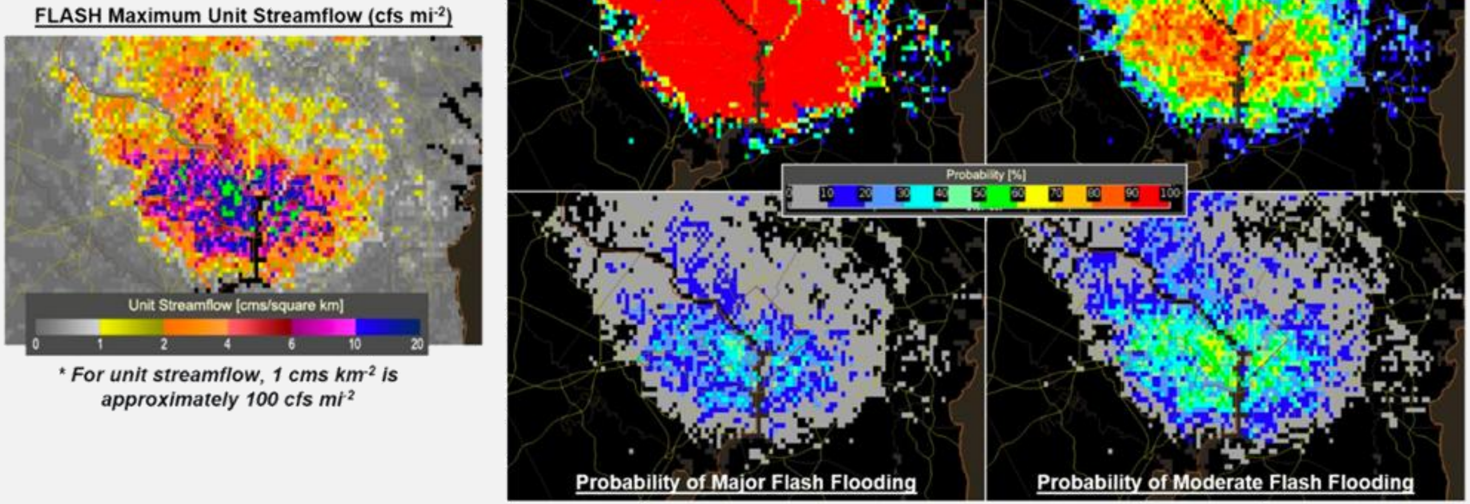
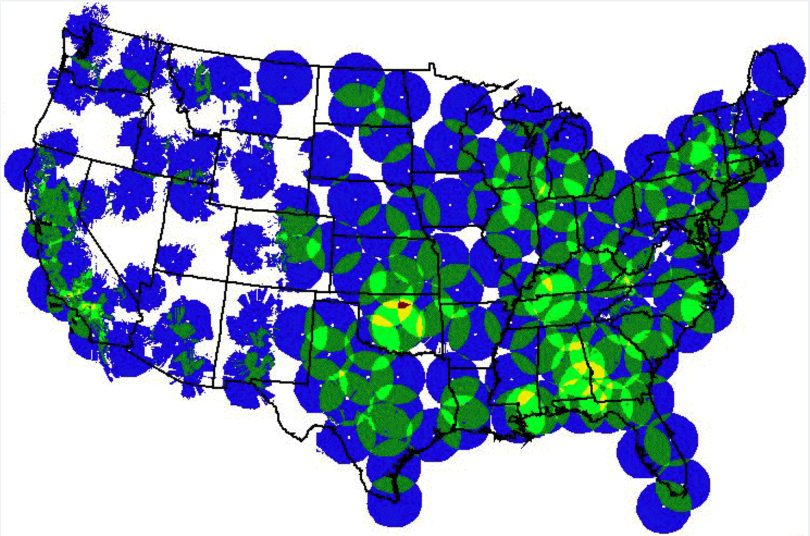


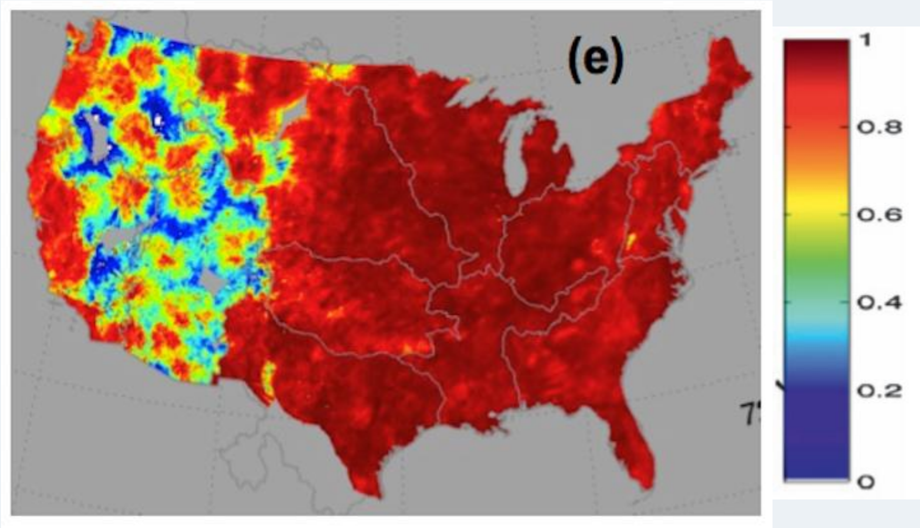
Figure 5. The Washington D.C. flash flood event as seen from the deterministic (left) and probabilistic (right) data at 1400 UTC 8 July 2019. The images were taken from the flash.ou.edu web page, which was used during the evaluations. Note that the units for the FLASH CREST Maximum Unit Streamflow product is in metric units ($m^3\ s^{-1}\ km^{-2}$).

Accuracy of MRMS precipitation estimates tied to quality of low-level radar coverage (Chen et al., 2013, *JHM*)

NEXRAD Radar coverage at 3km AGL



Correlation Coefficient of Radar-based Rainfall Estimates



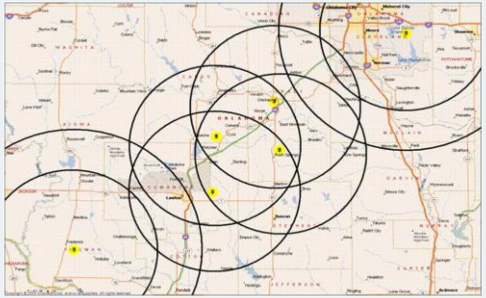
- Studies have shown reduced accuracy with rainfall estimation, tornado and flash flood warnings in radar gaps
- Greatest limitation of NEXRAD-based products is spatial coverage over inter-continental regions and oceans

Options for filling in the radar data voids – Terrestrial-based observations

McLaughlin et al. (2009), *BAMS*

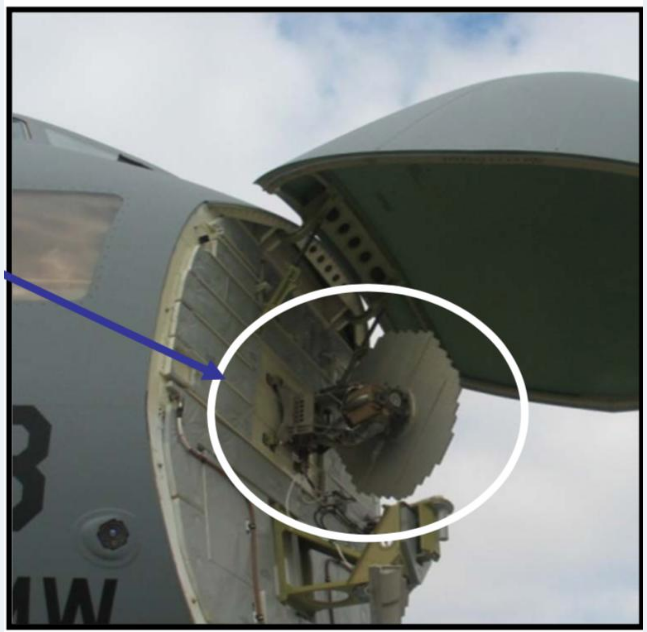
- Use X- and C-band radars as in CASA, Bay Area project, Alamosa radar
  - 100 m gate spacing at low altitudes
  - Integrated network for adaptive scanning
  - Attenuation loss at horizontal incidence
  - **Requires partners for sustained O&M**

White et al. (2013), *JTECH*

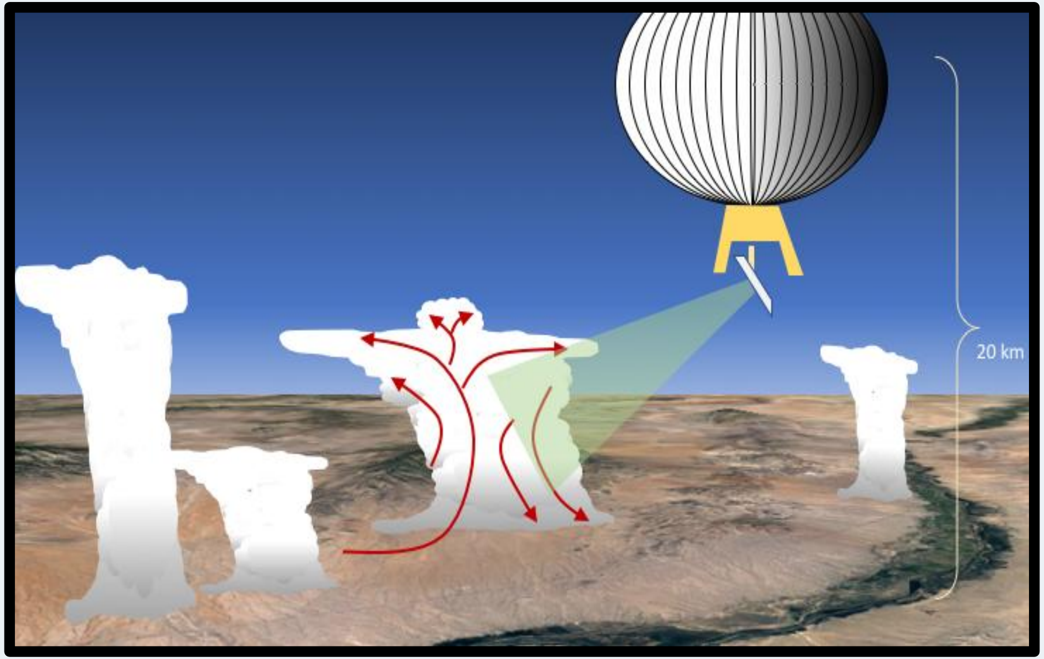


Options for filling in the radar data voids – Airborne radars

AiRNet: Aiborne Radar Network

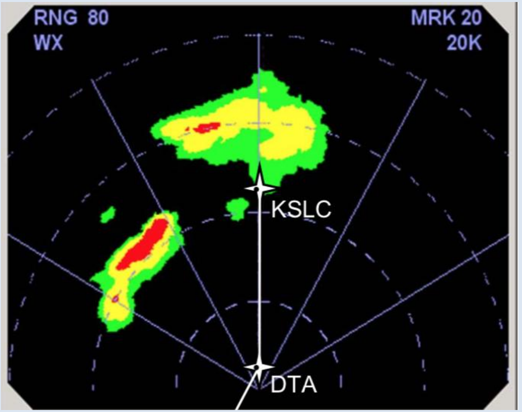


SOES: Stratospheric Observations of Earth Syste



Airborne Radar Network (AiRNet) – X-band Radars

Images courtesy of Honeywell



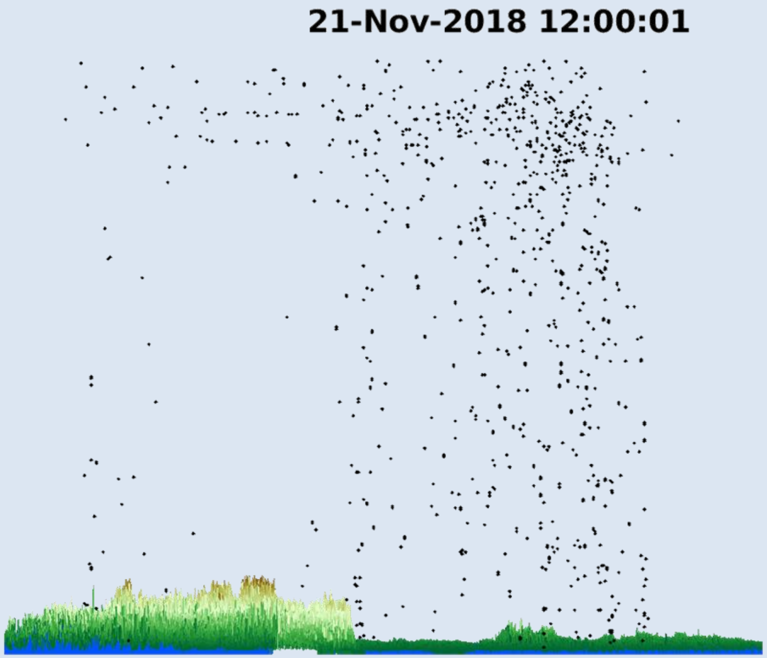
- A majority of commercial and corporate jets are flying with X-band, scanning radars in their nosecones
- At present, imagery from these radars are displayed in the cockpit for 30 min…and then are discarded

Airborne Radar Network (AiRNet) – Feasibility Study

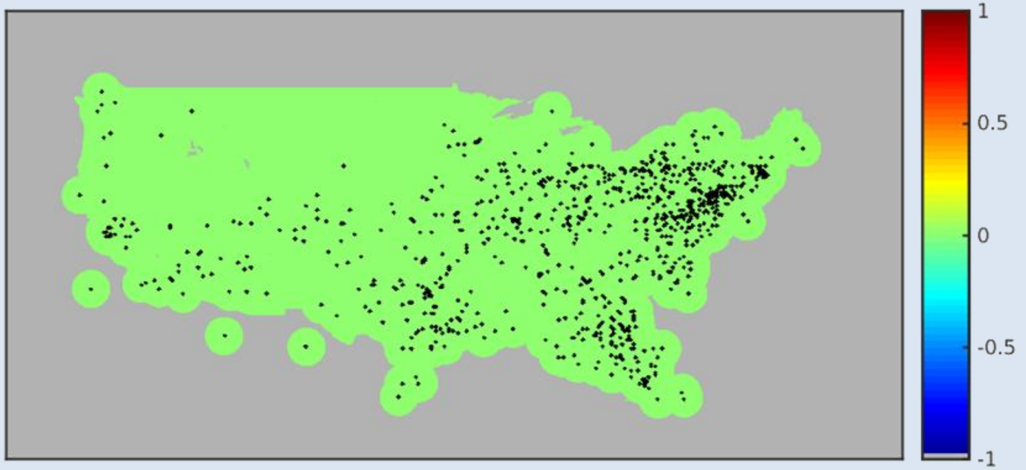
Flight track data courtesy of The Opensky Network via ADS-B Mode S broadcasts

Emerging Technologies

There are ~5000 aircraft over the US during peak operational times !



Space-time depiction of flight tracks

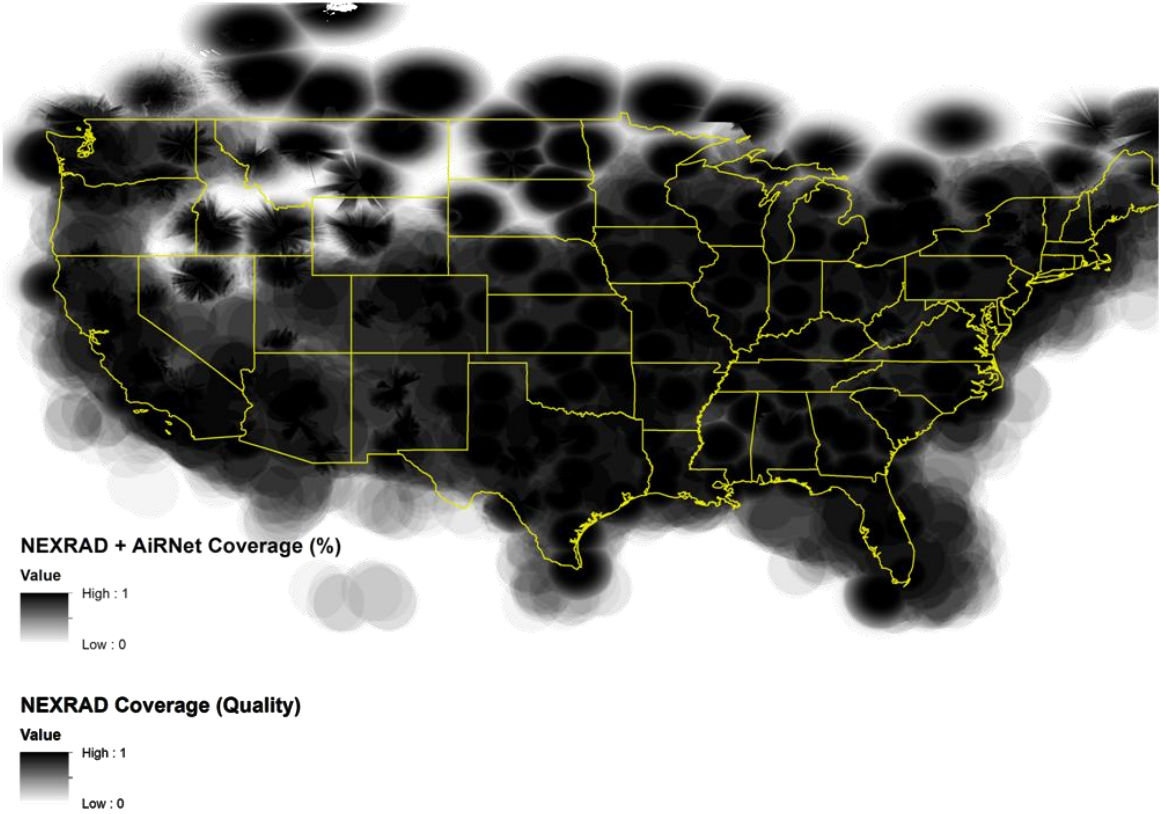


Accumulated portion of time in a day where there is surveillance by AiRNet within 150 km

"Any views expressed in this presentation are those of the presenters, and do not necessarily represent the views of the US DOC or NOAA. Presentation of the proposed technology at the 2019 ETW does not constitute an endorsement by NOAA."

Airborne Radar Network (AiRNet) – Feasibility Study

- Analysis combines operational NEXRAD coverage with the percent of time there is virtual coverage by AiRNet in 24 hr
- Incorporated flight tracks of commercial aircraft and assumed 3D surveillance out to 150 km in range



Summary of FLASH and precipitation forcings

- FLASH was transitioned to the NWS in 2016 and has advanced the tools for flash flood forecasting in NWS Forecast Offices

- Research continues to improve forcings, models, products
  - Experimentation with precipitation forecasts using NSSL's Experimental Warn-on-forecast System using Ensembles (NEWS-e)
  - Projects (i.e., AiRNet, SOES) initiated to fill in NEXRAD gaps in the West and over oceans
  - CREST model state updates with improvements in soil saturation, river stages, snowmelt contribution to runoff
  - Entire system being transitioned from deterministic to probabilistic