NCAR

# A Real-Time Hydrometeorology Research Testbed for Heavy Rainfall and Streamflow Prediction


Rita Roberts

and

*Jim Wilson, Dan Megenhardt, Jenny Sun, Dave Gochis, Barbara Brown*


National Center for Atmospheric Research

# NCAR's Short Term Explicit Prediction (STEP) Program

- Cross-divisional program to foster research on improvement of 0-12 hr forecasting of high impact weather.

- Focus is on prediction of heavy rainfall, flash floods and streamflow prediction.

- STEP Program includes:

  -Improvement of QPE

  -Development and testing of 3DVar, 4DVar, latent heat nudging and ensemble models

  -Developing and testing expert (heuristic) nowcasting system (AutoNowcaster)

  -Development and testing of new microphysical schemes

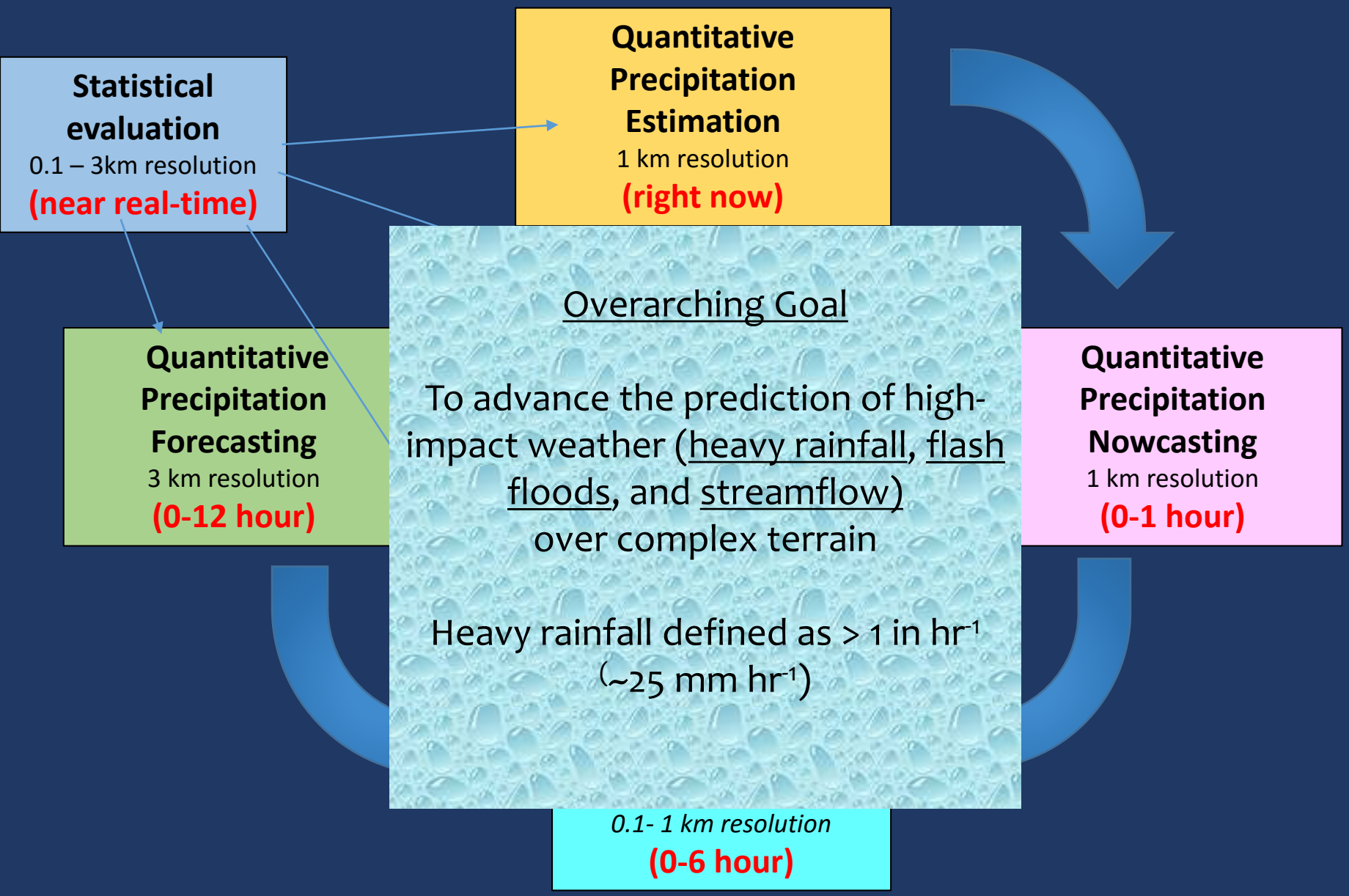
  -Development and testing of statistical verification methodologies

  - Development and testing of coupled atmospheric and hydrologic streamflow prediction

- Demonstrate these capabilities in real-time and assess their performance

# STEP Hydromet Prediction System

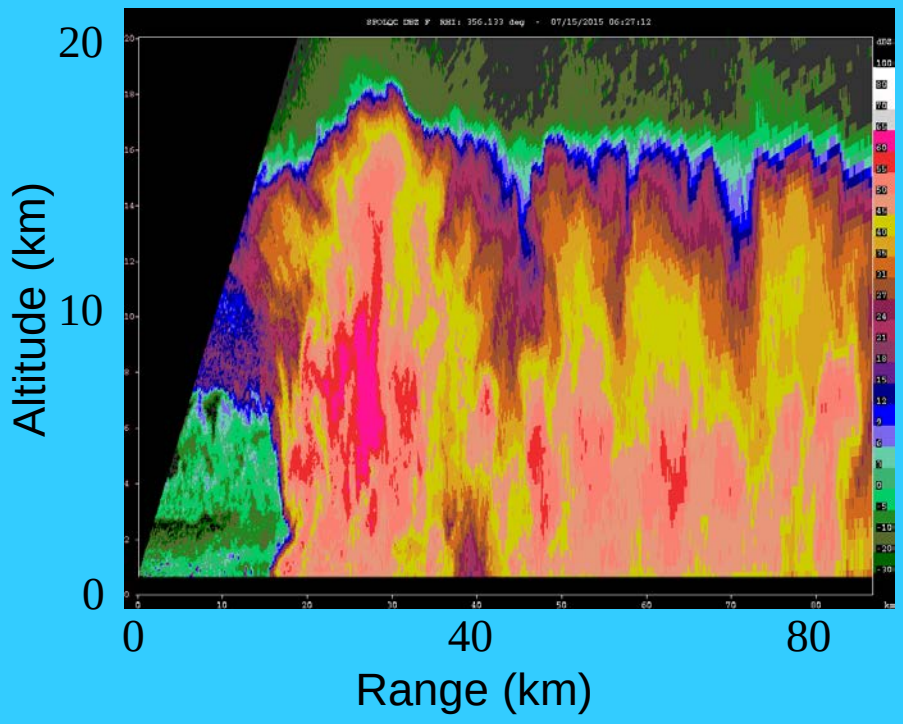
*Integration of different nowcast capabilities into one seamless 0-12 hr prediction system*



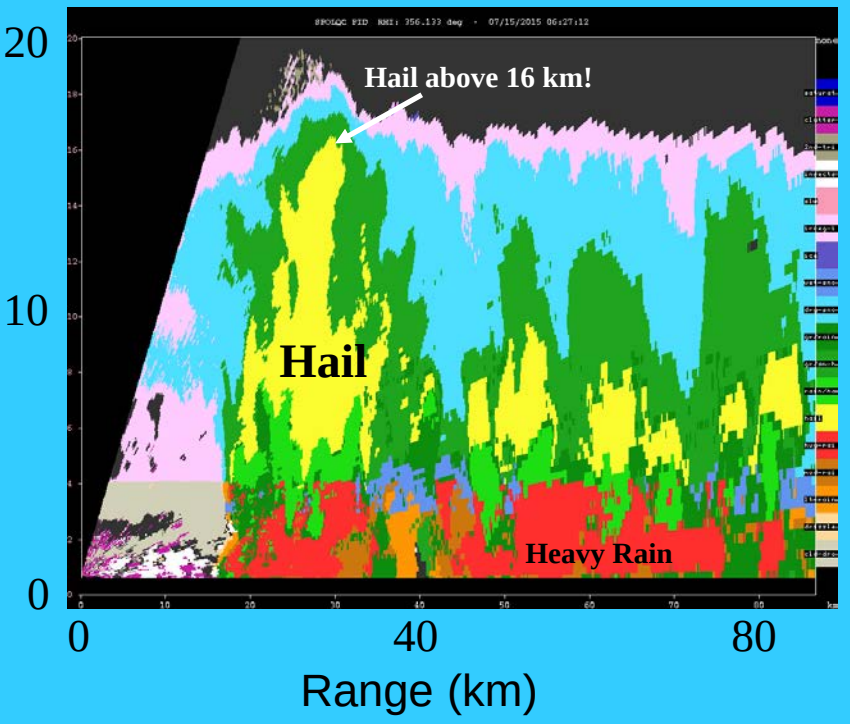
# NCAR S-Pol Dual-polarization fields used in rainfall estimation:

Dual-pol rainrate relationships: Z, Z-Zdr, KDP, KDP-ZDR
Dual-pol derived Particle Identification Detection (PID) algorithm

S-Pol Reflectivity

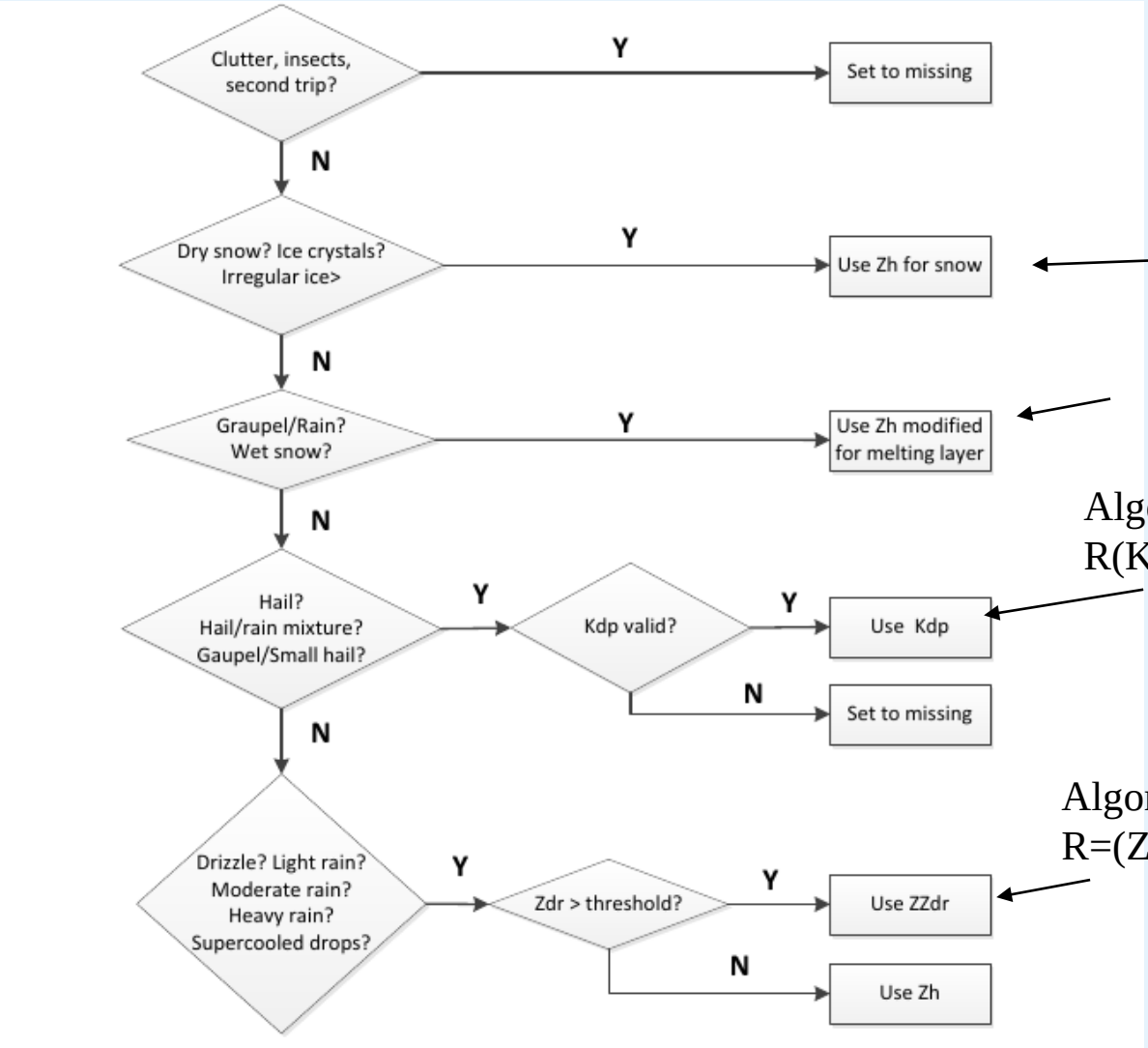



NCAR Particle ID




- NCAR S-Pol deployed during the Plains Elevated Convection At Night (PECAN) experiment
- An intense mesoscale convective system was observed on 15 July 2015
- Hail detected up to an altitude of 16 km!

- The NCAR Hybrid Algorithm uses the NCAR PID to select the rainfall relationship for each particle type




Algorithm uses $Z=200S^{1.6}$

In the melting layer, measured reflectivity is reduced by 10 dBZ.

Algorithm uses $R(K_{DP}) = \text{sign}\,(K_{DP})44|K_{DP}|^{0.822}$

Algorithm uses $R=(Z,ZDR) = 0067Z^{0.927}ZDR^{-3.43}$

*Dixon, M., et al: 2015: A dual-polarization QPE method based on the NCAR Particle ID Algorithm: description and results. 37th Conference on Radar Meteorology.*

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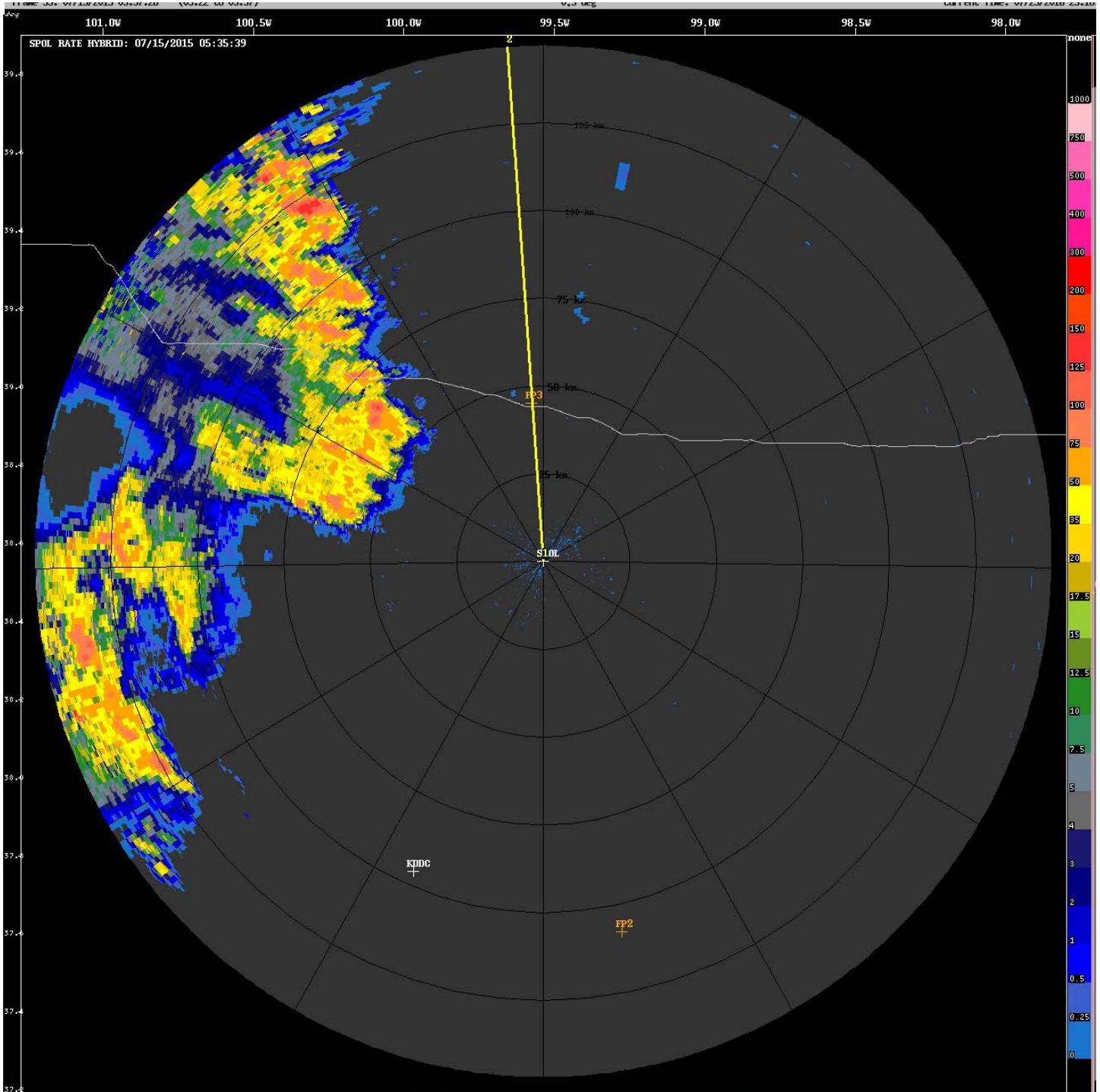
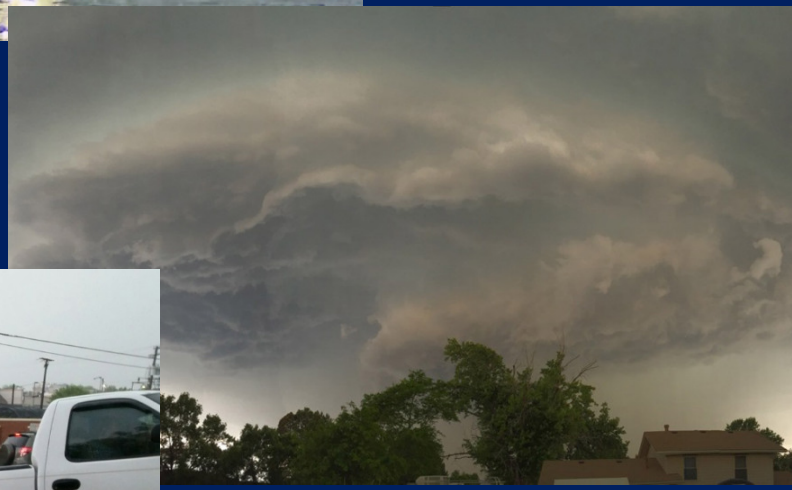
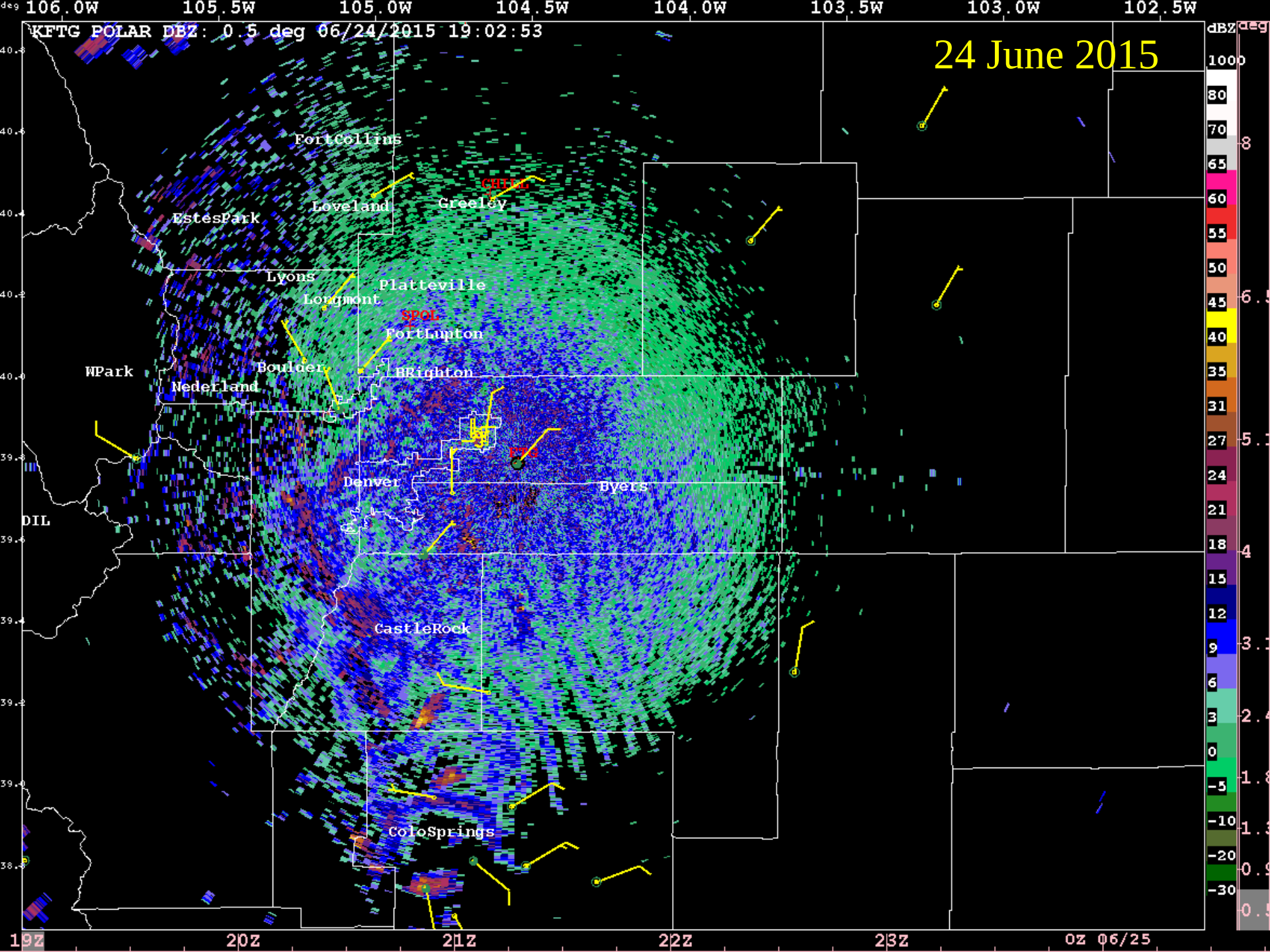
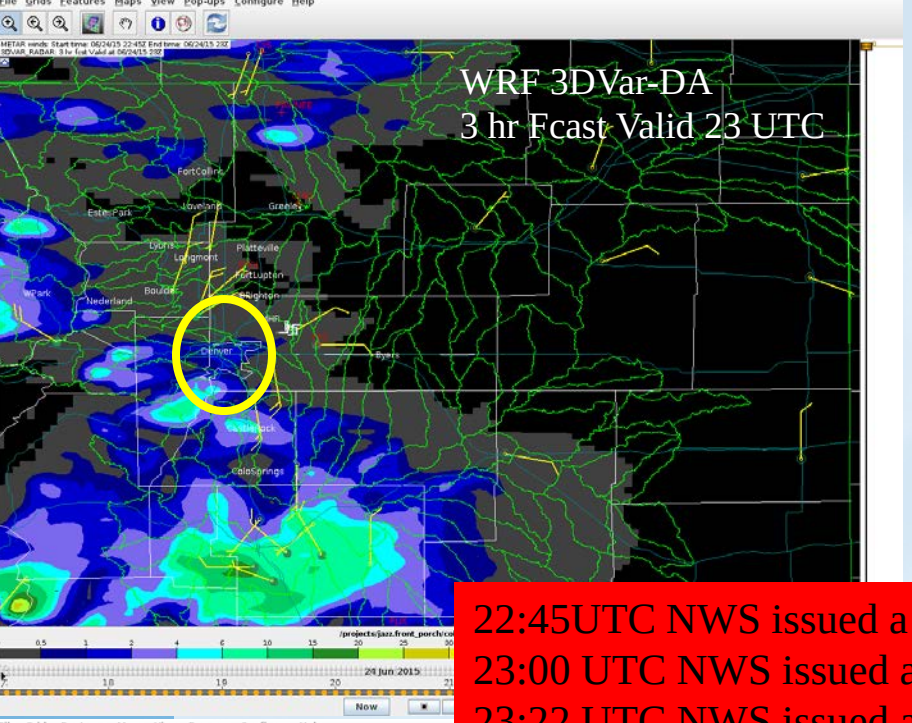


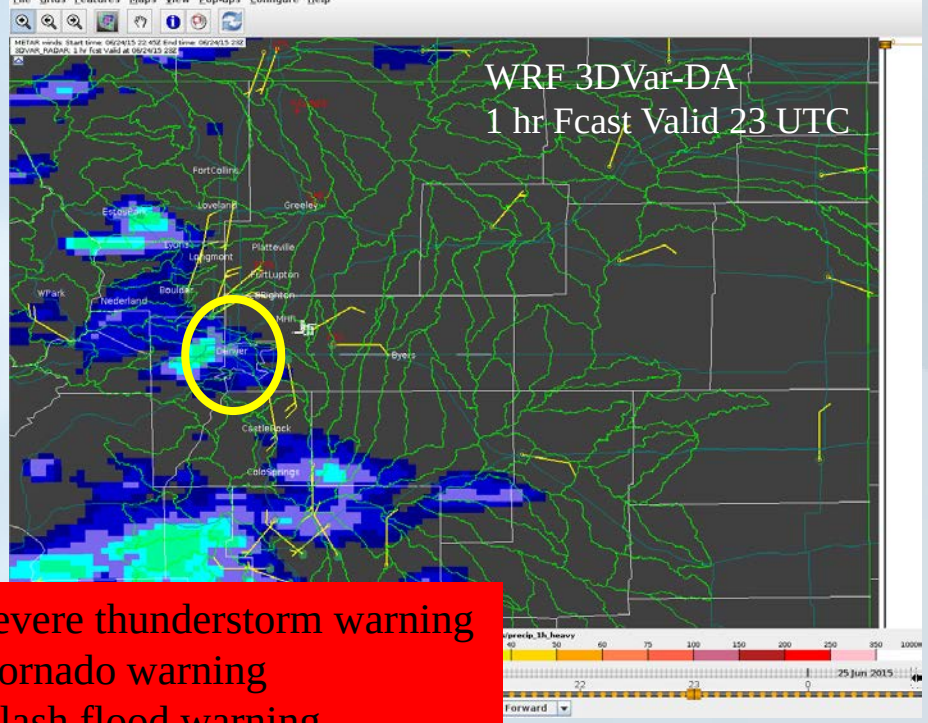

S-Pol PID and precipitation accum fields

# 24 June 2015 – Denver Metro Flash flood, hail and tornado

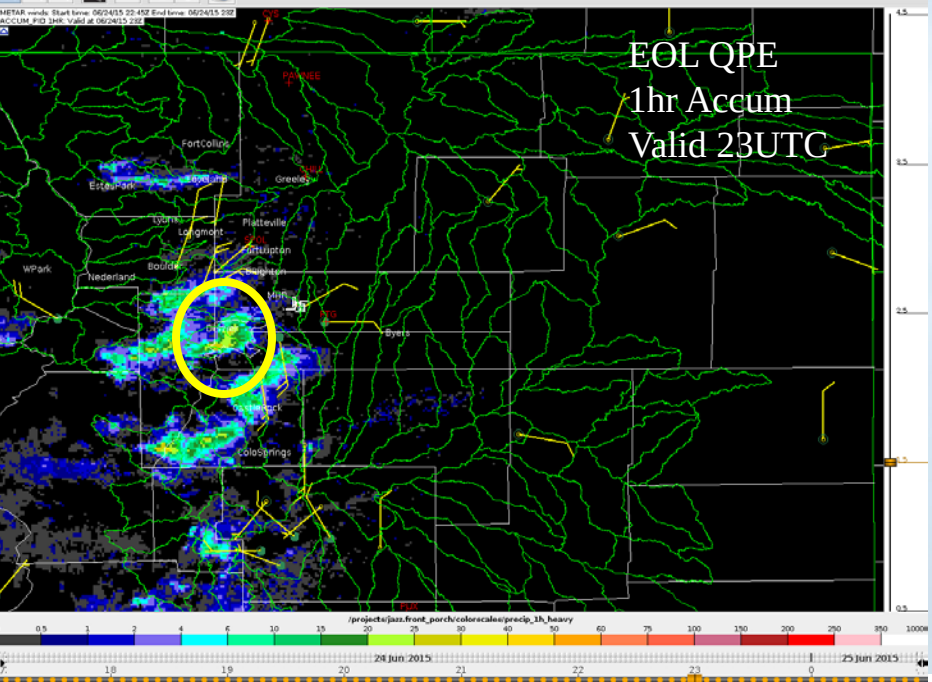


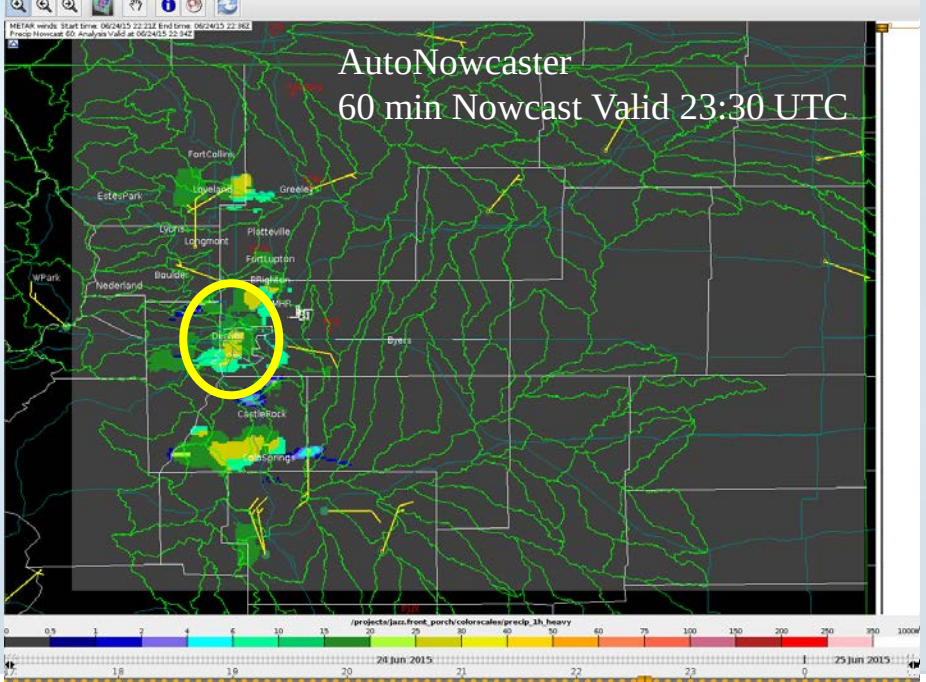

KFTG POLAR DBZ: 0.5 deg 06/24/2015 19:02:53
24 June 2015
106.0W
105.5W
105.0W
104.5W
104.0W
103.5W
103.0W
102.5W
40.8
40.6
40.4
40.2
40.0
39.8
39.6
39.4
39.2
39.0
38.8
FortCollins
Loveland
Greeley
CHILL
EstesPark
Lyons
Longmont
Platteville
SPOL
FortLupton
Boulder
Brighton
WPark
Nederland
Denver
FTG
Byers
DIL
CastleRock
ColoSprings
dBZ
1000
80
70
65
60
55
50
45
40
35
31
27
24
21
18
15
12
9
6
3
0
-5
-10
-20
-30
deg
8
6.5
5.1
4
3.1
2.4
1.8
1.3
0.9
0.5
19Z
20Z
21Z
22Z
23Z
0Z 06/25




22:45UTC NWS issued a severe thunderstorm warning
23:00 UTC NWS issued a tornado warning
23:22 UTC NWS issued a flash flood warning

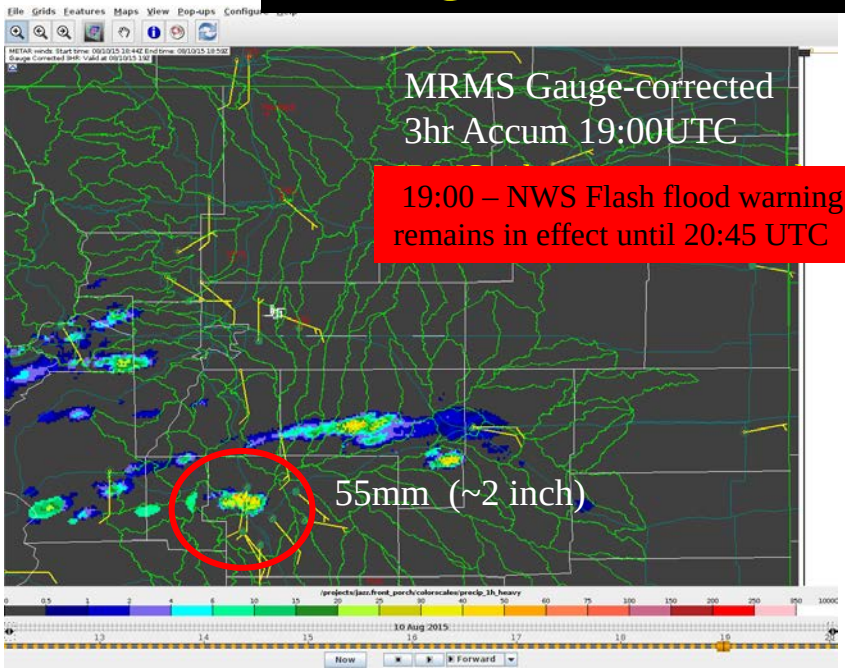


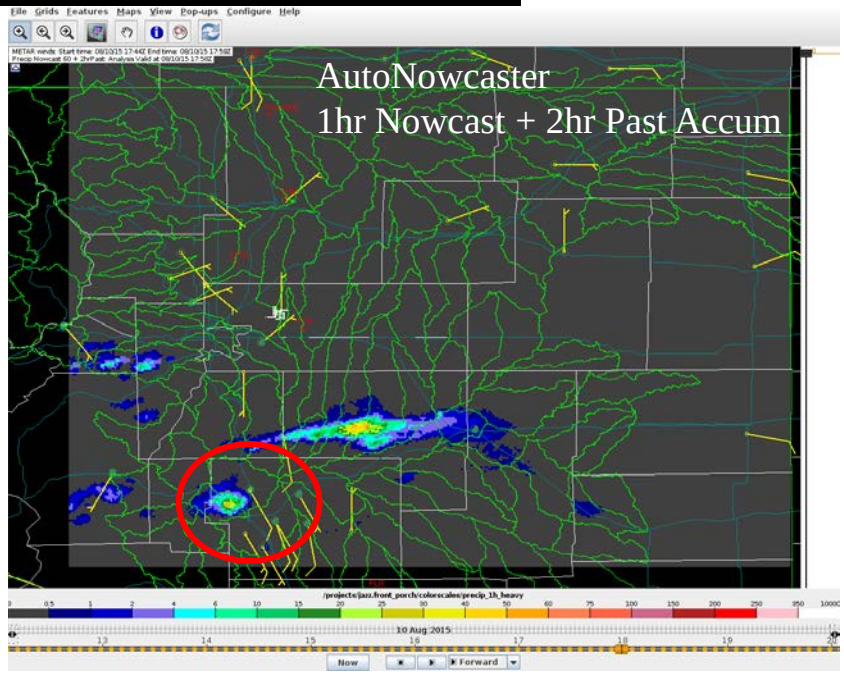
# 10 August 2015 – Flooding in Manitou Springs

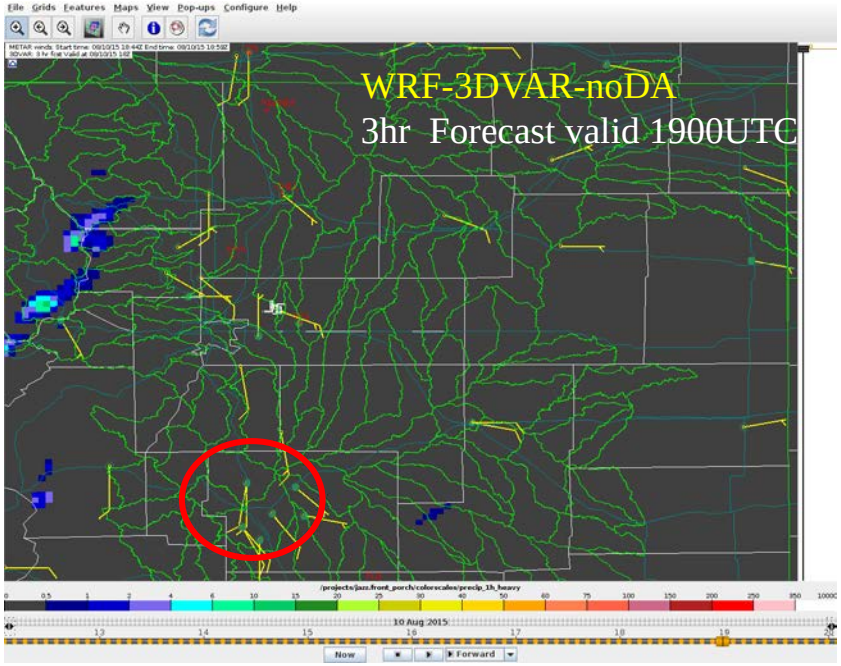
http://kdvr.com/2015/08/10/heavy-rain-floods-streets-in-Manitou-Colorado-springs-areas

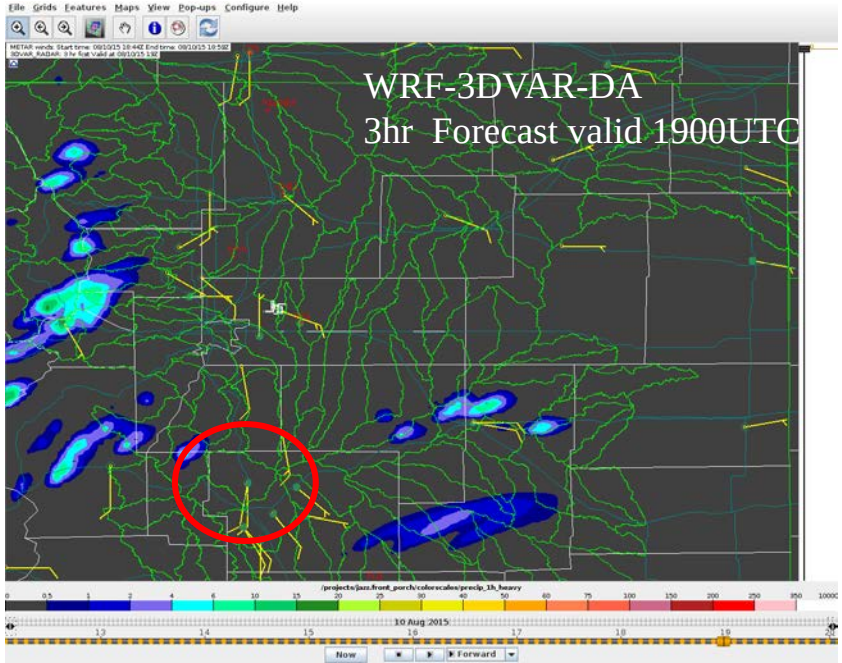
# 10 August 2015 – WRF 3DVar 3 hr forecast

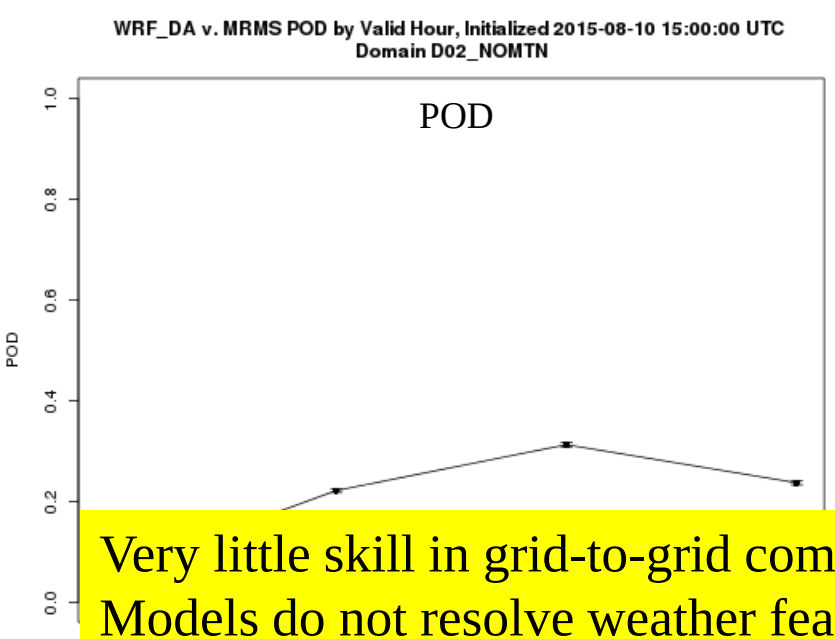


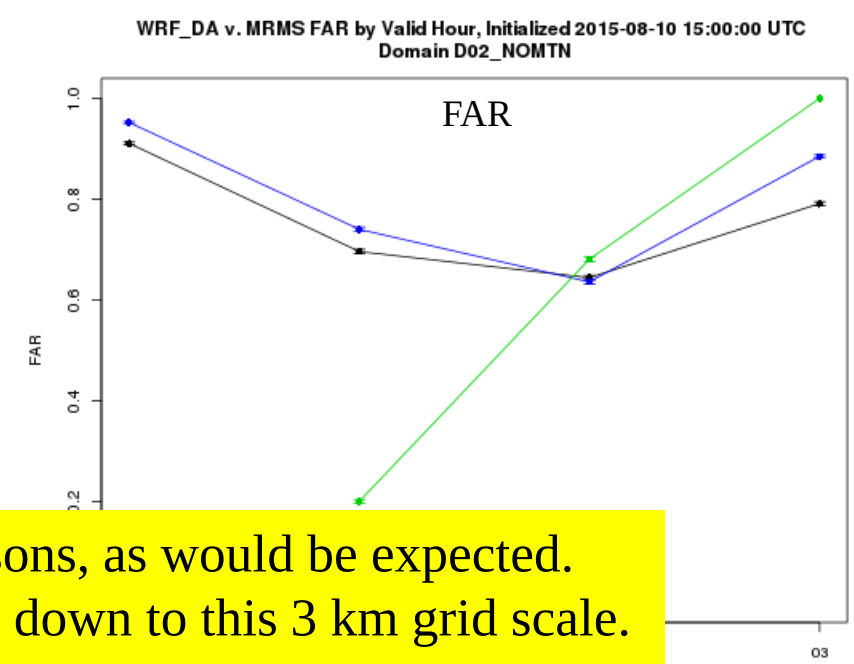

19:00 – NWS Flash flood warning remains in effect until 20:45 UTC



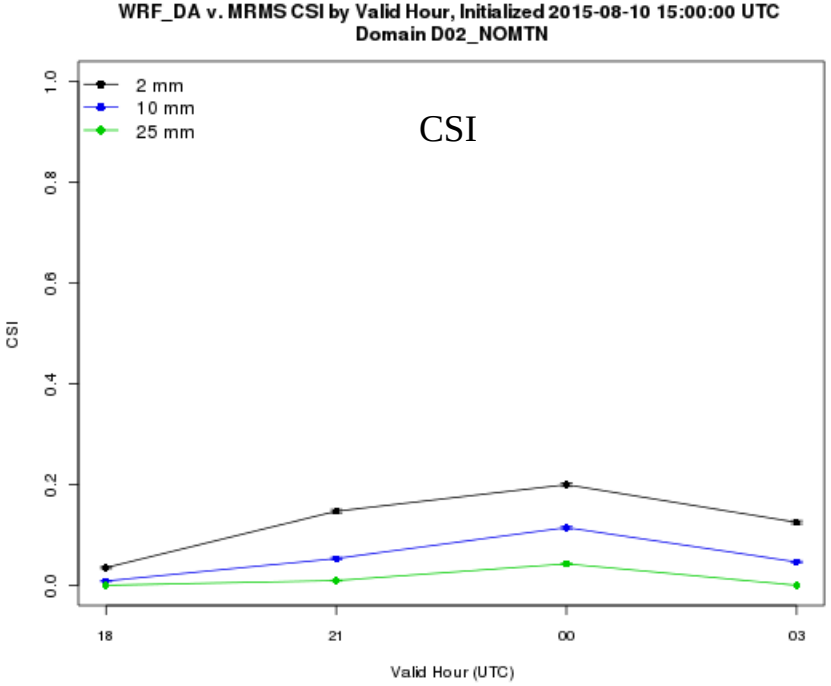



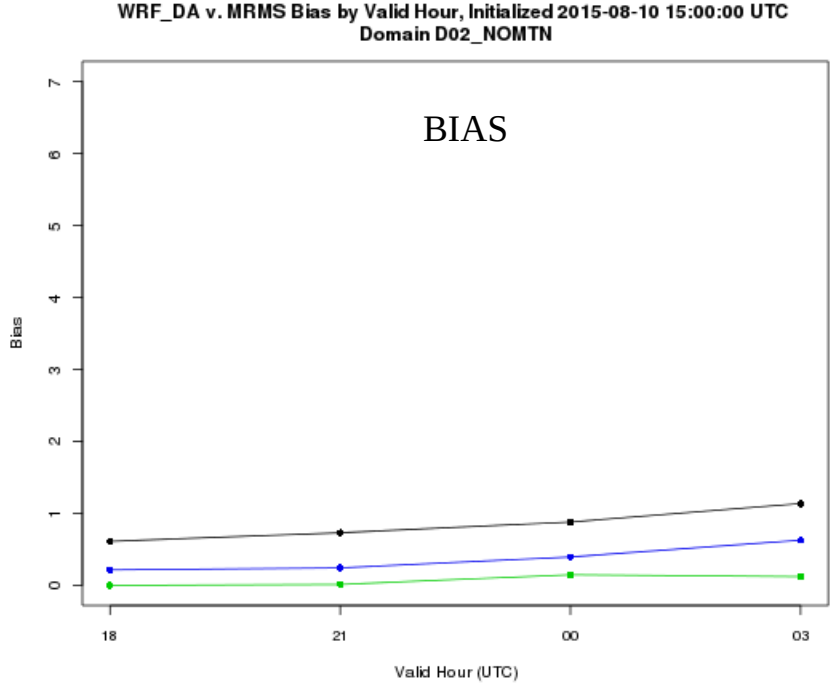





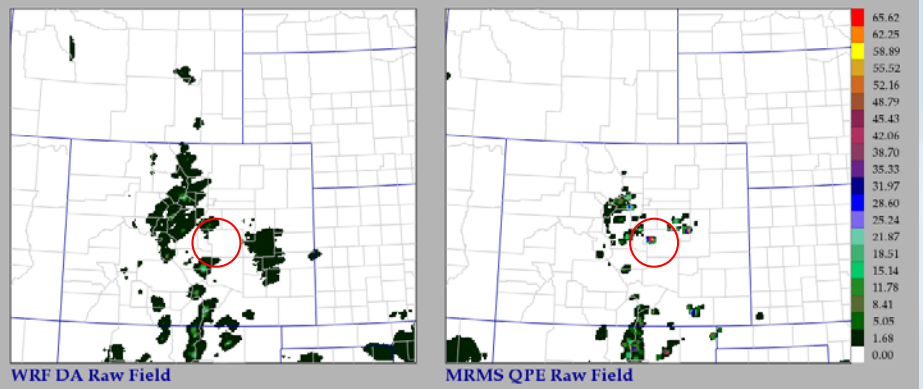



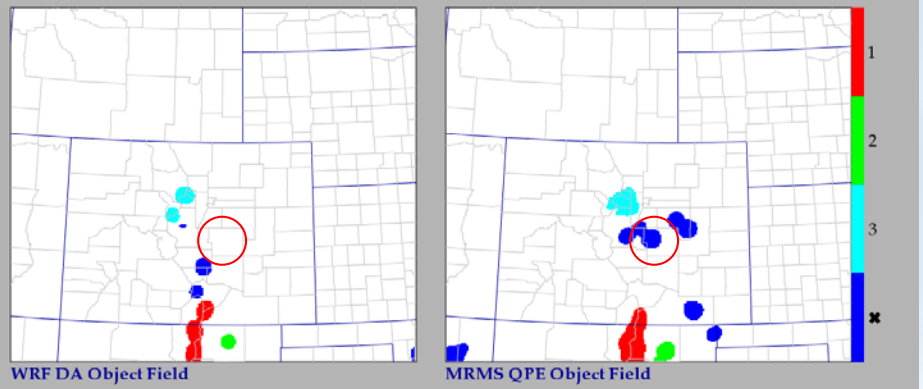

Very little skill in grid-to-grid comparisons, as would be expected.
Models do not resolve weather features down to this 3 km grid scale.
CSI scores used in past; most modelers using FSS now.



# Method for Object-based Diagnostic Evaluation (MODE)



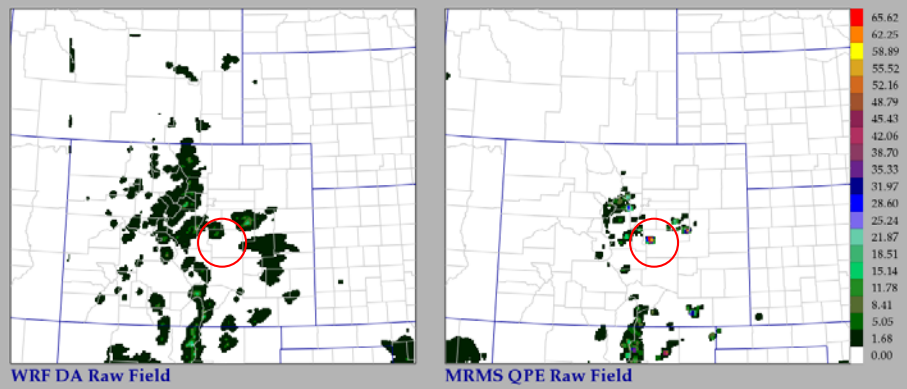

WRF DA vs. MRMS QPE

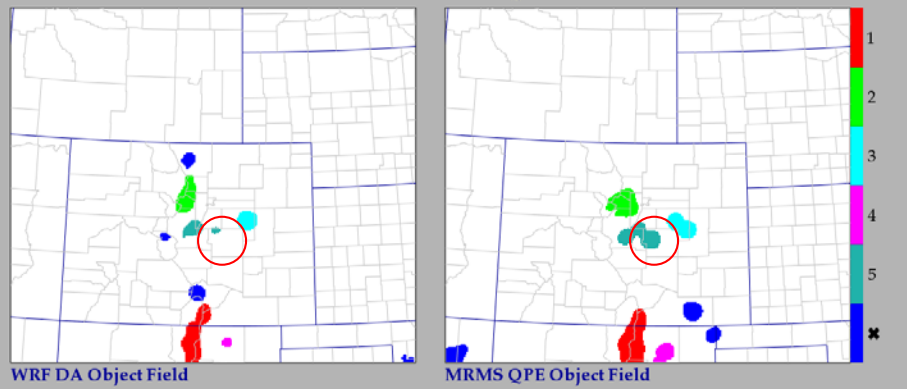
Valid August 10, 2015 19h
Lead 04h

Radius 6
Threshold >=1.000

| | Simple Objects | Cluster Objects | Simple Area | Cluster Area | Unmatched Area | 10 % | 50 % | 90 % |
|---|---|---|---|---|---|---|---|---|
| Fcst | 8 | 3 | 1,244 | 946 | 298 | 0.00 | 0.63 | 7.78 |
| Obs | 8 | 3 | 2,545 | 1,275 | 1,270 | 0.00 | 0.70 | 9.80 |

| Cluster | Area (F/O) | Centroid Distance | Overlap Area | Symmetric Difference | 50 % (F/O) | 90 % (F/O) | Total Interest |
|---|---|---|---|---|---|---|---|
| | 545 / 667 | 5.85 | 414 | 798 | 0.69 / 2.30 | 8.96 / 10.90 | 1.00 |
| | 115 / 192 | 8.10 | 43 | 264 | 0.38 / 1.55 | 7.14 / 44.75 | 0.97 |
| | 286 / 416 | 7.03 | 143 | 559 | 0.97 / 1.70 | 7.21 / 14.65 | 0.97 |




WRF DA vs. MRMS QPE

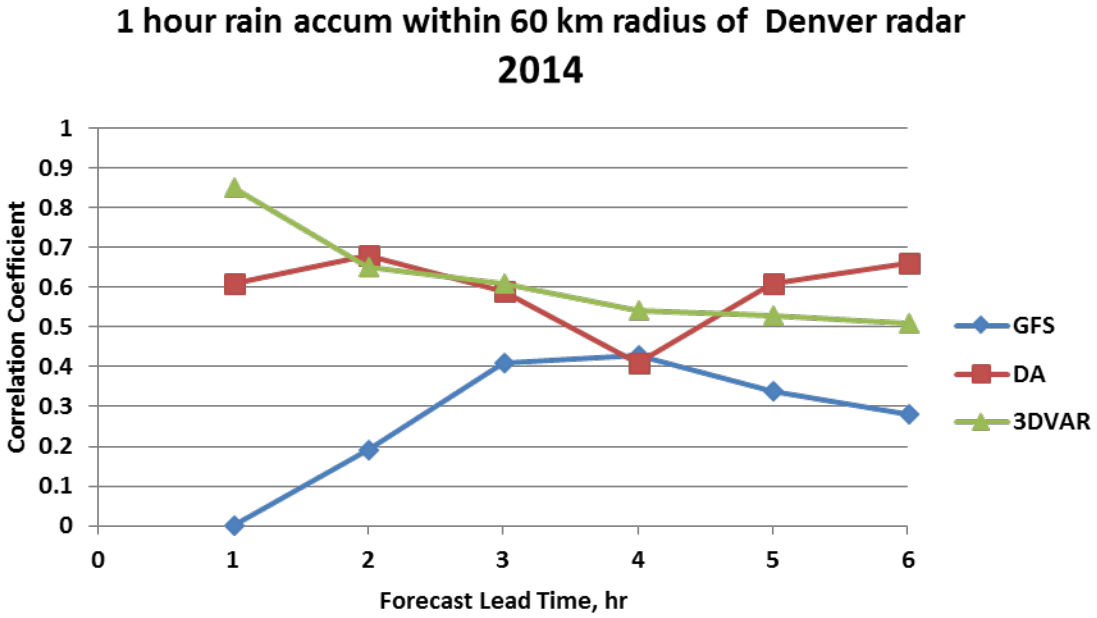
Valid August 10, 2015 19h
Lead 01h

Radius 6
Threshold >=1.000

| | Simple Objects | Cluster Objects | Simple Area | Cluster Area | Unmatched Area | 10 % | 50 % | 90 % |
|---|---|---|---|---|---|---|---|---|
| Fcst | 10 | 5 | 1,638 | 1,318 | 320 | 0.02 | 1.10 | 6.54 |
| Obs | 8 | 5 | 2,545 | 2,033 | 512 | 0.00 | 0.70 | 9.80 |

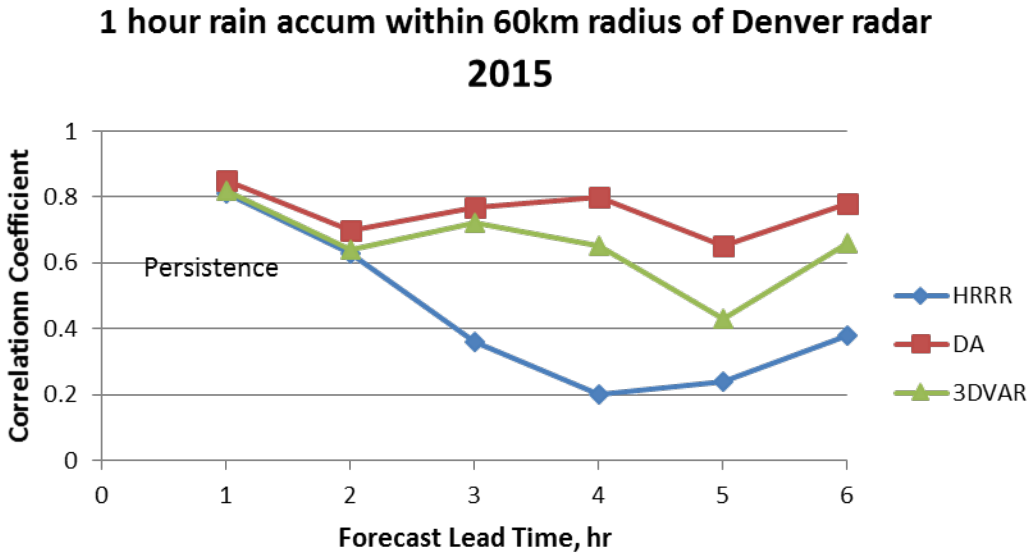
| Cluster | Area (F/O) | Centroid Distance | Overlap Area | Symmetric Difference | 50 % (F/O) | 90 % (F/O) | Total Interest |
|---|---|---|---|---|---|---|---|
| | 554 / 667 | 4.16 | 455 | 766 | 1.05 / 2.30 | 8.98 / 10.90 | 1.00 |
| | 327 / 416 | 6.20 | 227 | 516 | 1.27 / 1.70 | 4.60 / 14.65 | 0.97 |
| | 200 / 315 | 4.36 | 146 | 369 | 1.26 / 4.00 | 7.95 / 32.30 | 0.97 |
| | 49 / 192 | 8.67 | 13 | 228 | 1.67 / 1.55 | 5.31 / 44.75 | 0.91 |
| | 188 / 443 | 8.67 | 103 | 528 | 1.49 / 2.20 | 4.53 / 34.98 | 0.94 |

# Comparison of NWP models with MRMS QPE




Rainfall amounts are the average hourly rainfall accumulation within a 60 km radius of the Denver radar.

Note: MRMS radar-retrieved QPE is biased high, compared to surface rain gauges.



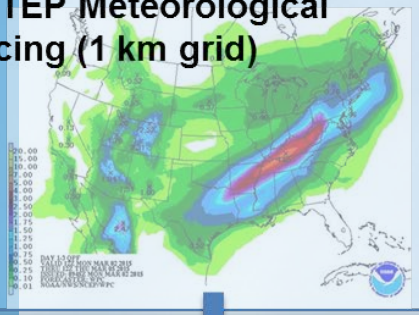
# Streamflow prediction with WRF-Hydro

NCAR

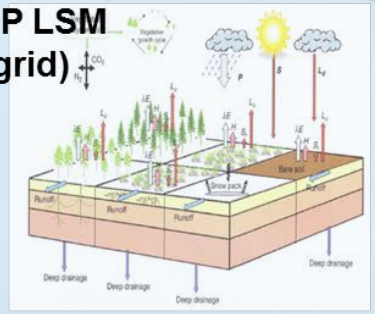
## Modeling Chain

WRF-Hydro is a hydrological model coupled with the WRF atmospheric model

1. STEP Meteorological Forcing (1 km grid)

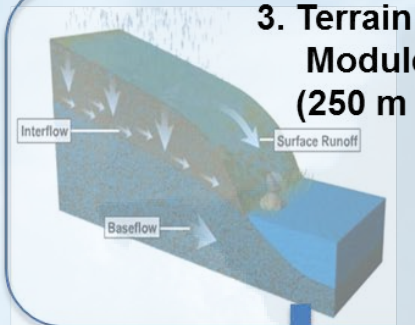


2. NoahMP LSM (1 km grid)



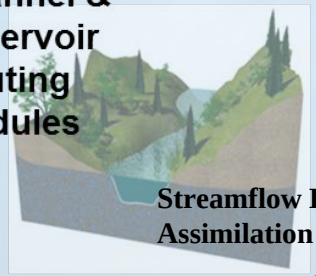
2-way coupling

3. Terrain Routing Module (250 m grid)

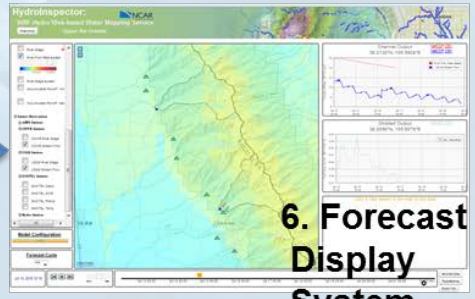



4. NHDPlus Catchment Aggregation (2.7M unique catchments and river reaches)

5. Channel & Reservoir Routing Modules

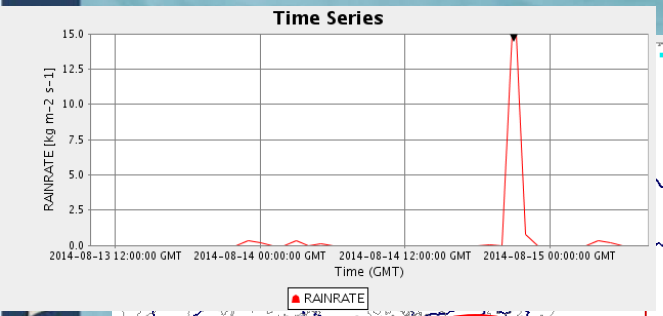


Streamflow Data Assimilation



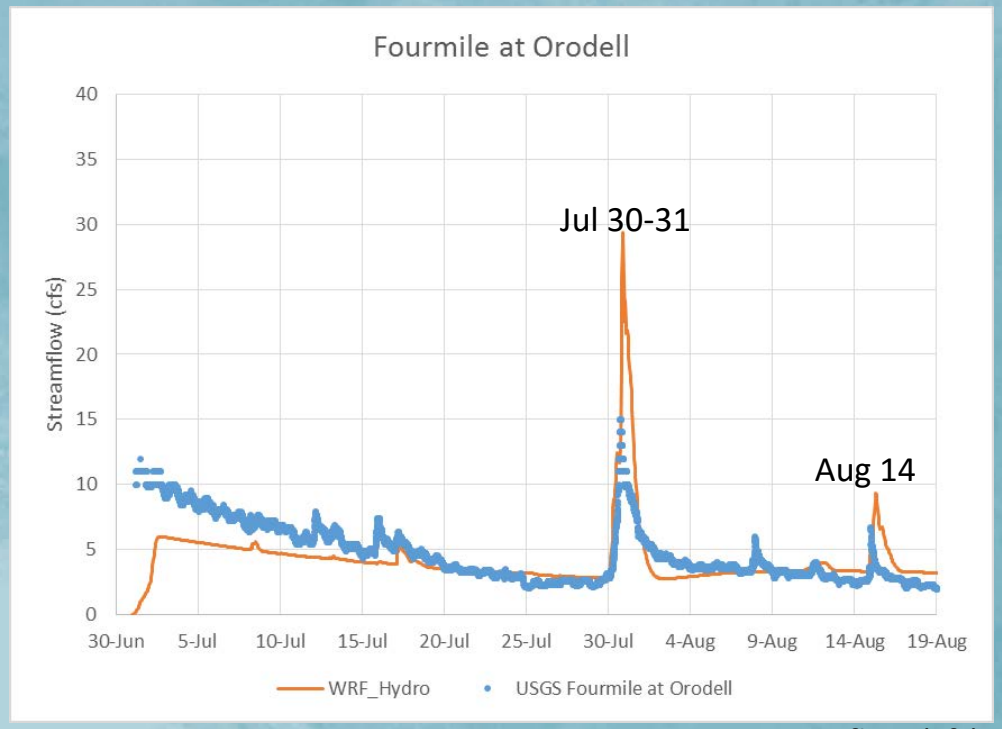
6. Forecast Display System

# 2014 Re-runs: Fourmile Canyon watershed






Precipitation Rate (mm/hr) Aug 14, 21Z



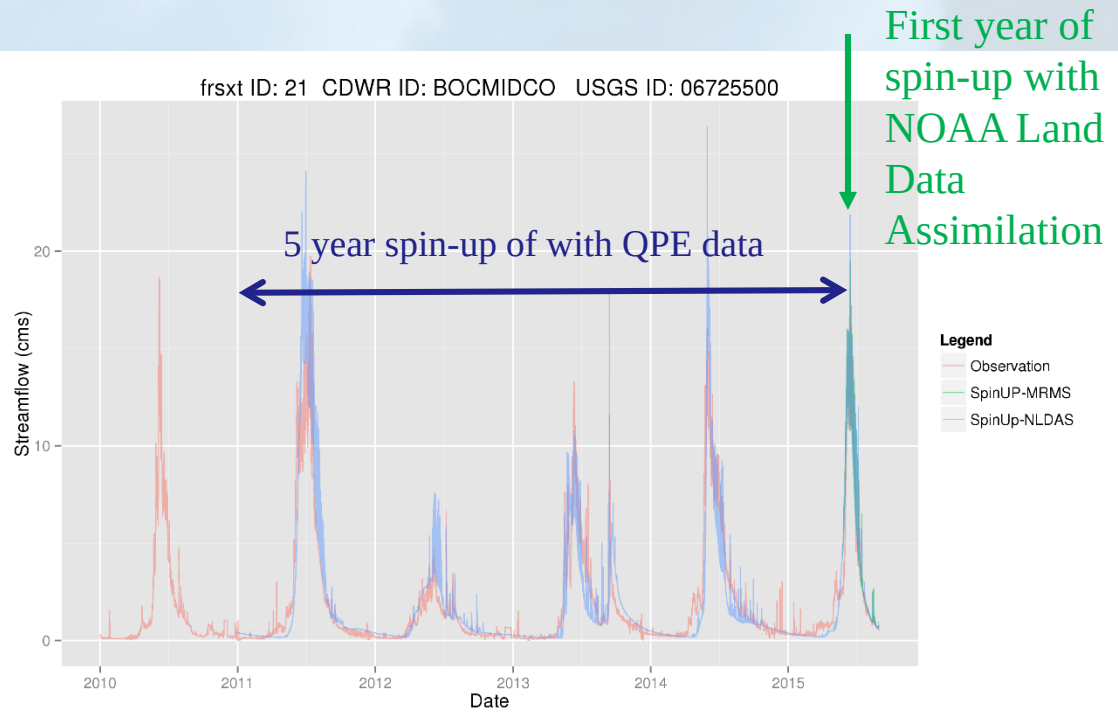

Streamflow (cfs)

# Streamflow prediction with WRF-Hydro

## Calibration Process

- Multi-year calibration period (2010-2015)
- Comparison of operational precipitation products
- Adjustment of key model parameters:
  - Infiltration factor
  - Drainage factor
  - Hydraulic conductivity
  - Surface water retention
  - Overland flow roughness

Predictions are produced every 15 min in real-time but it is an ongoing process to calibrate and optimize the model for the Colorado Front Range and urban basins.



# 2015

16 heavy rainfall and flash flood events

In 13 of the heavy rain events, storms were triggered by:

- collision of gust fronts,
- along stationary convergence lines
- or where gust front enhances convection along foothills

| DATE | Storm Trigger | Steering Level Wind (700mb) | Total PW (inches) |
|---|---|---|---|
| 1 June 2015 | Gust front collision produces squall line | 240º/5 kts | 0.67 |
| 4 June 2015 | West-moving gust front triggers/enhances convection along foothills | 210º/5kts | 0.7 |
| 11 June 2015 | South-moving cold front triggers convection | 290º/10kts | 1.02 |
| 15 June 2015 | Storms move off foothills west of Co Springs; no gust front evident | 30º/5kts | 0.86 |
| 24 June 2015 | Storm gust front off mtns collides with gust front from south | 260º/10kts | 0.68 |
| 9 July 2015 | Storms form above DCVZ stationary boundary | 225º/5kts | 0.94 |
| 10 July 2015 | Storm trains off mtns early; gust front collision later | 255º/5kts | 0.81 |
| 19 July 2015 | Storms originate over mtns; no obvious gust front | 300º/10kts | 0.95 |
| 21 July 2015 | Storms initiate above stationary boundary; organize into squall line | 210º/25kts | 0.98 |
| 1 August 2015 | Storms form above Palmer Divide; no gust front | 180º/10kts | 0.91 |
| 2 August 2015 | Gust front from mtn convection triggers storms in Denver Metro | 95º/5kts | 0.85 |
| 10 August 2015 | Gust front collision over Denver Metro | 30º/5kts | 0.84 |
| 11 August 2015 | Storms form above DCVZ | 175º/20kts | 0.93 |
| 14 August 2015 | N-NE moving gust front enhances storm over Lyons Festival | 170º/5kts | 1.04 |
| 15 August 2015 | Mesoscale boundary triggers storms south of Denver | 325º/10kts | 0.97 |
| 16 August 2015 | Storms over mtns move S-SE over Boulder; no gust front | 330º/5kts | 0.93 |
| | | | |

# Required NWP improvements for reliable “warn on forecast” of convective weather phenomena

- Data assimilation must accurately reproduce present storm location and intensity
- Data assimilation must accurately reproduce boundary layer convergence lines.
- Gust fronts from initial storms must be accurately predicted.
- Secondary convection triggered by thunderstorm outflows and convergence boundaries must be predicted
- Realistic precipitation rates must be predicted

# Summary

- The goal of the STEP program is to continually work toward improving 0-12 hr nowcast capabilities.
- NWP models not there yet  in providing “warn-on” forecasts for high impact weather.
- The 0-1 hr precipitation accumulation Autonowcaster nowcasts can provide the temporal and spatial specificity needed for increasing the lead time on issuing watches and warnings.
- Quality-controlled QPE is crucial for obtaining precipitation rate and intensity, and nowcasting the potential for flash floods and streamflow in a seamless system.
- A variety of verification of tools are essential for evaluating the performance of each component and the overall performance of the seamless prediction system.