Colorado Front Range Flood of 2013

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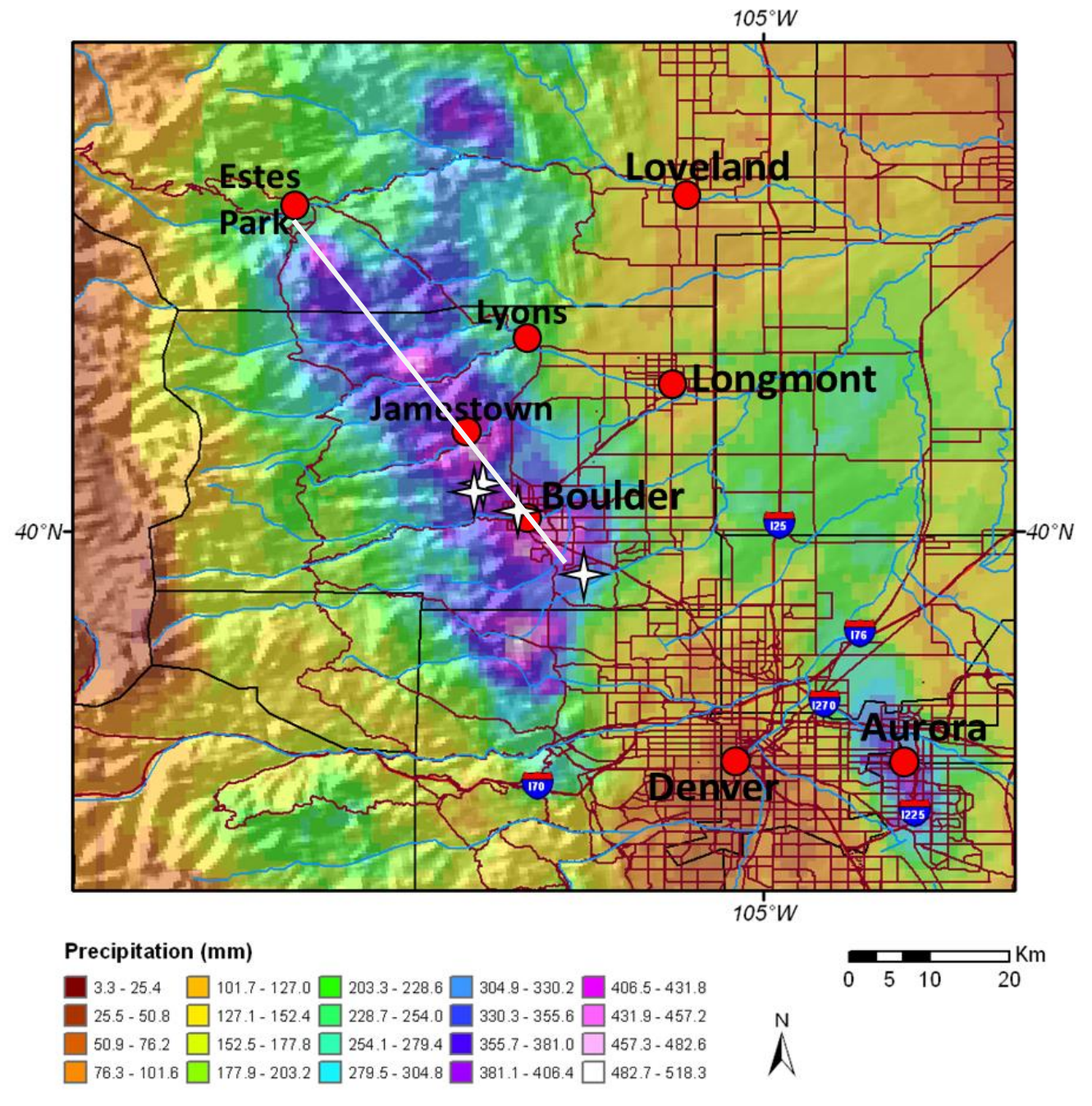
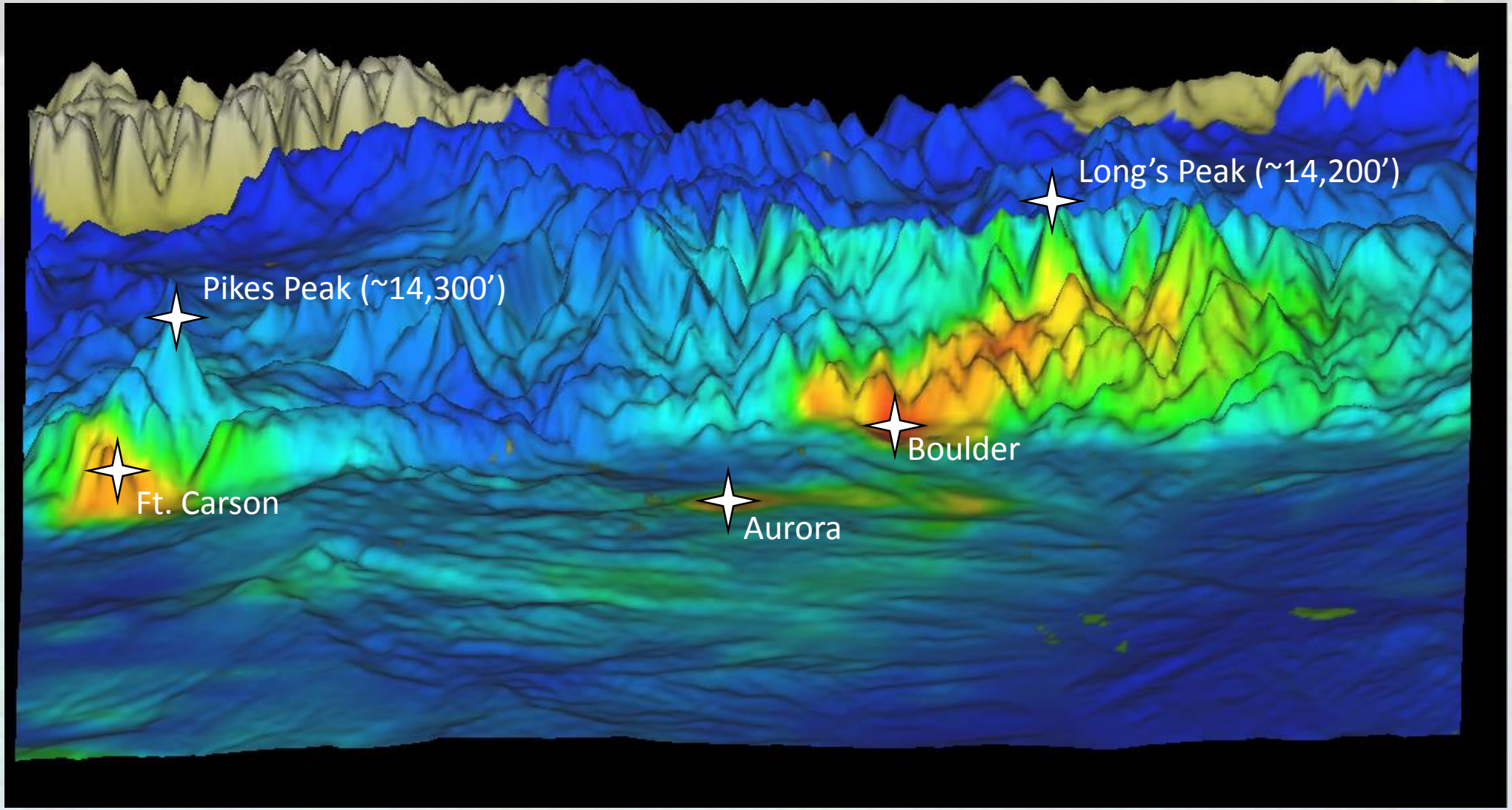
Total Precipitation:

- 9-17 September maximum total accumulation in excess of 18” (450 mm)
  - Similar to annual avg. precipitation for Boulder
  - Maximum 7-day rain totals est. 0.1% rainfall event (NOAA-HDC)
- SE-NW orientation NOT parallel to orographic barrier
- Multiple episodes
- Single day Colorado record 12.46” (Ft. Carson)
- ~ 6” up to 10,000’ (3300 m) AGL
- Multiple river drainages affected
- NOTE: disdrometer locations



Total Precipitation:

NOAA/NWS/MBRFC MPE 0-15 inches



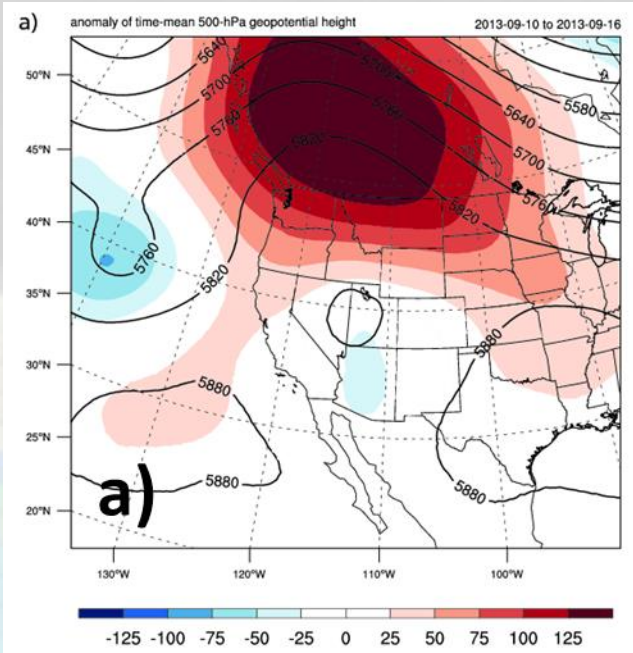
Impacts from the September 2013 Colorado Floods

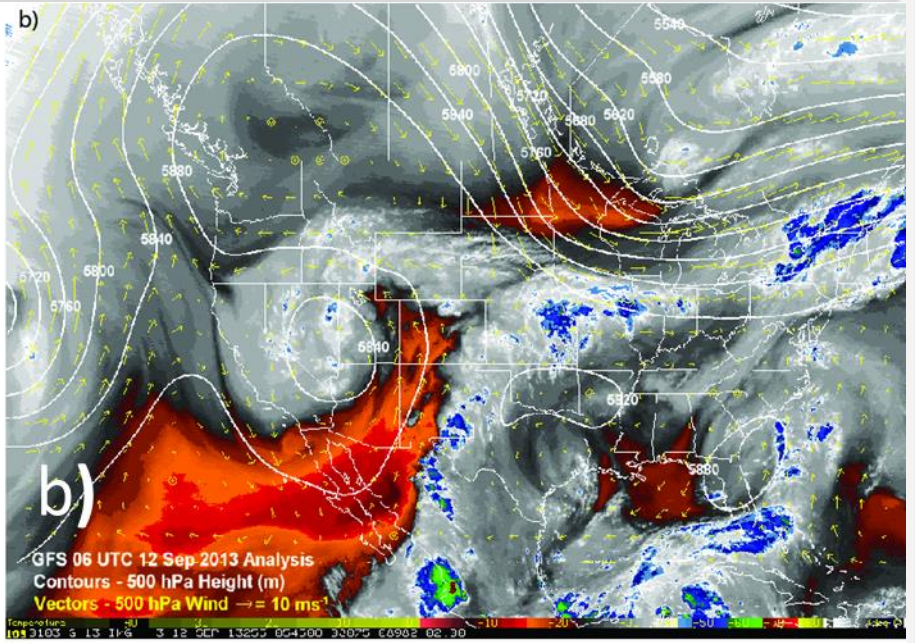
- Flooding less than 1.0% probability widespread across several counties
- 9 fatalities
- 18 Federally declared county disaster areas
- > 18,000 people forced to leave homes
- Est. ~ $2B dollars in damage
- > 400 mi transportation corridors destroyed
- 1100 debris flows

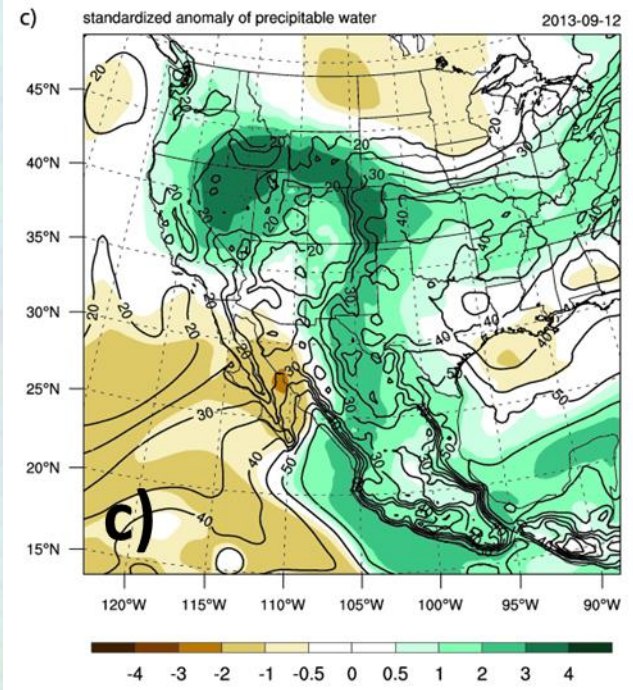
Synoptic setting: An unusual circulation…

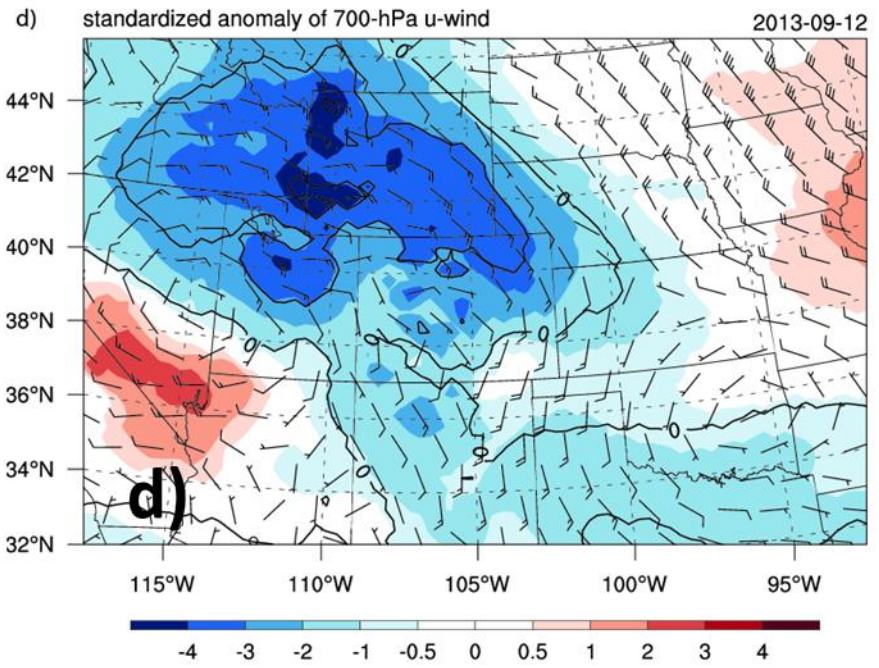
- Strong blocking ridge over western N. America associated with 3-days of record heat in Denver
- Cutoff low drifted under ridge
- Northward flow on western subtropical high in combination with cutoff low tapped monsoon/tropical moisture
- Long E-W baroclinic zone across upper Midwest localized convergence in north-eastern Colorado

Courtesy Russ Schumacher, CSU

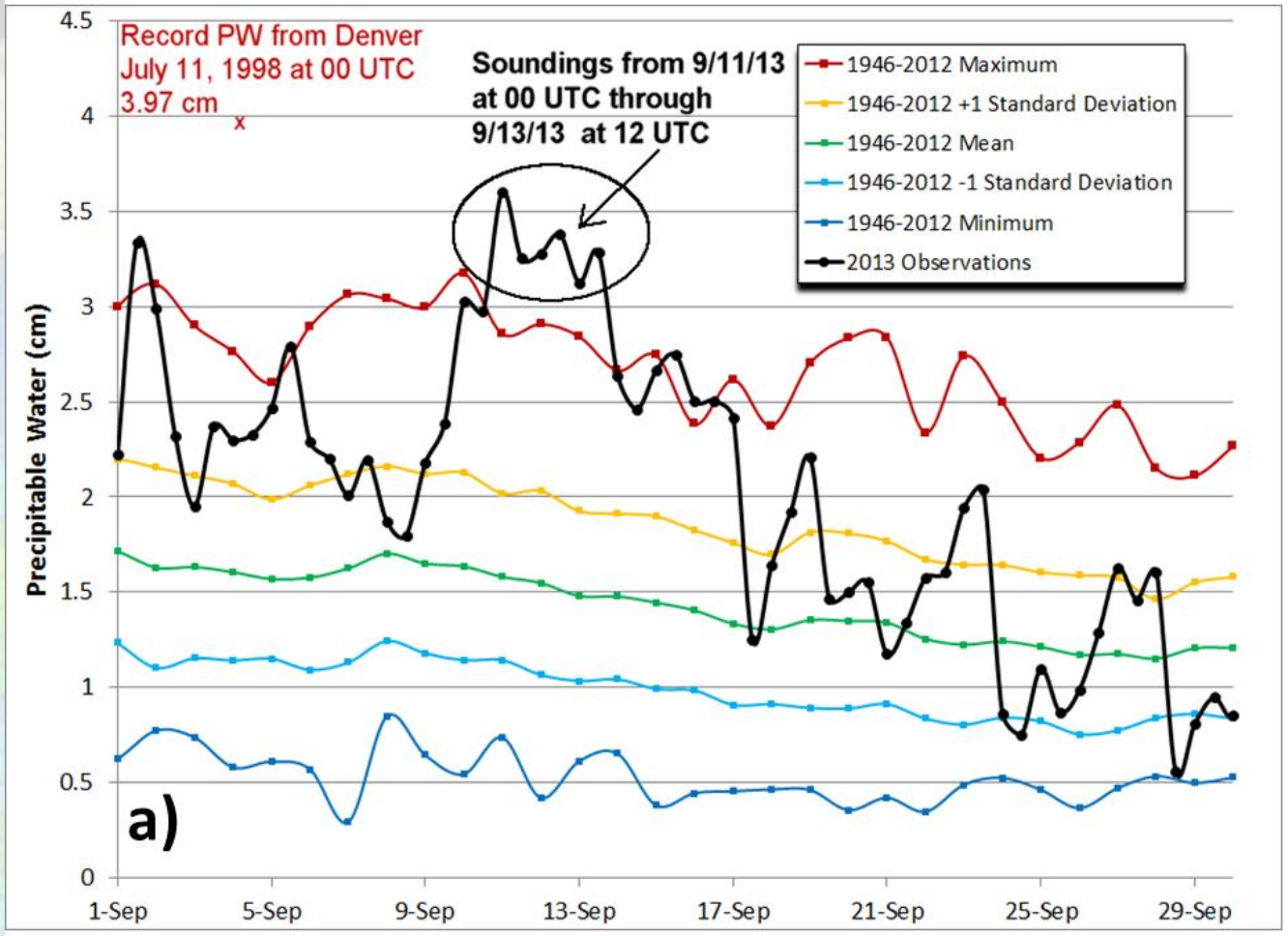


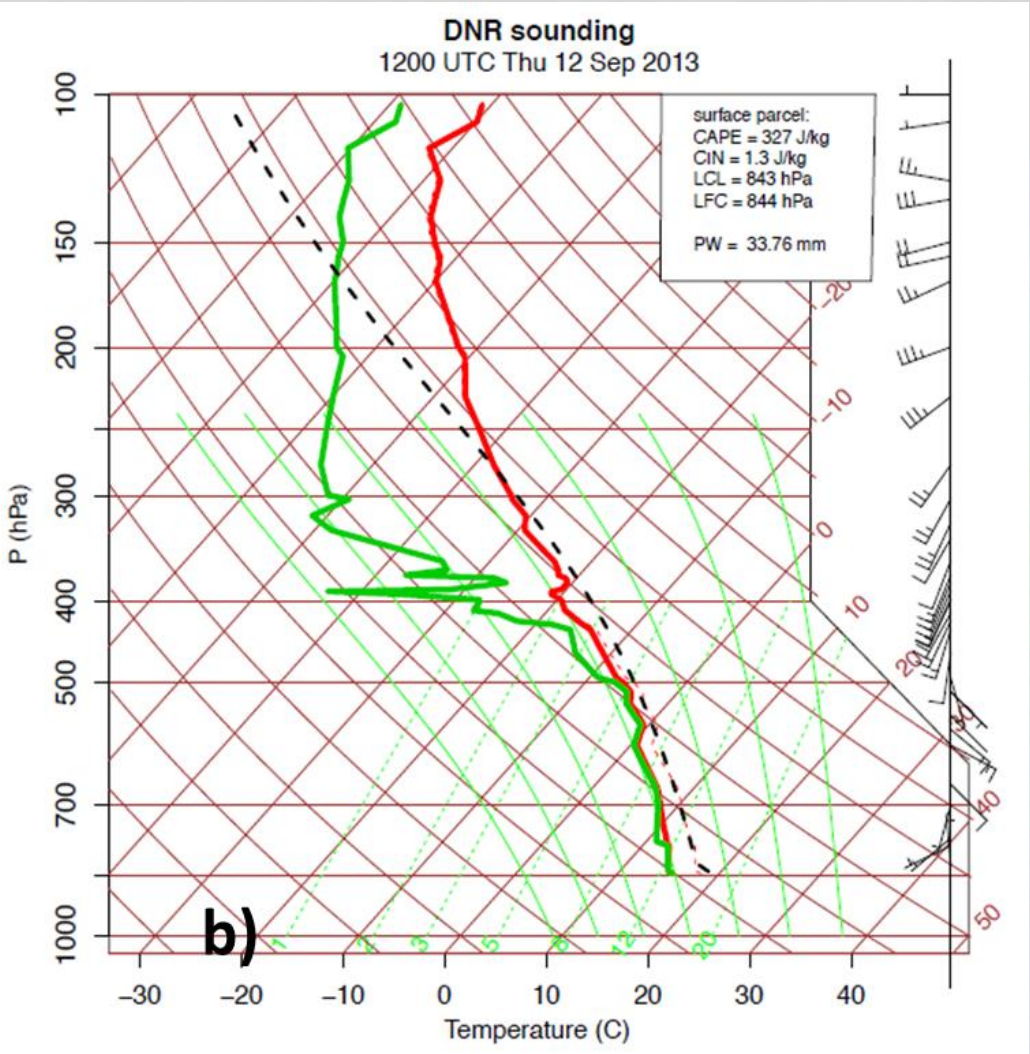






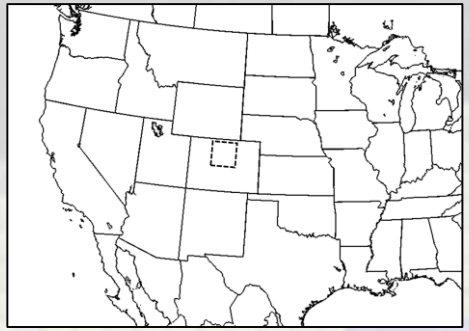
Synoptic Setting: Record Moisture….

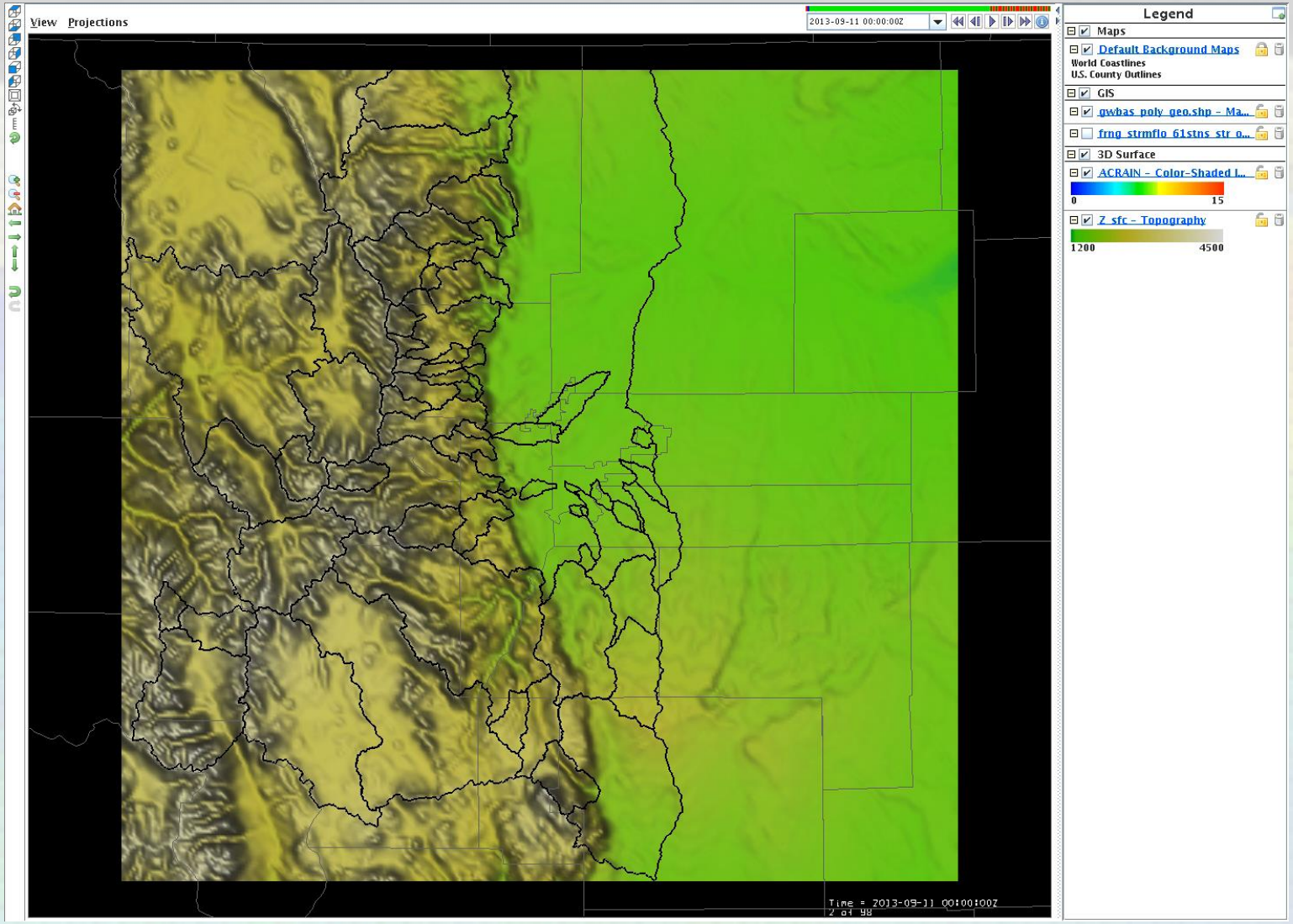




Courtesy Russ Schumacher, CSU

Chronology of rainfall…

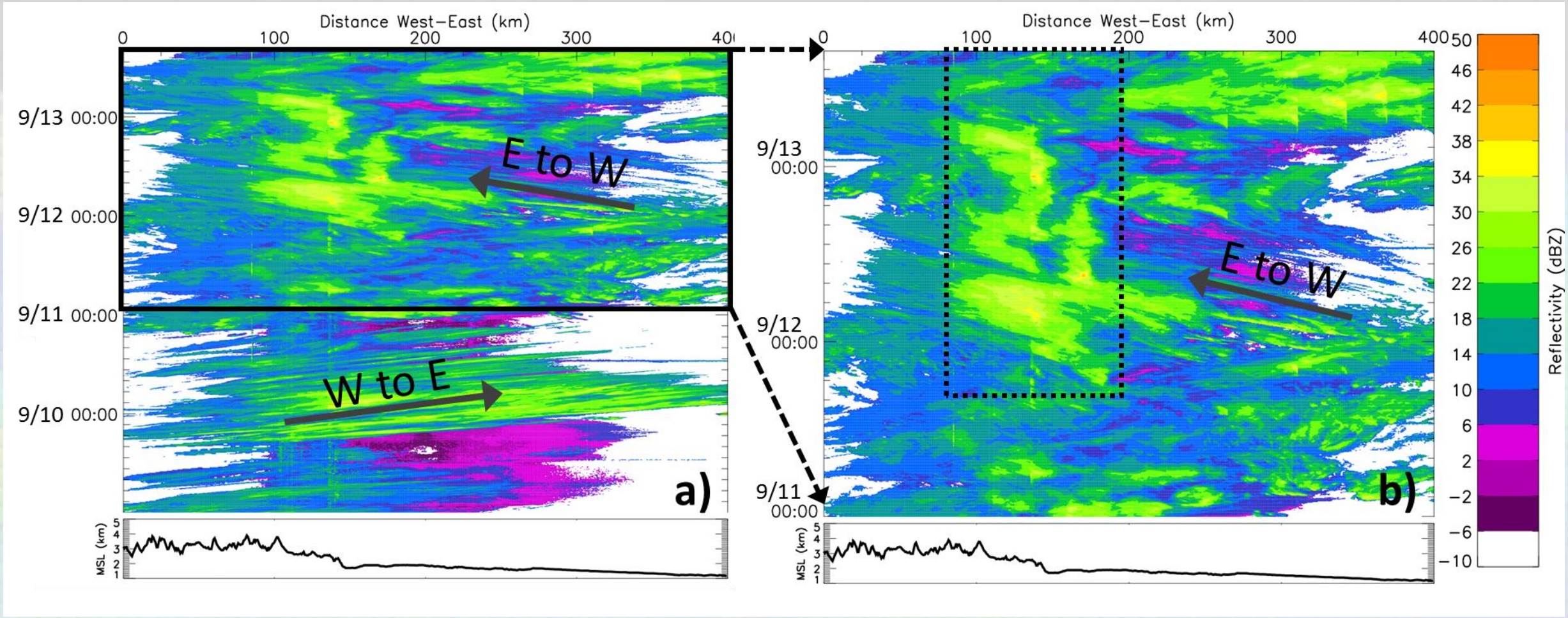




NOAA-MBRFC Hourly MPE accumulated rainfall from 00z 9/11 through 00z 9/13

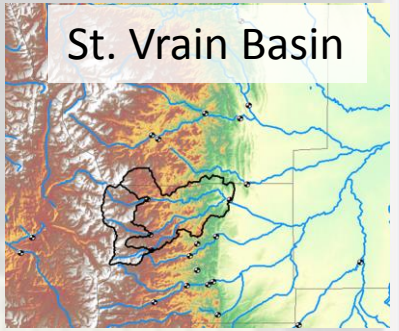
Chronology of rainfall…

Courtesy Katja Friedrich, CU

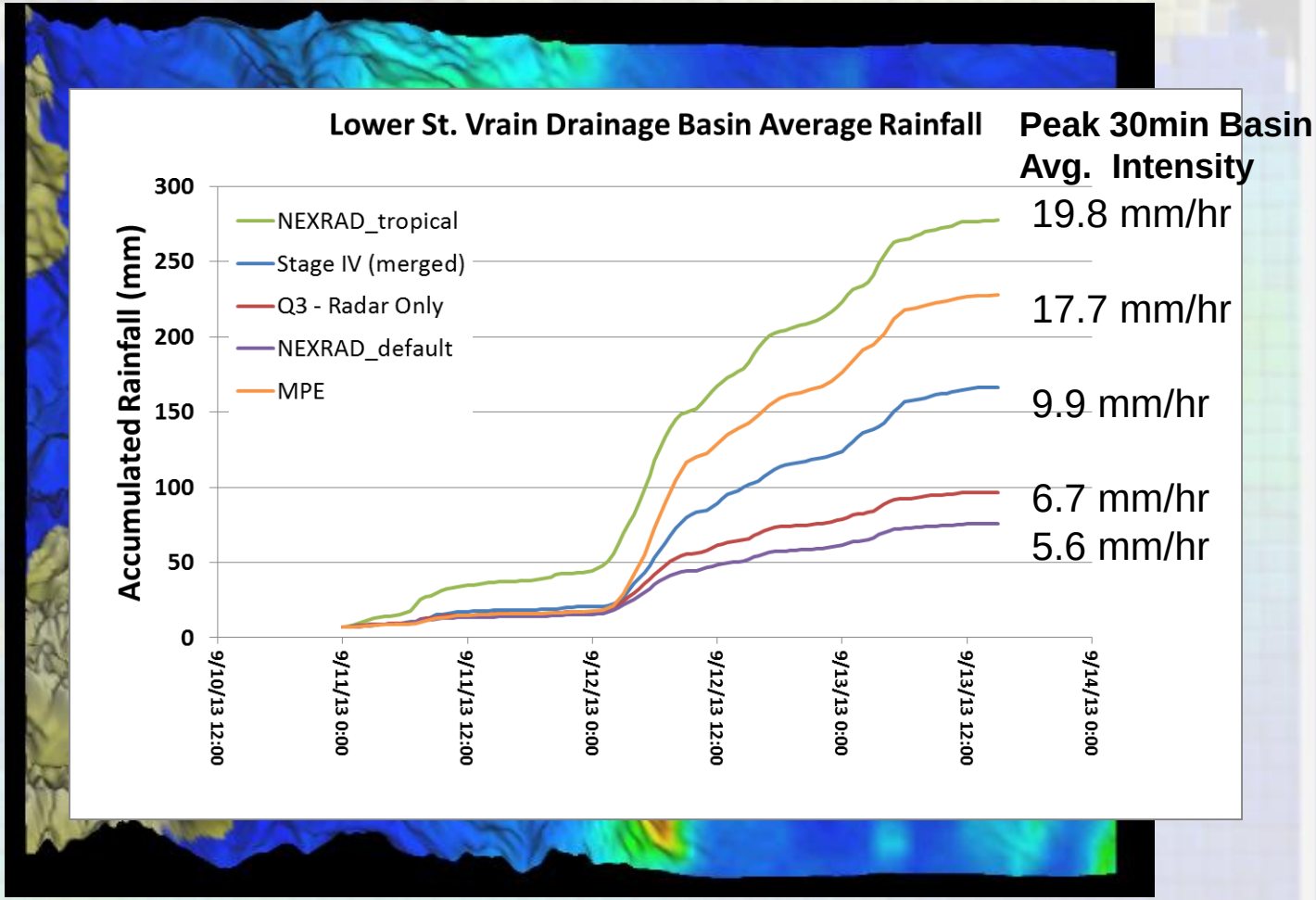


- **Multiple regimes**
- **Flow reverses late on 9/11 with E-W track**
- **Stationary, persistent, retraining echoes persist along mountain front**

QPE Uncertainty….

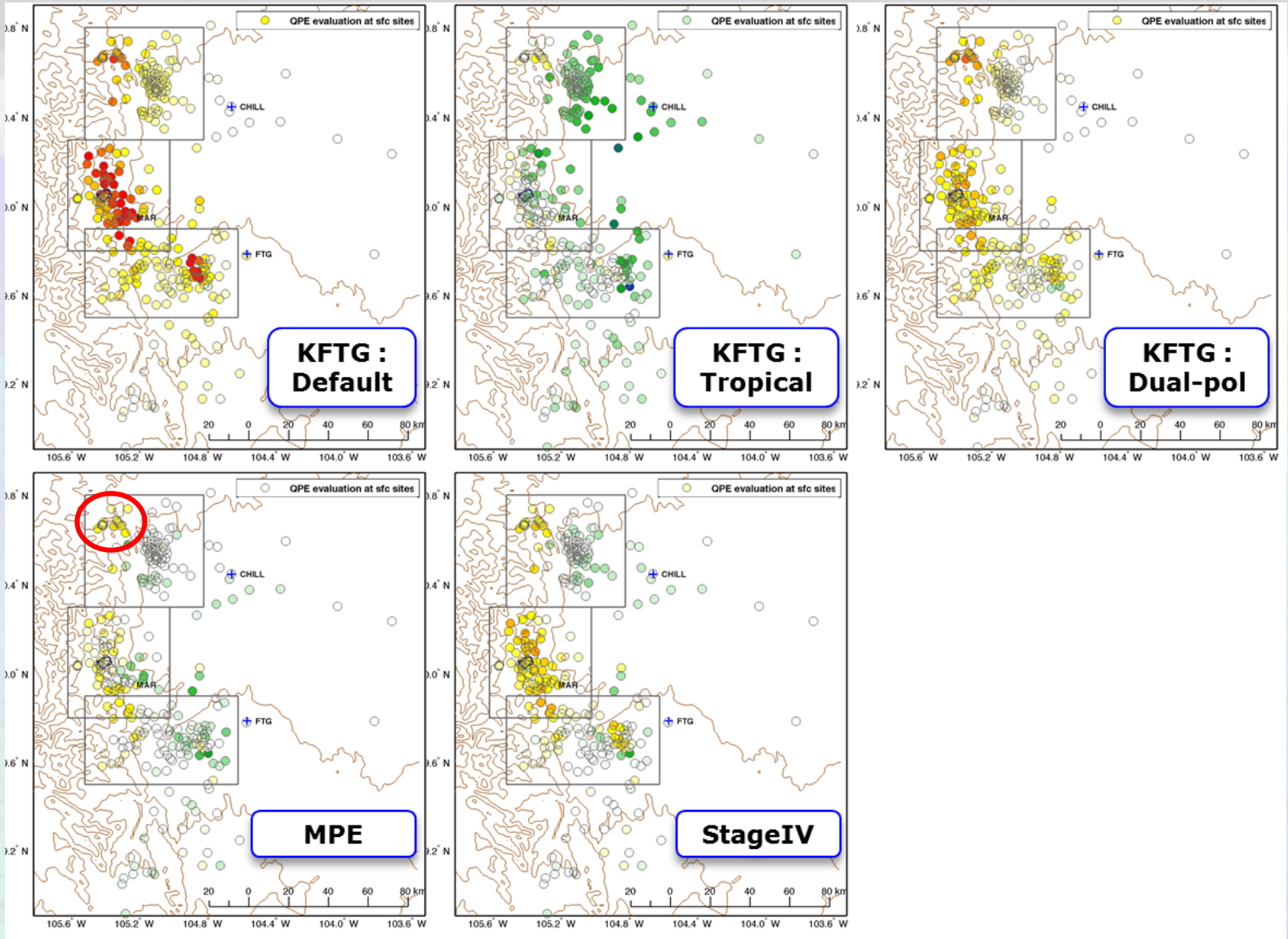


- Massive uncertainty in operational QPE products during the event
  - NEXRAD (2 Z-Rs, 1 dual-pol)
  - Q3
  - Stage IV
  - MPE
- Factor of 5 difference in basin average rainfall (St. Vrain)



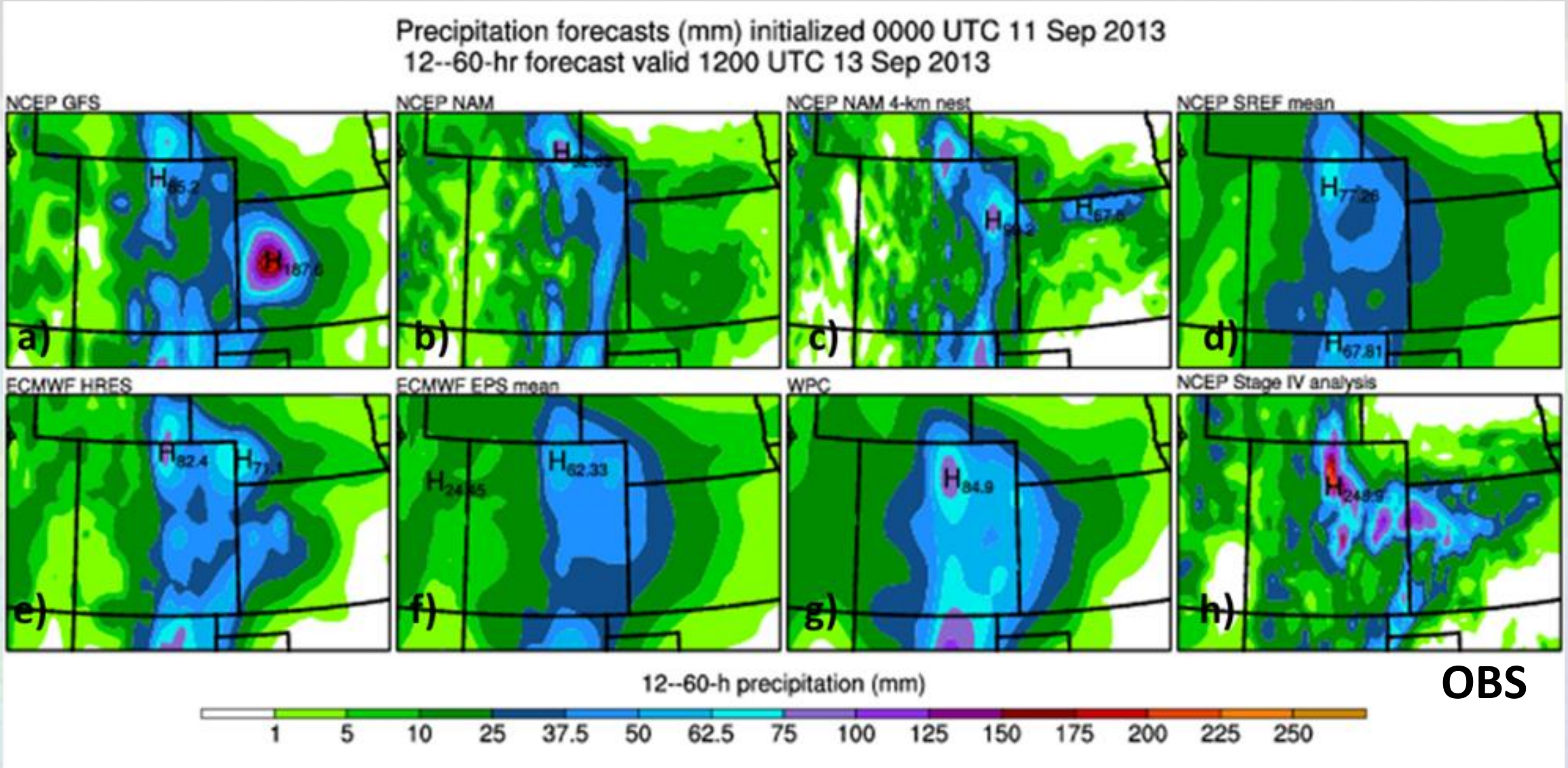
QPE Uncertainty….

- Massive uncertainty in operational QPE products during the event
  - NEXRAD, Q3, Stage IV, MPE
  - Evaluation of these products currently underway
- Large uncertainty in QPE translates in to large uncertainty in *simulated* flows



QPF Uncertainty….

Courtesy Russ Schumacher, CSU

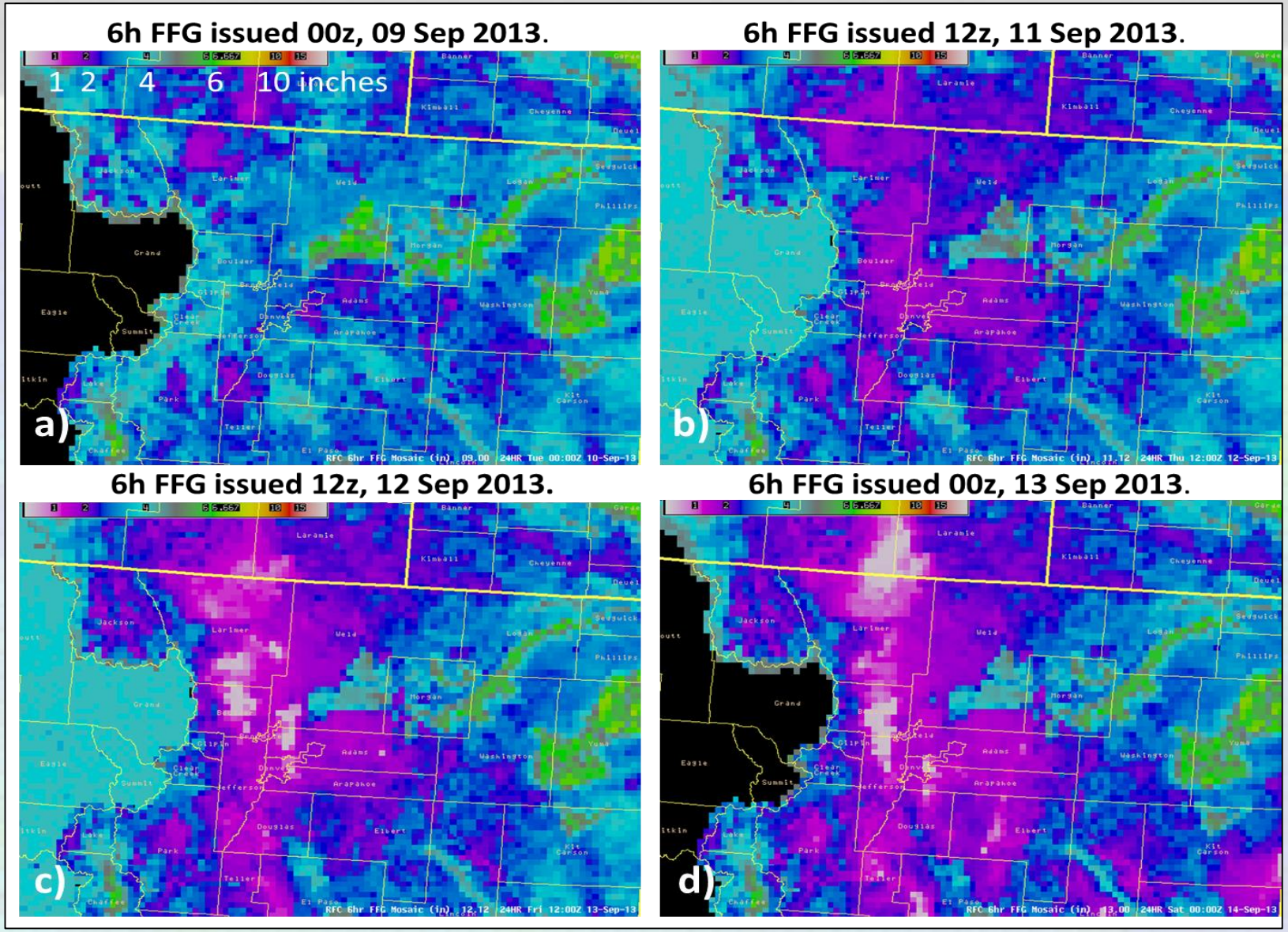


OBS

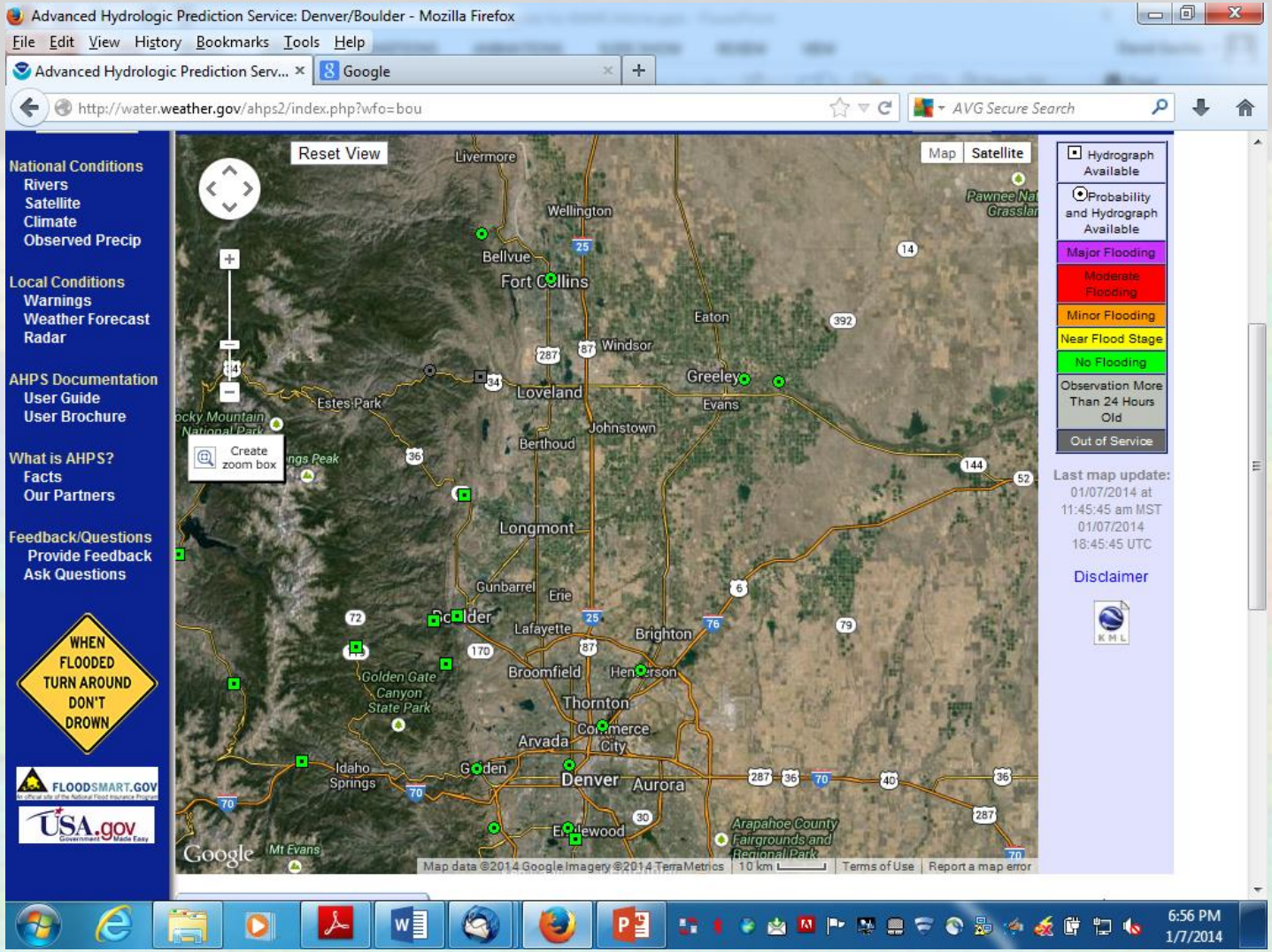
Flood prediction….

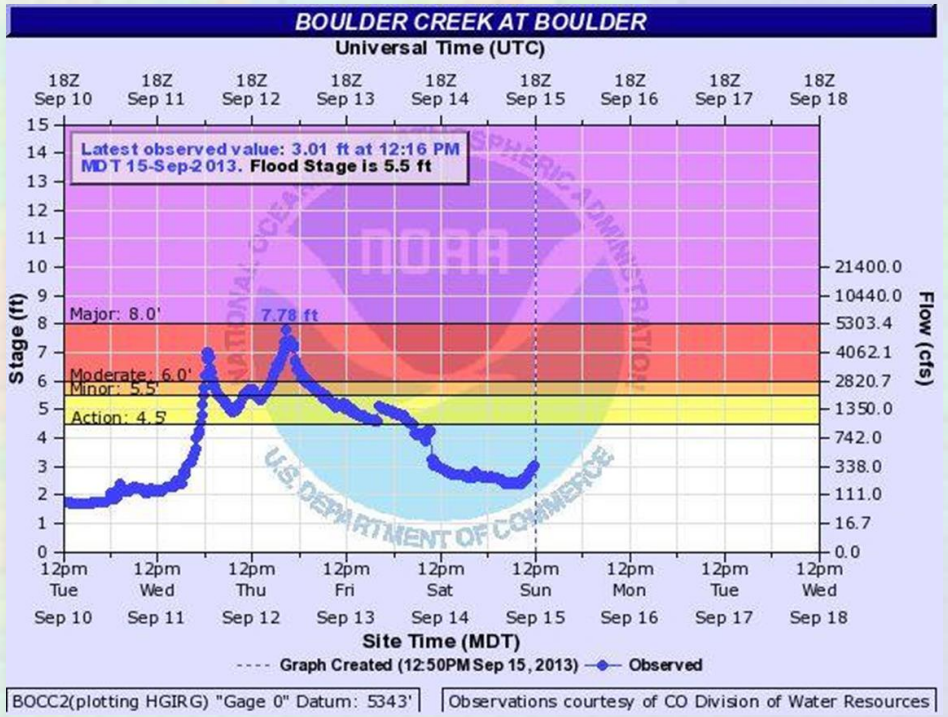
Courtesy NOAA/NWS/MBRFC

- Soil reached saturated level (akin to peak snowmelt season) at 10,000’
- MBRFC Flash Flood Guidance captured progressive saturation and lowered flood thresholds from 5” to less than 0.25”



Map of existing River Forecast Points



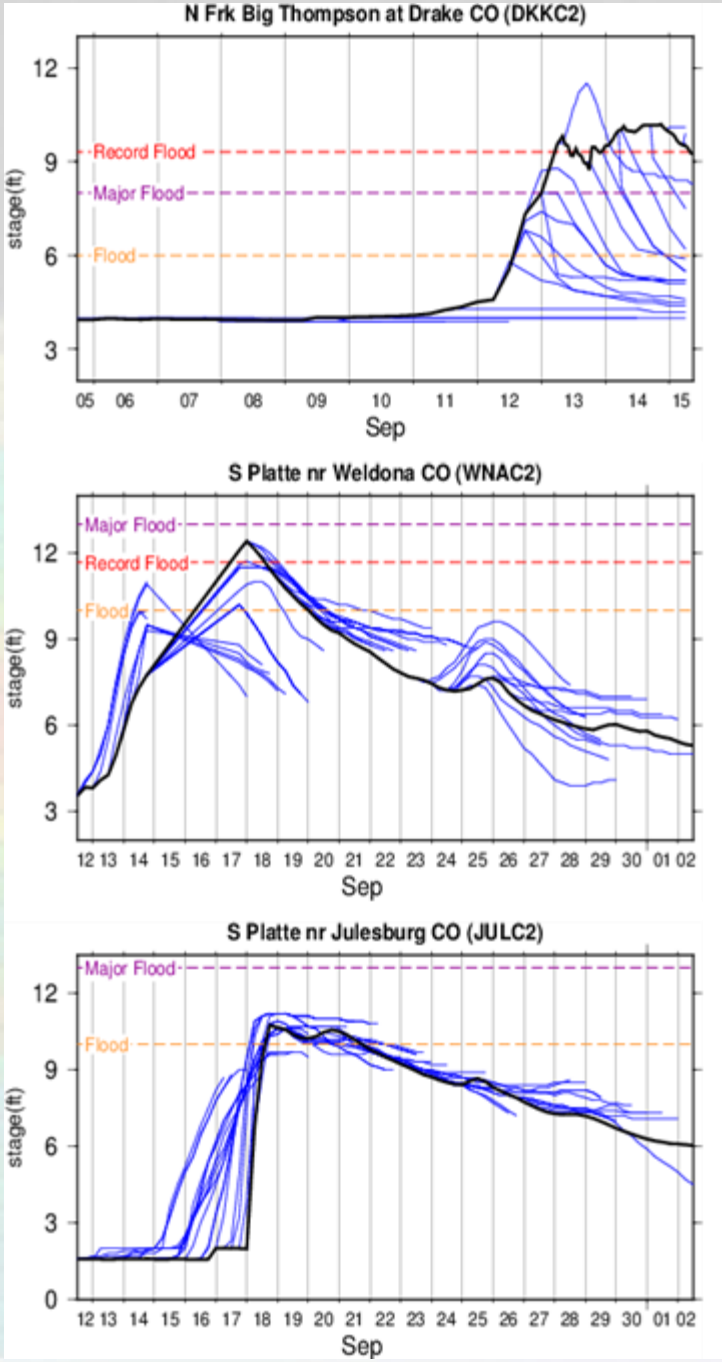


NWS hydrologist was quickly overwhelmed with > 12 'site specific' flood models during event…

Flood prediction….

- MBRFC streamflow forecast exhibit no prediction of flood until event begins in mountain watersheds
- Successive forecasts have too aggressive recession

- Large-river forecasts perform better as flows are already ‘in-the-system’
- Propagation to Julesburg (Neb. Border) handled reasonably

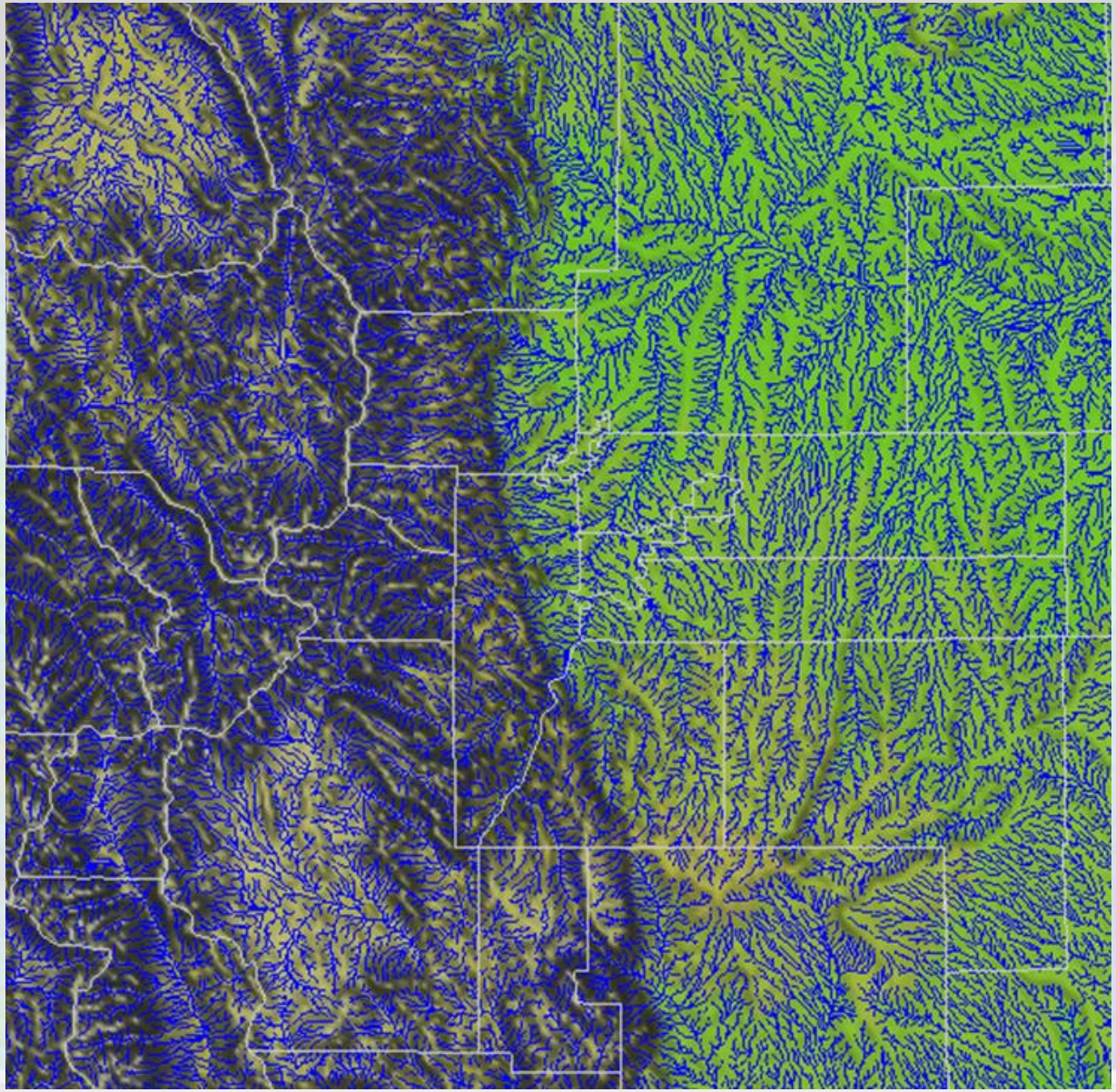


Courtesy NOAA/NWS/MBRFC

Fully-coupled Hydrometeorological Prediction

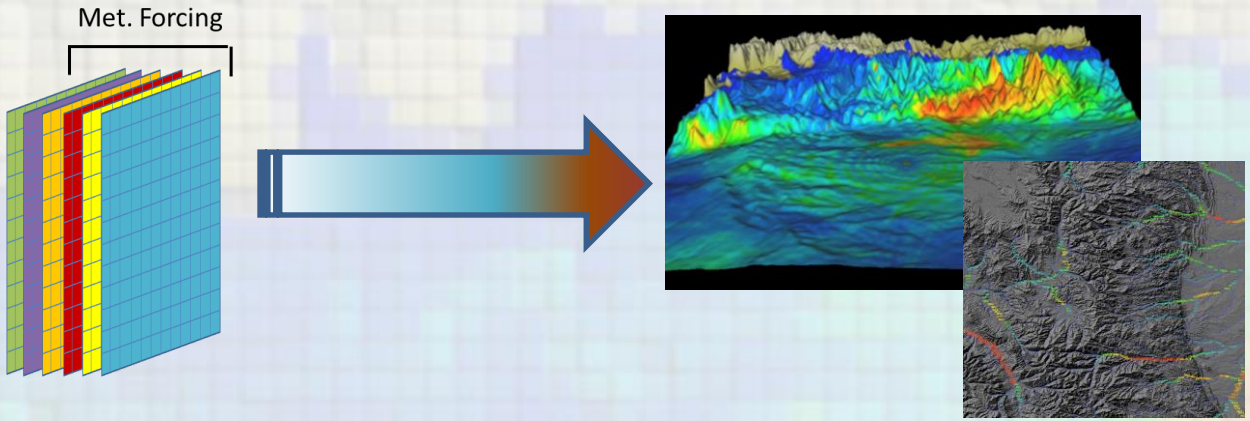
- WRF v3.5:
  - 16, 4, 1 km nests
  - Thompson MP
  - Noah LSM w/ WRF-Hydro routing modules
  - Initialized 00z Sep. 11
  - 48 hour forecast
  - NOAA/NCEP GFS boundaries and initial conditions

- WRF-Hydro configuration:
  - 100m grid (active on 1km WRF grid)
  - Diff. wave overland and channel
  - Gridded Boussinesq GW
  - Simple ‘pass-through’ baseflow
  - Noah LSM (coupled)
  - Noah MP (uncoupled)

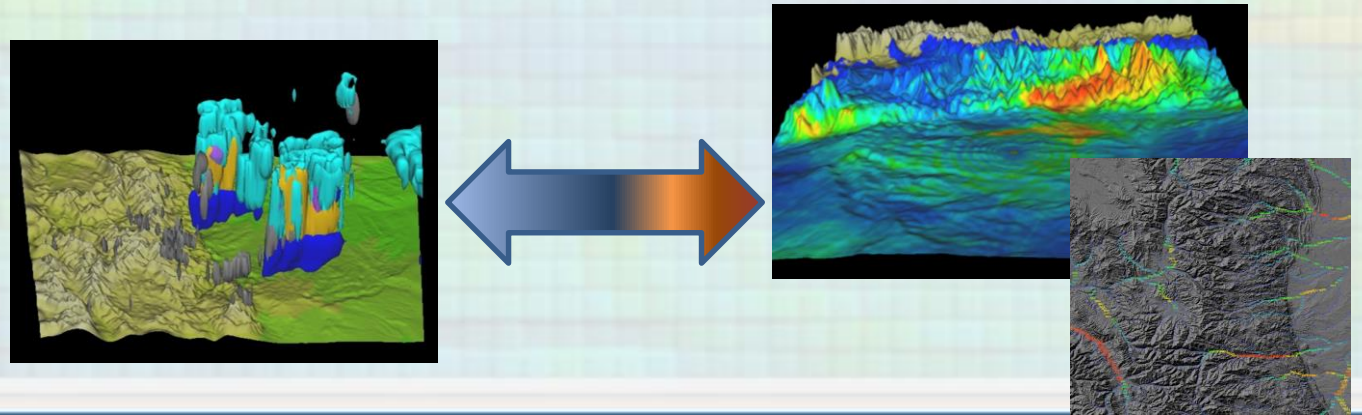


WRF-Hydro Application:

One-way ('uncoupled') →



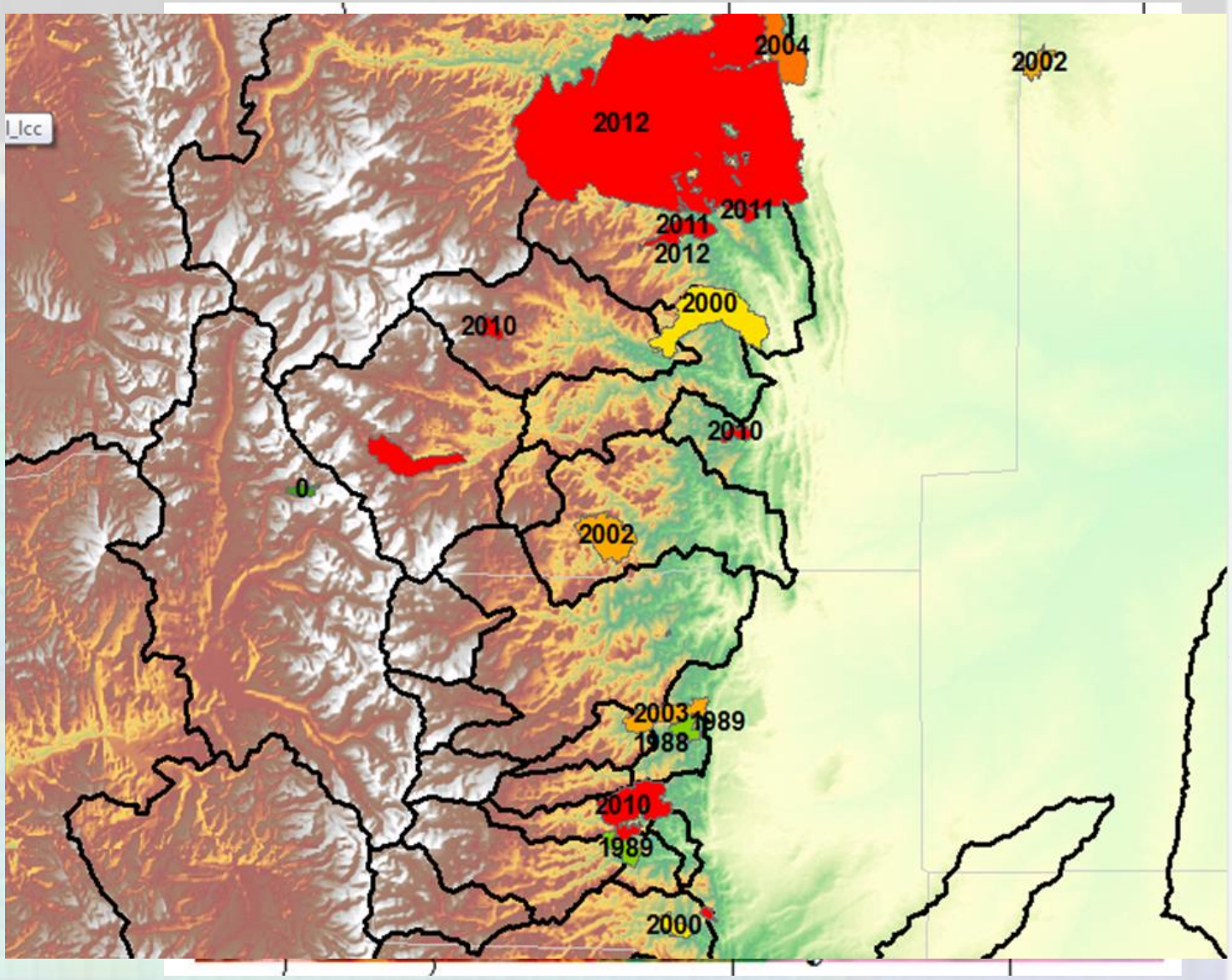
Two-way ('coupled') ↔



- Modes of operation..1-way vs. 2-way
- Model forcing and feedback components:
  - Forcings: T, Press, Precip., wind, radiation, humidity, BGC-scalars
  - Feedbacks: Sensible, latent, momentum, radiation, BGC-scalars

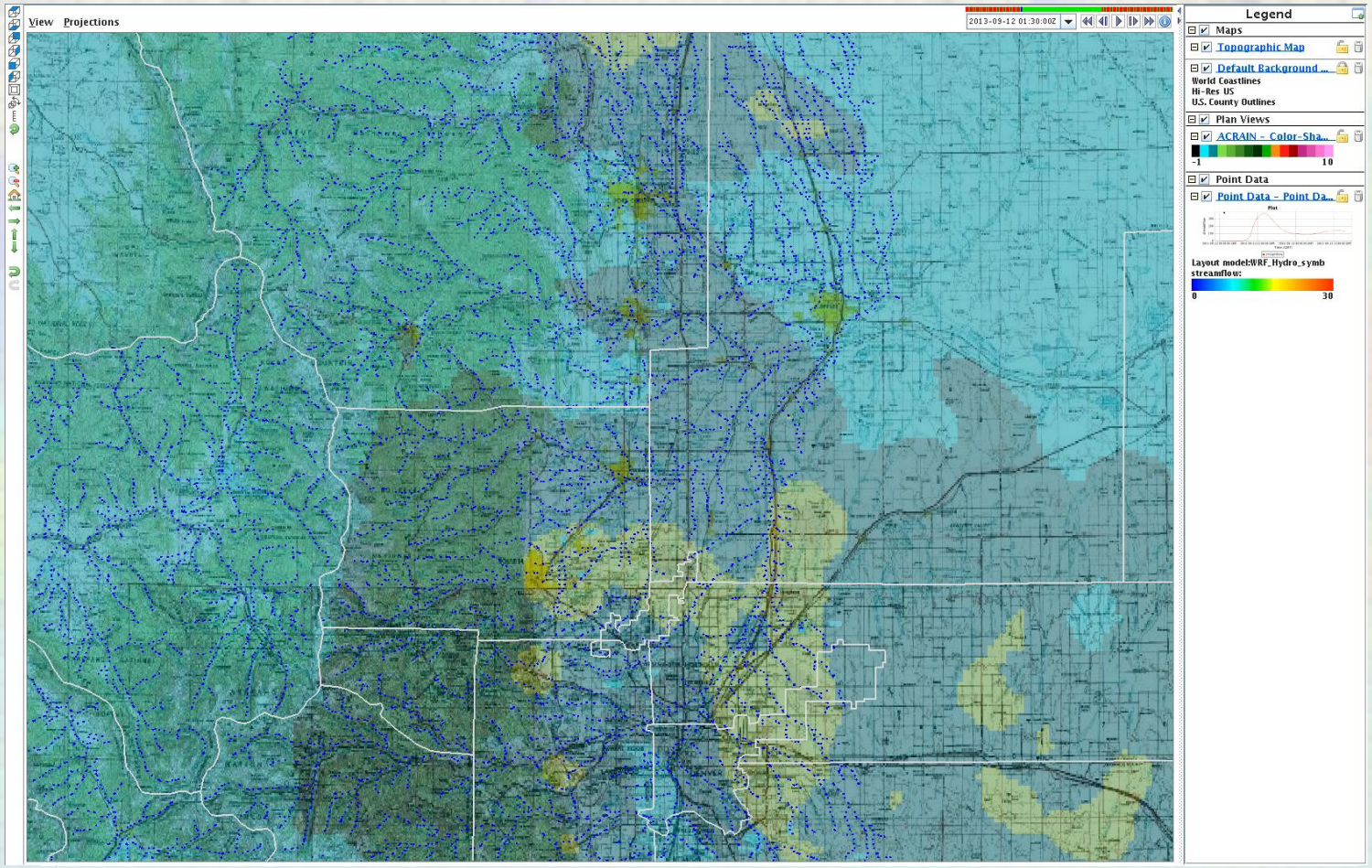
Fully-coupled Hydrometeorological Prediction

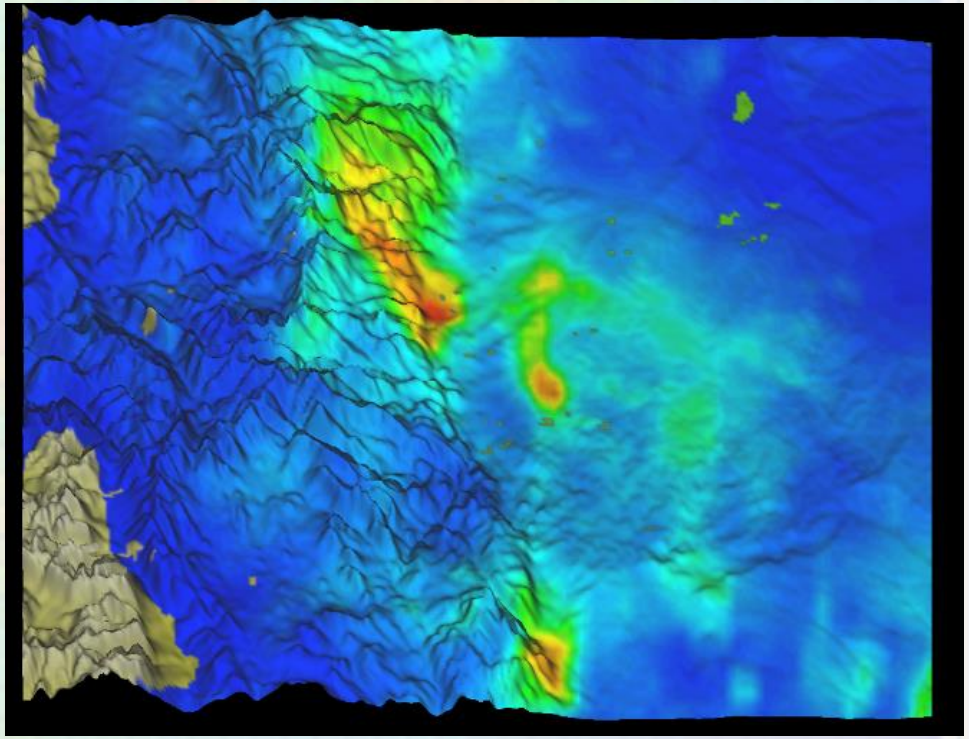
- Antecedent model setup, calibration and validation:
  - Polarimetric radar QPEs (CSU-CHILL & NOAA-ESRL)
  - Post-wildland fires in Front Range
  - Urban Flooding in Denver
- Hydraulic parameter sets geographically regionalized across following regimes:
  - Plains
  - Foothills
  - High mountains
  - Urban catchments
  - Burn severity in recent burn areas



WRF-Hydro Applications:

1. Regional Flood Forecasting - Sep. 2013 Front Range



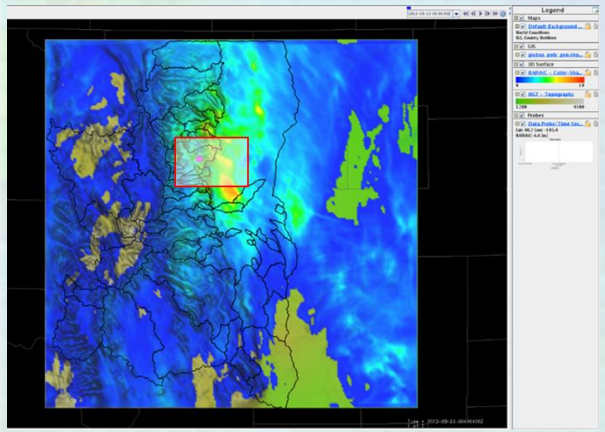


MPE – driven WRF-Hydro, Sep 11-13, 2013

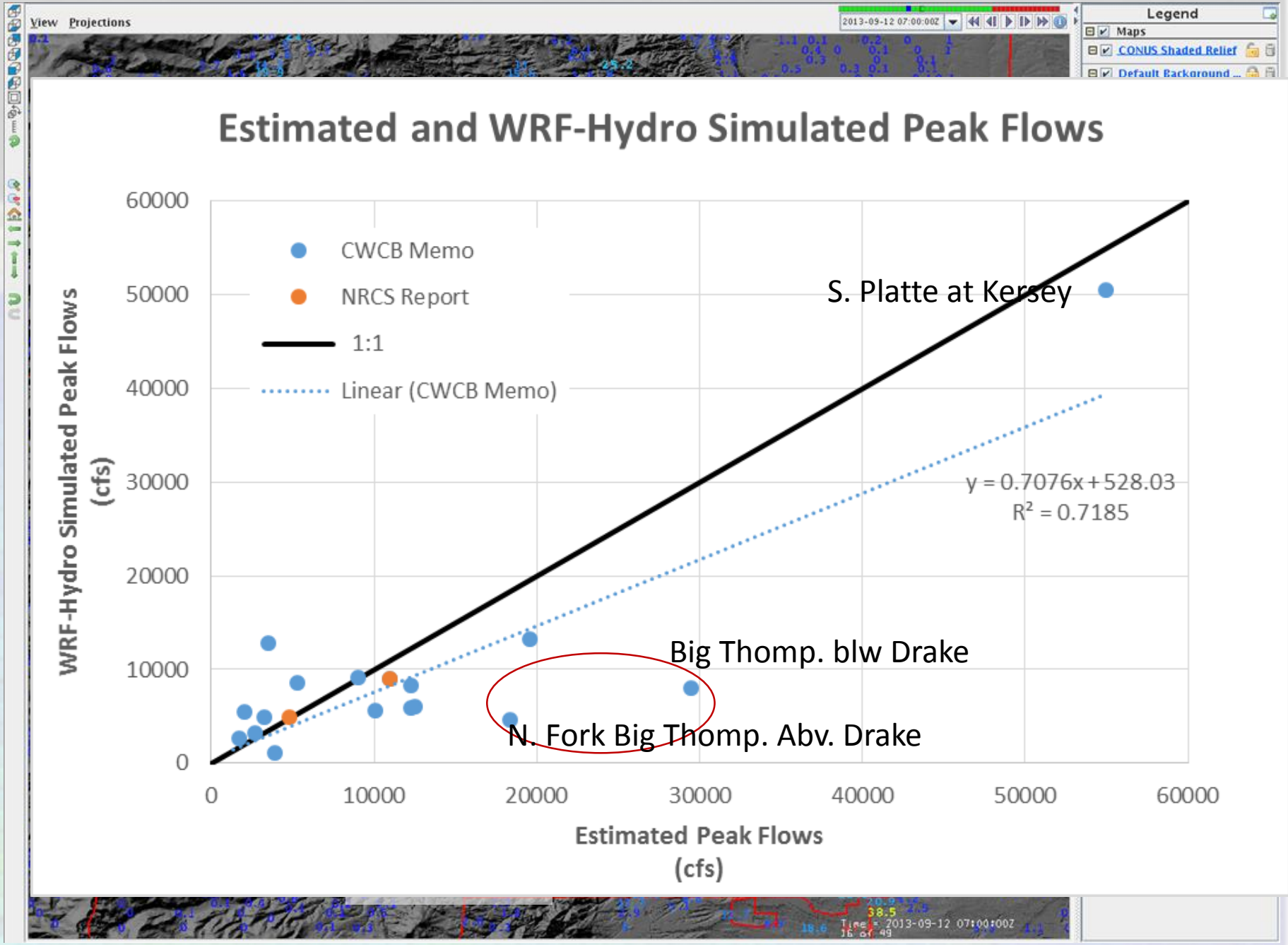
Forecasted streamflow coupled WRF/WRF-Hydro model

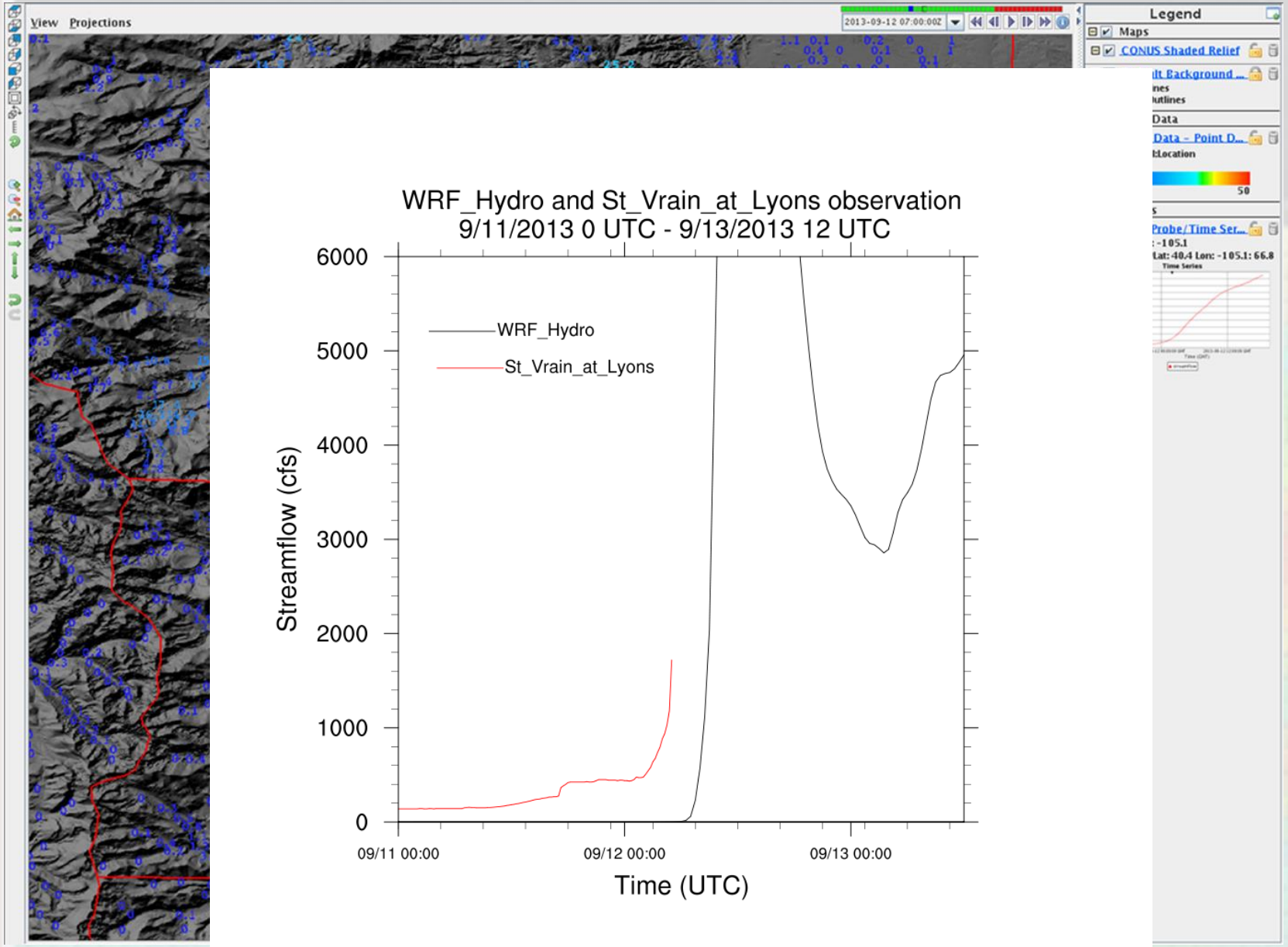
Initialization: 9/11 00z

Valid: 9/12 07z



Streamflow in cms





Validating Storm flow Simulations

MPE

CDWR Estimated Peak Flows:

Boulder Cr. in town: ~5300 cfs
Fourmile Canyon:?
James Creek: 3,300 cfs
Lefthand Creek: 3,520 cfs
St. Vrain: 19,600 cfs

Forecasted accumulated rainfall:

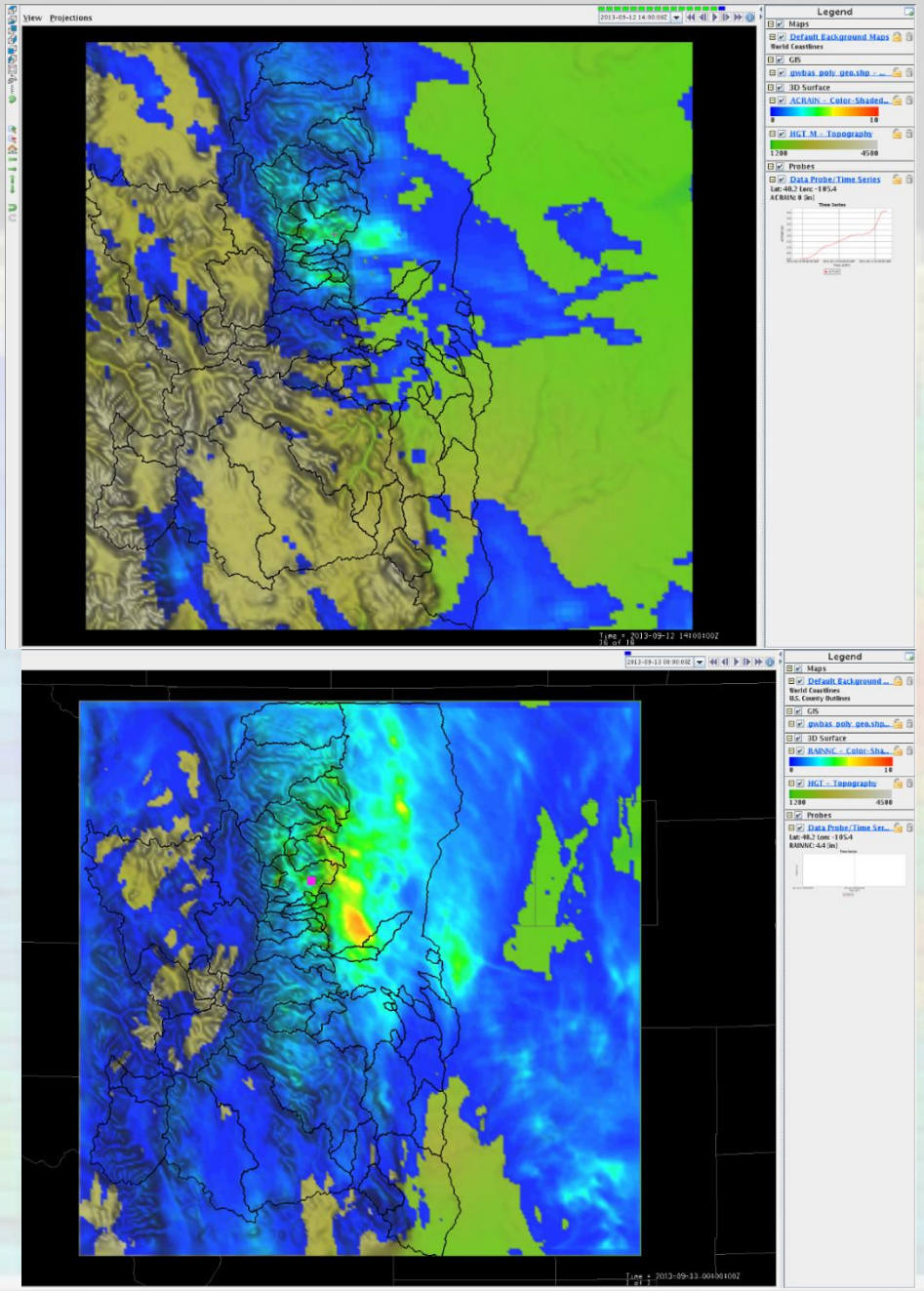
Uncoupled NOAA-ESRL HRRR:
15-hr Initialized:
9/11 23z (1700 LT)

Coupled WRF/WRF-Hydro model

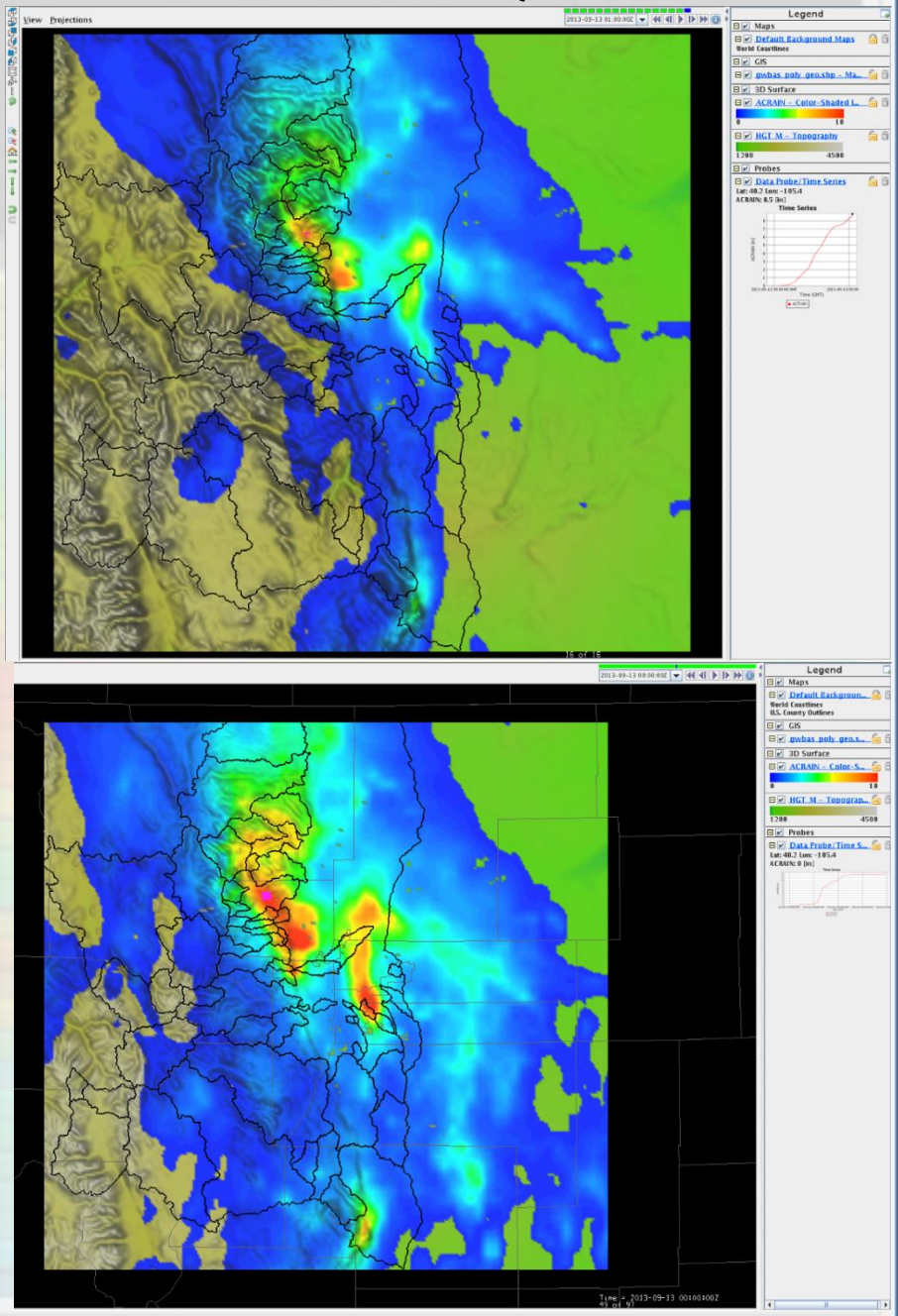
Initialization:
9/11 00z

Valid: 9/12 07z

Forecast



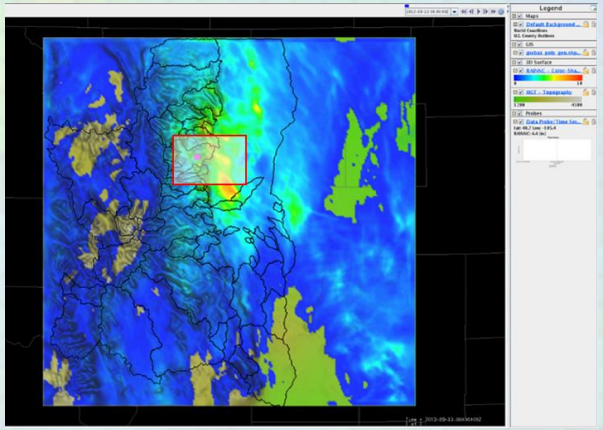
NEXRAD QPE



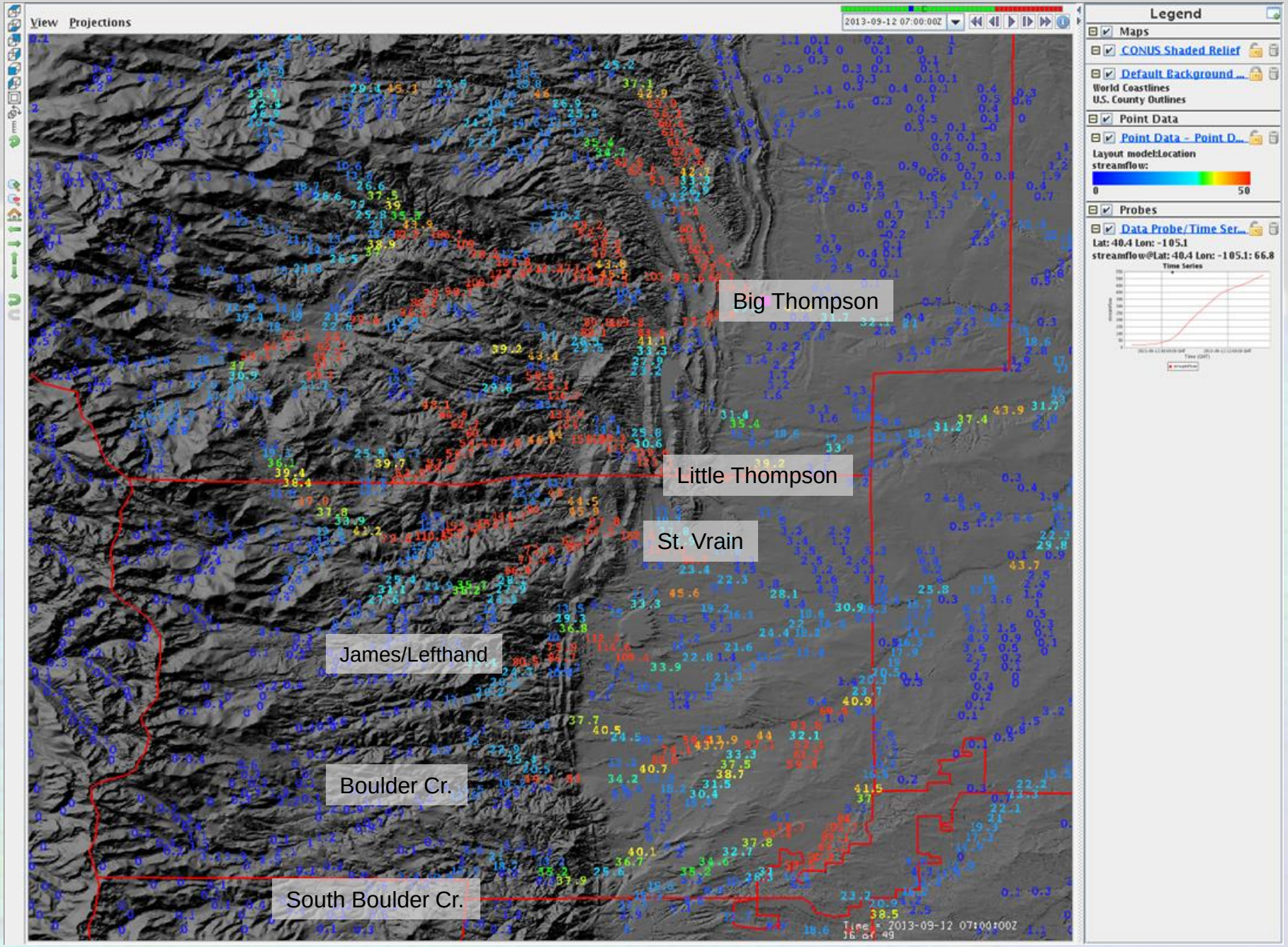
Forecasted streamflow coupled WRF/WRF-Hydro model

Initialization: 9/11 00z

Valid: 9/12 07z



Streamflow in cms



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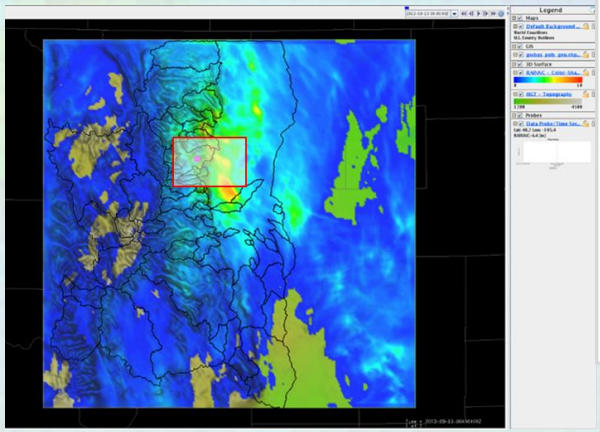
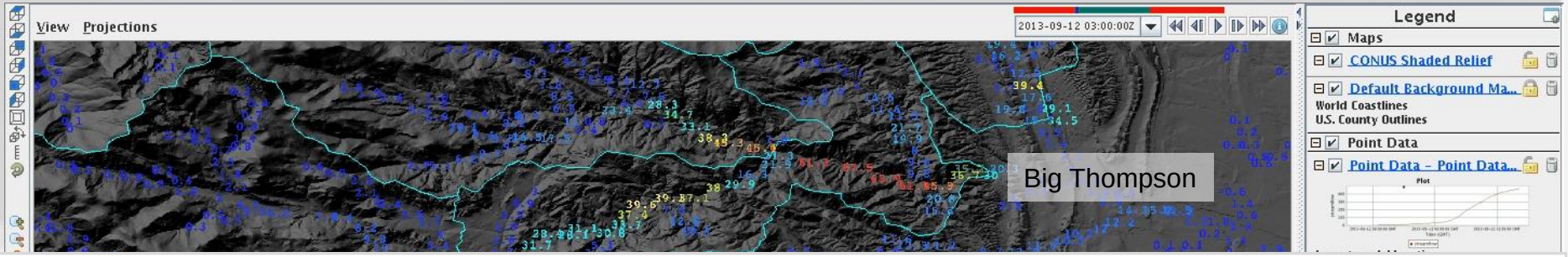
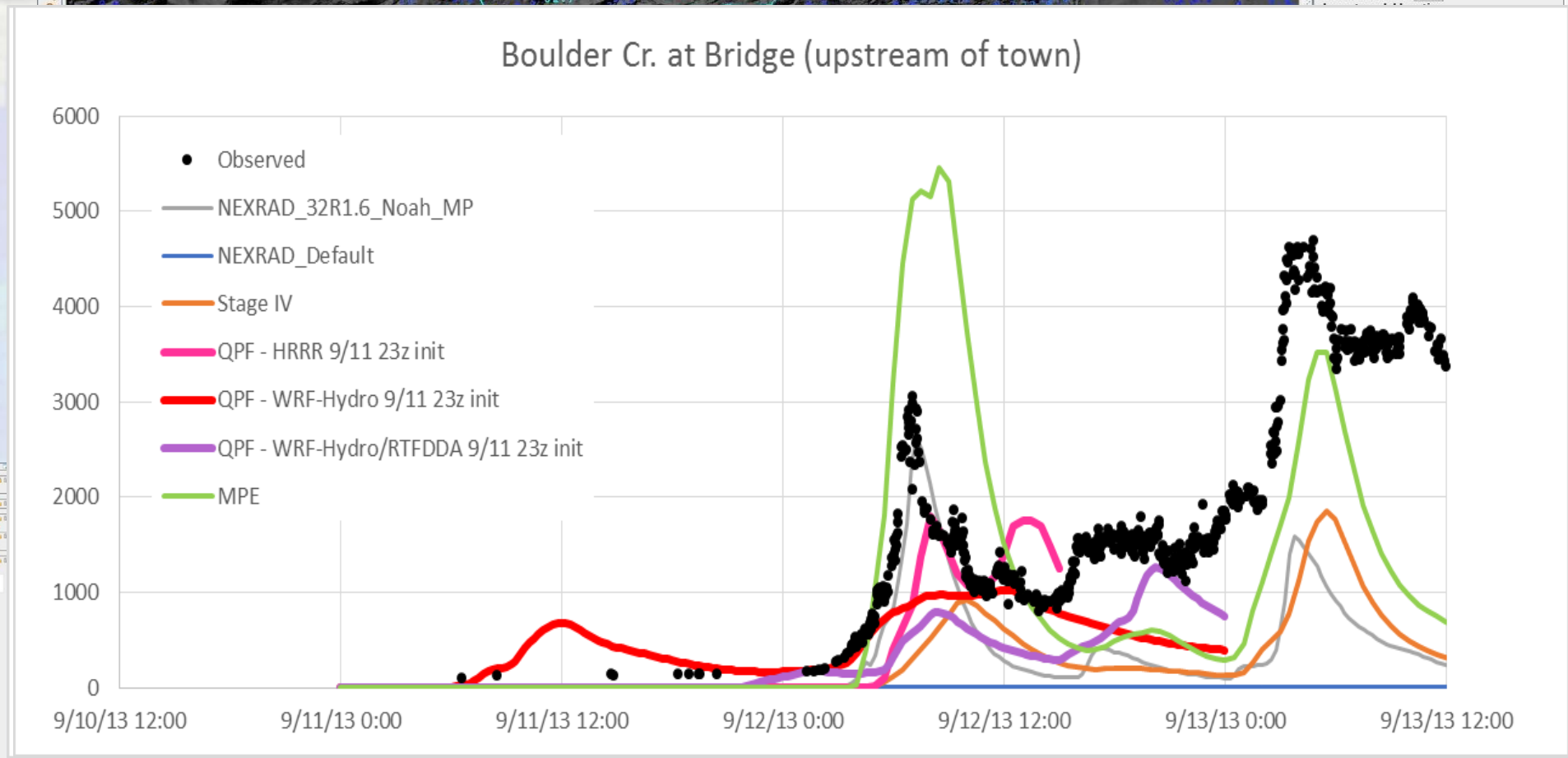
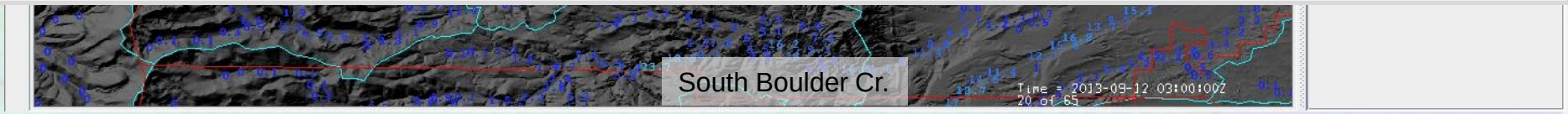


Streamflow in cms







Lessons learned

- There are significant opportunities for improving QPE, QPF and streamflow forecast guidance…lots of work remains however…

- Coupled modeling systems allow for production of spatial information across a range of scales which provides critical situational awareness despite model biases and uncertainties

- Applied to a recent catastrophic flood event in hindcast mode the WRF-Hydro system exhibited value in predicting regional aspects of the regional flooding threat at lead times 15-24 hrs in advance…
  - Predicted flow values were significantly biased low due to low bias in QPFs…
  - Opportunity for post-processing of QPFs if forecast climatologies can be established
  - Land cover ‘disturbance’ parameters (e.g. wildland fire) need to evolve using updated data

Acknowledgements

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- NWS: Matt Bunkers
- NWS/WPC: David Novak and Mark Klein
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- CWCB: Kevin Houck
- NCAR: Bob Henson