Diagnosing possible human influences on heavy Colorado flood-inducing rainfall in September 2013

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M Wehner
D Stone
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Submitted, PNAS

Image: denverpost.com

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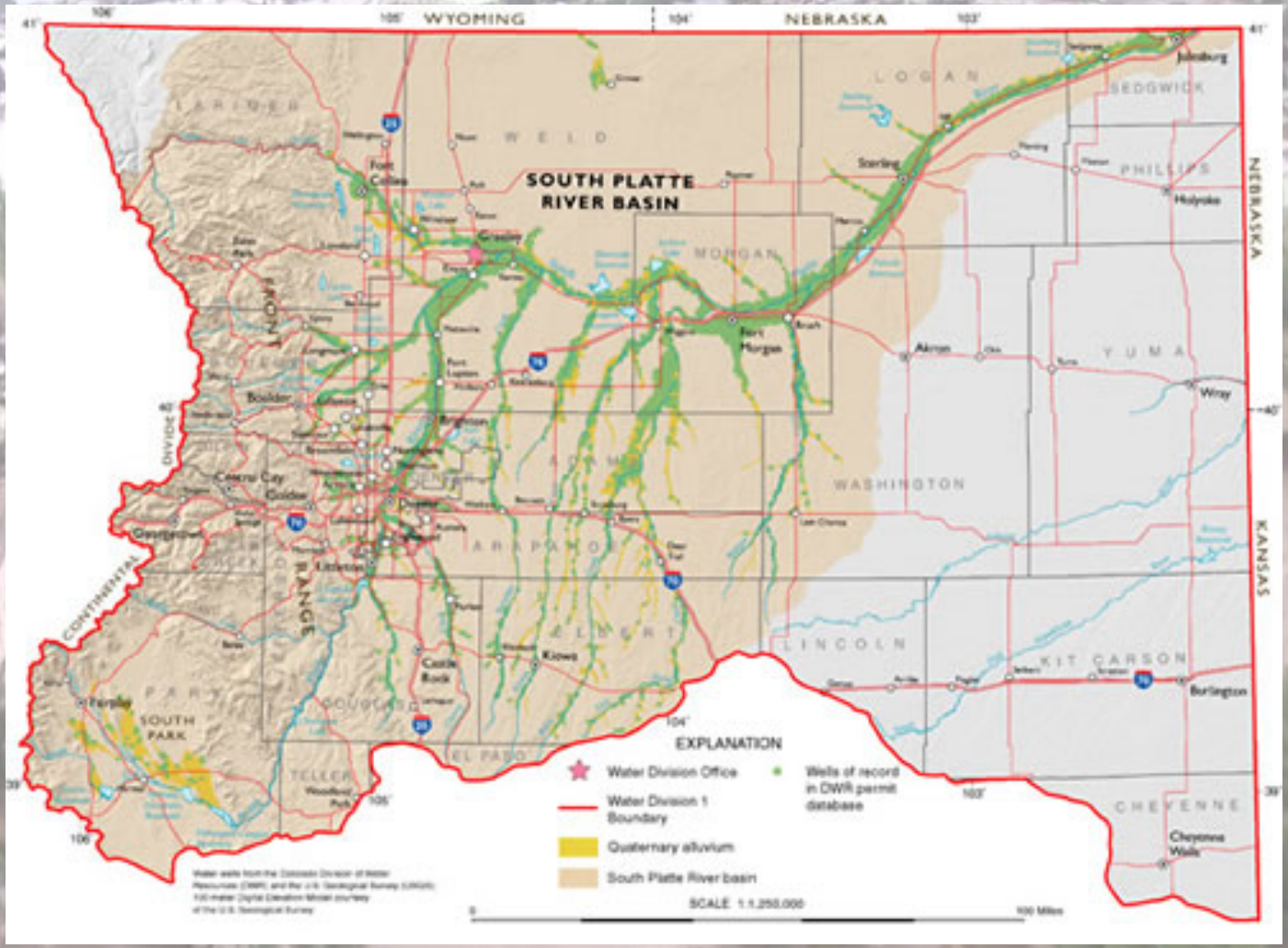


Image: nytimes.com

Colorado Sep 2013 floods: impact

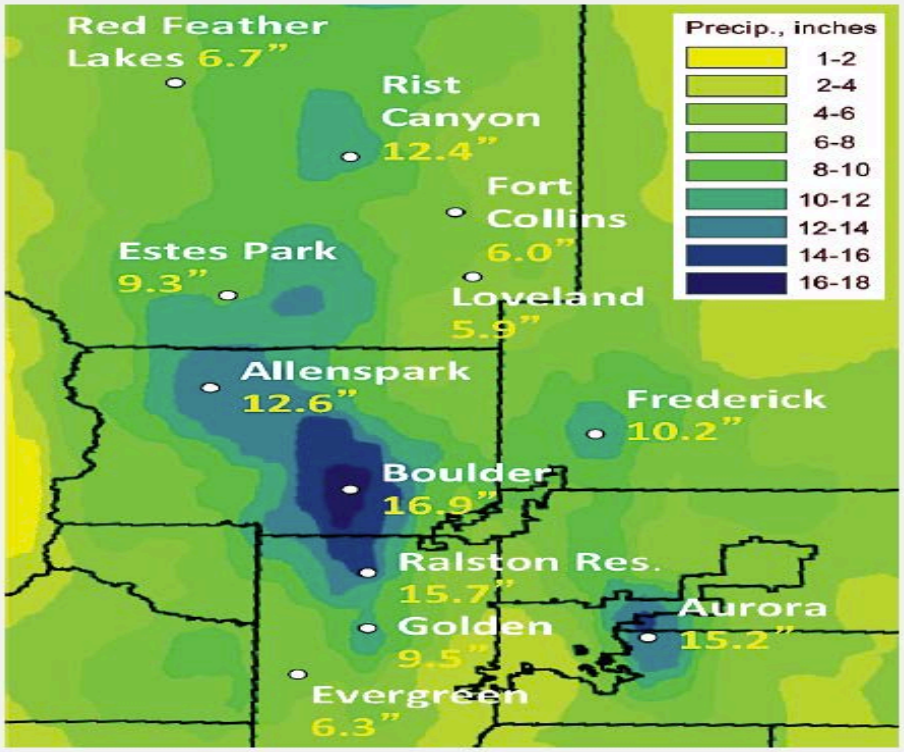
Longmont, CO
denverpost.com

Severe floods occurred along the Colorado Front Range during the second week of September 2013.

- At least 8 deaths; 11,000 evacuated
- Nearly 19,000 homes damaged, and over 1,500 destroyed, costing >$2 bn
- 50 state highway bridges damaged/destroyed, and rail lines affected

Lyons, CO
usatoday.com

Colorado Sep 2013 floods: hydrology



Total precipitation from 9/9 - 9/15/2013, showing large areas with >10" of rain and the maximum of ~17" in Boulder. Representative totals of >6" for selected locations are shown. (Map: Colorado Climate Center, CSU)

Floods occurred along the Front Range from Colorado Springs to Fort Collins

A result of several days of record / near-record, very heavy rainfall (and antecedent saturated soil at higher ground) – rare for September.

Strongest deluge in a 36h period from 11-13 Sep

Boulder County worst hit, with 9.08" recorded Sep 12 and up to 17" by Sep 15 (annual = 20.7")

Rainfall preliminarily estimated to be ~1/1000 year event in some places

Colorado Sep 2013 floods: meteorology

Rainfall due to North American Monsoon-like (late July and early August) conditions.
➔ Atypical for September.

Involved a stationary large-scale weather pattern:

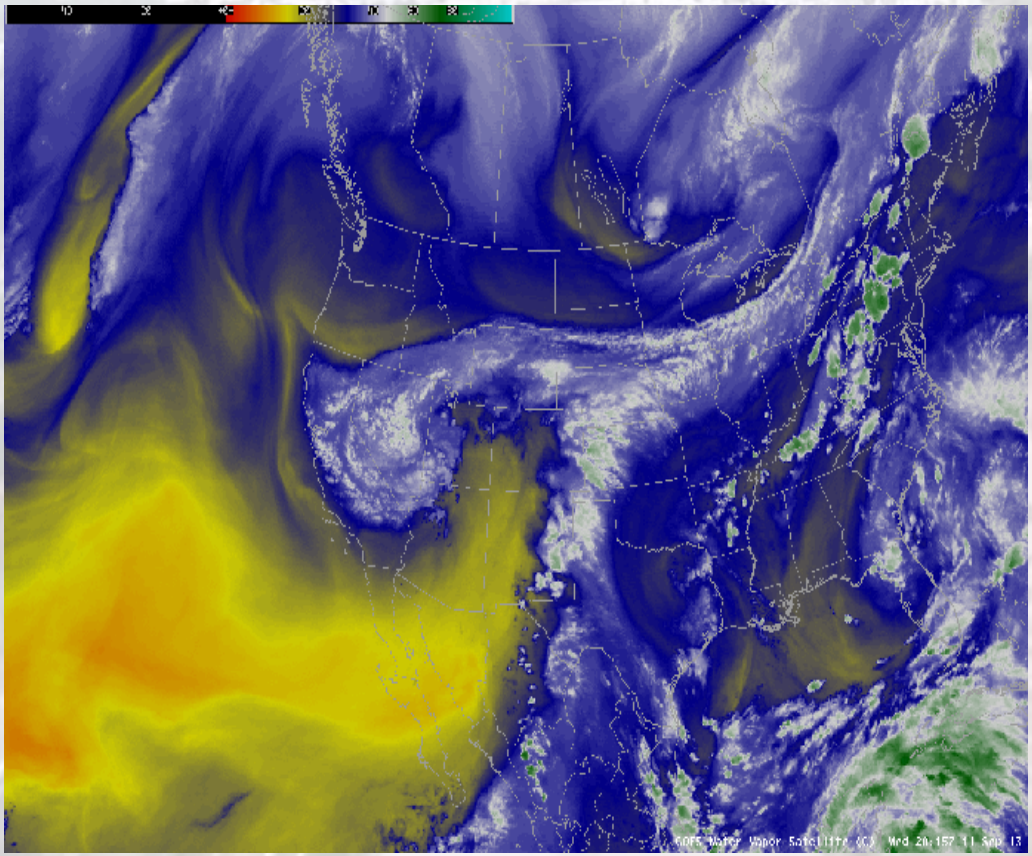
- An upper-level low pressure system over the Great Basin drove a strong plume of deep moisture inland from the Pacific and Gulf of Mexico against the Front Range

- Concurrently blocked by a dome of high pressure to the east bringing in moist air at lower levels from the Great Plains

- (Similar conditions to 1938 CO floods)

coflood2013.colostate.edu

Colorado Sep 2013 floods: meteorology



Water vapour for 12 September 2013, from GOES-15 and GOES-13 satellites

cimss.ssec.wisc.edu/goes/blog/archives/13876

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Colorado Sep 2013 floods: experiment design

- Can we say something about the influence (if any) of anthropogenic climate change on the odds of this flood event occurring at that time

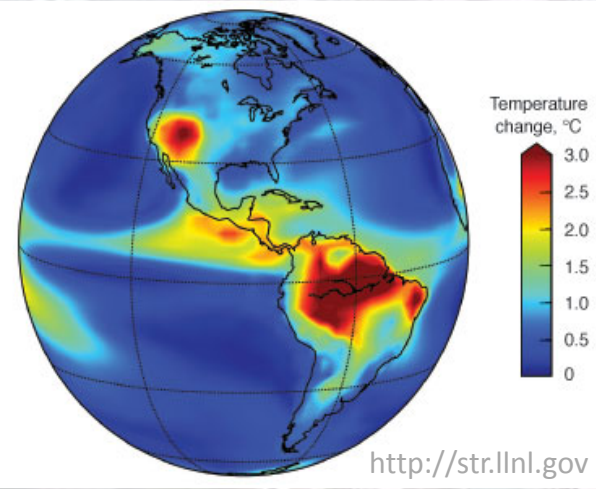
- Two contemporary 'schools of thinking' about this
  - Probabilistic: changes in exceedance frequency of 'event magnitude'
  - Mechanistic: changes in magnitude of some 'event frequency'

- Here we adopt a framework that uses both these schools

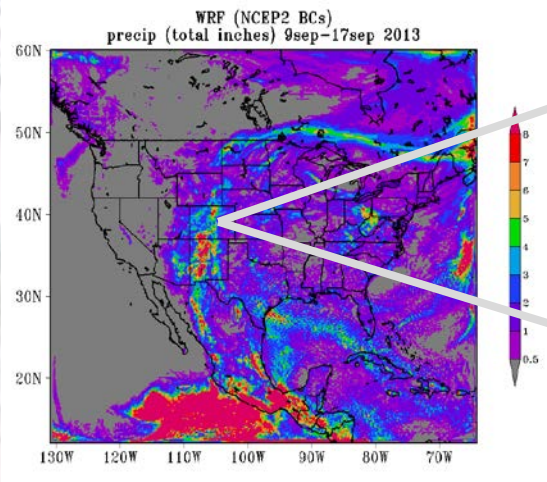
- As part of this, we use observational- AND model-based framework (as opposed attribution community convention of simply model based)…

Colorado Sep 2013 floods: experiment design

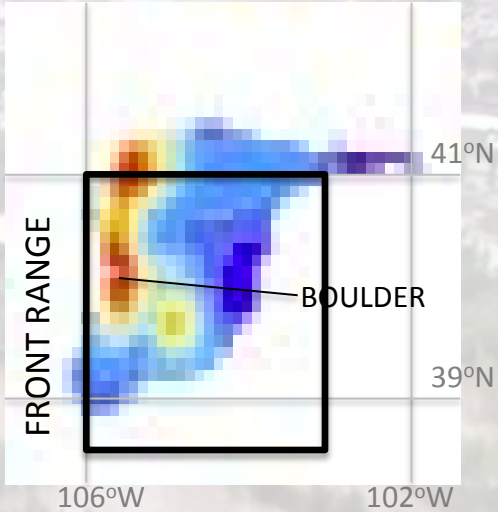
NCEP RE-ANALYSIS (~100km)



WRF MODEL (12km)



NORTH EAST COLORADO



1. Take Sep 2013 weather from re-analysis, under both actual anthropogenic conditions and 'adjusted' non-ant conditions

2. Feed into a regional weather model over North America

3. Extract rain over Northeast Colorado (most of South Platte river basin)

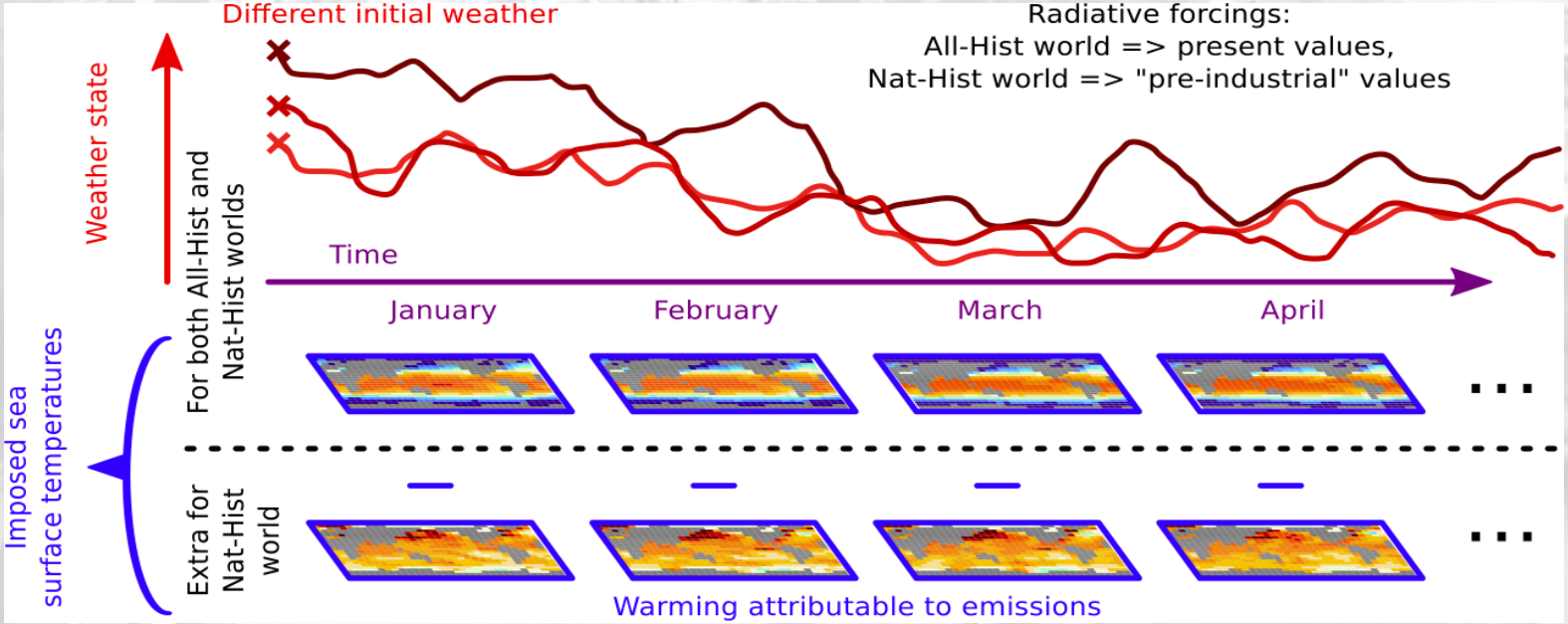
Adjusted SST, T, u,v, pr, and q based on changes from CAM5.1 historical forcing simulations with and without anthropogenic climate drivers

Generate 'time slice' simulations; 101-member i.c. ensembles per anthro / non-anthro conditions

Examine 7-day totals (9-15 Sep 2013)

Colorado Sep 2013 floods: experiment design

CREATING 'ADJUSTED' NON-ANT CONDITIONS FROM RE-ANALYSIS

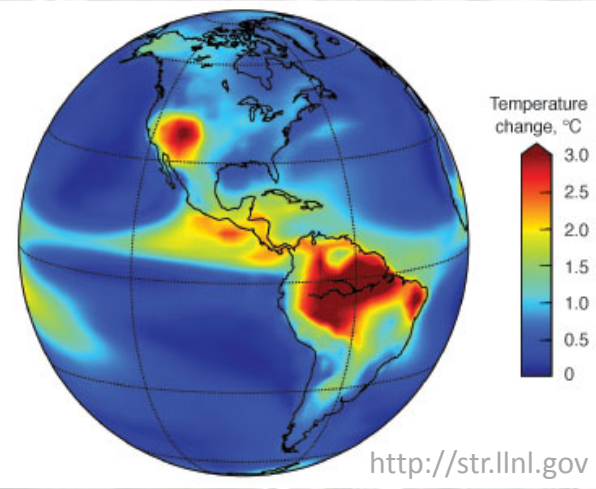


1. Run CAM5.1 historical all-forcing 50-member ensembles through 2013
2. Re-run, but remove anthropogenic atmospheric pollutants (GHGs, sulphates, etc.), and corresponding signal in SSTs*

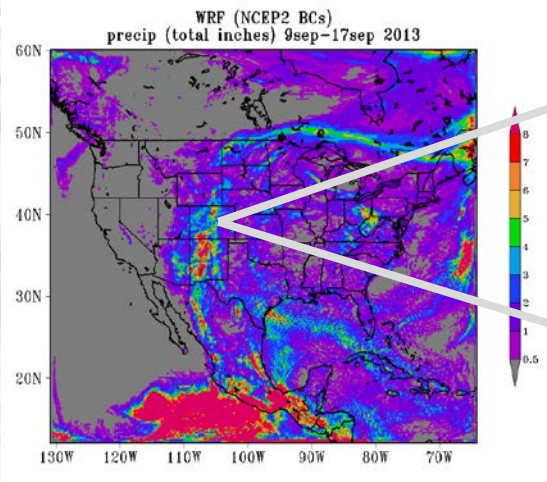
   [*Signal is taken from CMIP5 multi-model mean SST warming between historical all forcings, and natural simulations.]
3. Take difference in atmospheric variables, and remove from re-analysis

Colorado Sep 2013 floods: experiment design

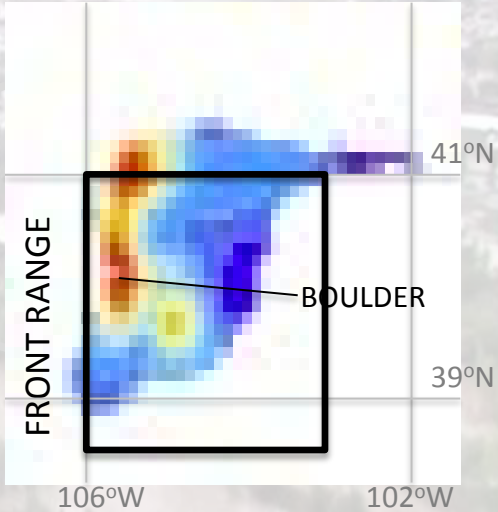
NCEP RE-ANALYSIS (~100km)



WRF MODEL (12km)



NORTHEAST COLORADO



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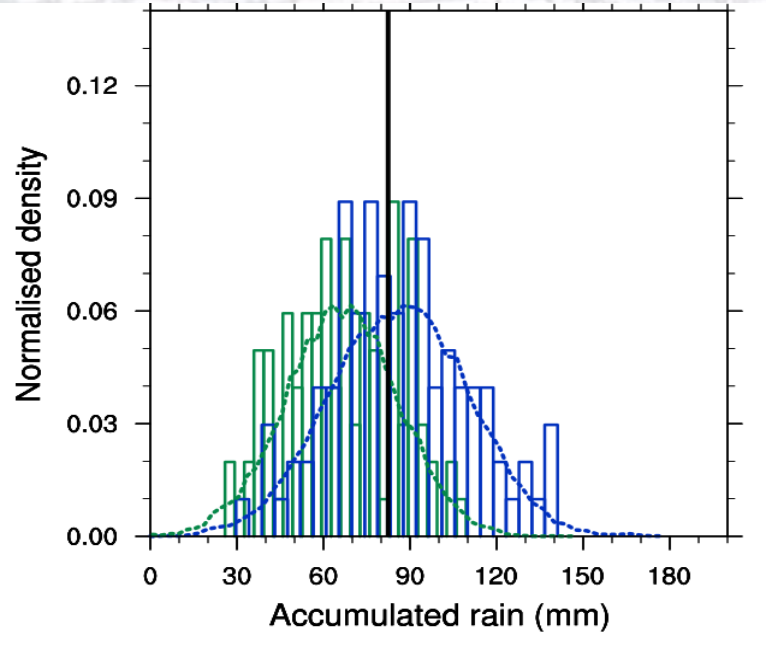
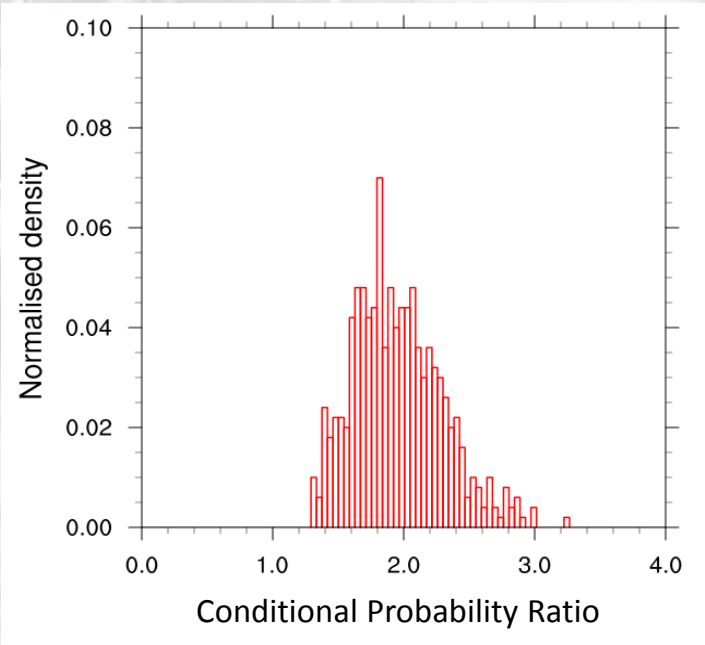
Colorado Sep 2013 floods: current results

7-DAY RAIN HISTOGRAMS



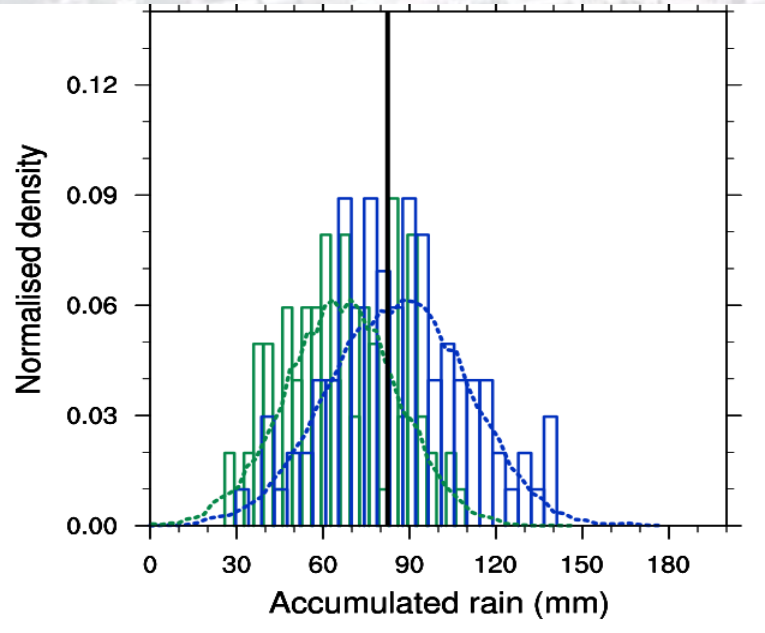
CHANGE IN ODDS OF HEAVY 7-DAY RAIN



- We compute probability of exceeding the observed (black line) heavy 7-day rainfall total, in both our anthro (P1) and non-anthro (P0) model ensembles
- Find best estimate of about a doubling in odds of a heavy 7-day rain occurrence. I.e. Median of 'Conditional Probability Ratio', CPR = P1/P0, is ~2.

Colorado Sep 2013 floods: current results

7-DAY RAIN HISTOGRAMS



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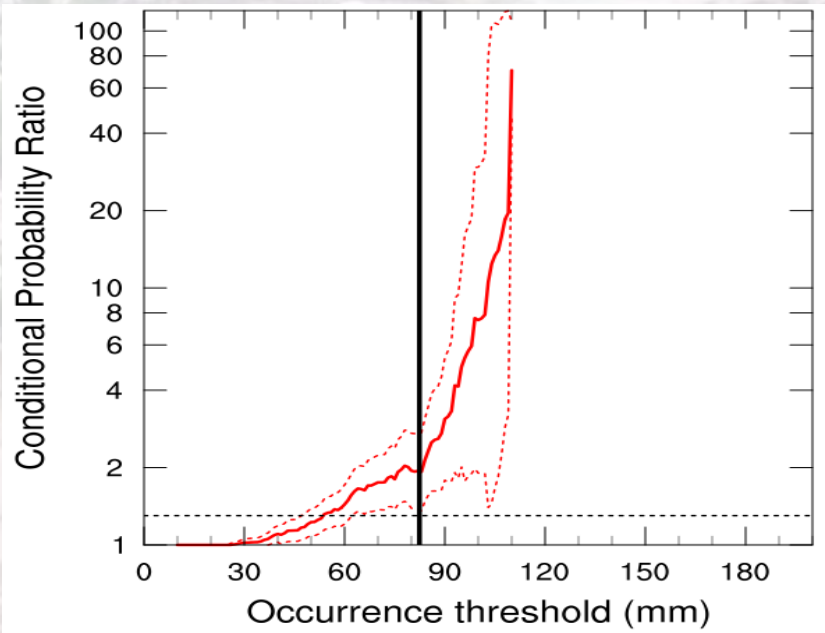


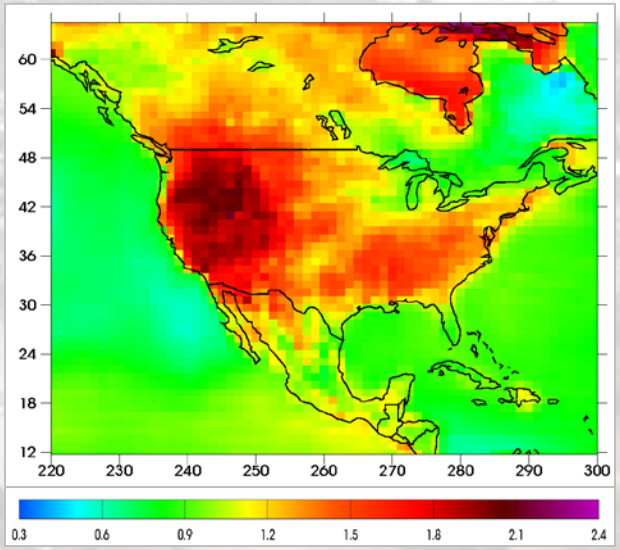
- But this increase in odds is quite sensitive to threshold, which in turn depends on several factors
- However, lower bound on increase is less sensitive (~30-50% increase)

Colorado Sep 2013 floods: mechanisms?

- We find a substantial shift in our rainfall distributions over the South Platte basin (increase in mean of ~30%)

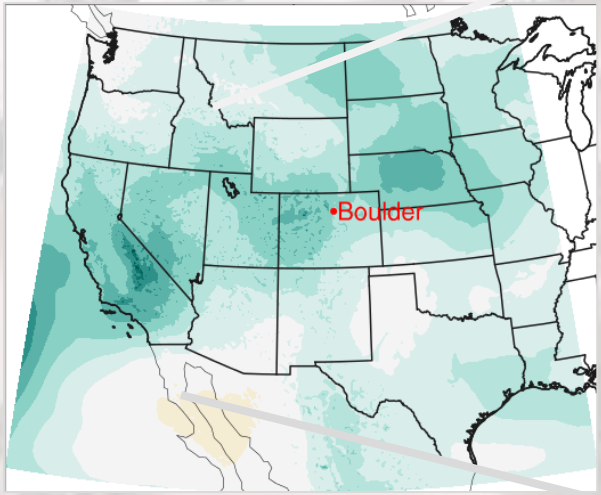
  -> well beyond a thermodynamic (~7%/K) induced increase, given ΔT = ~1.5K

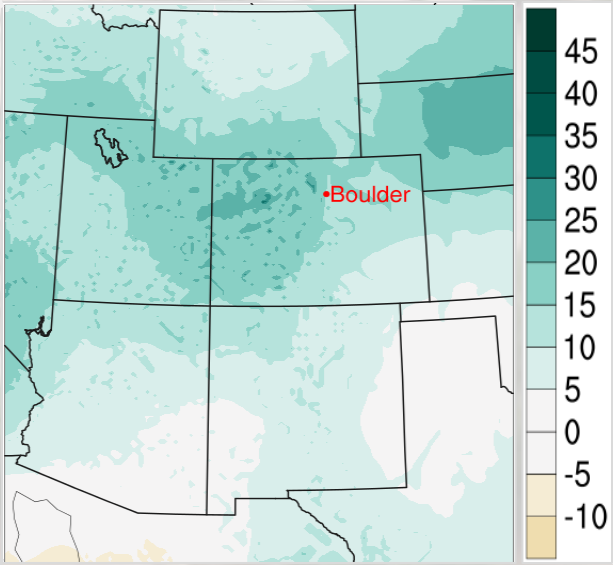
ΔT (K)



- But increase in precipitable water (~15%) appears broadly consistent with temperature increase

ΔPW (%)





Colorado Sep 2013 floods: mechanisms?

- Hoerling *et al.* (2014) also investigated the floods in a similar 'time slice' set-up:

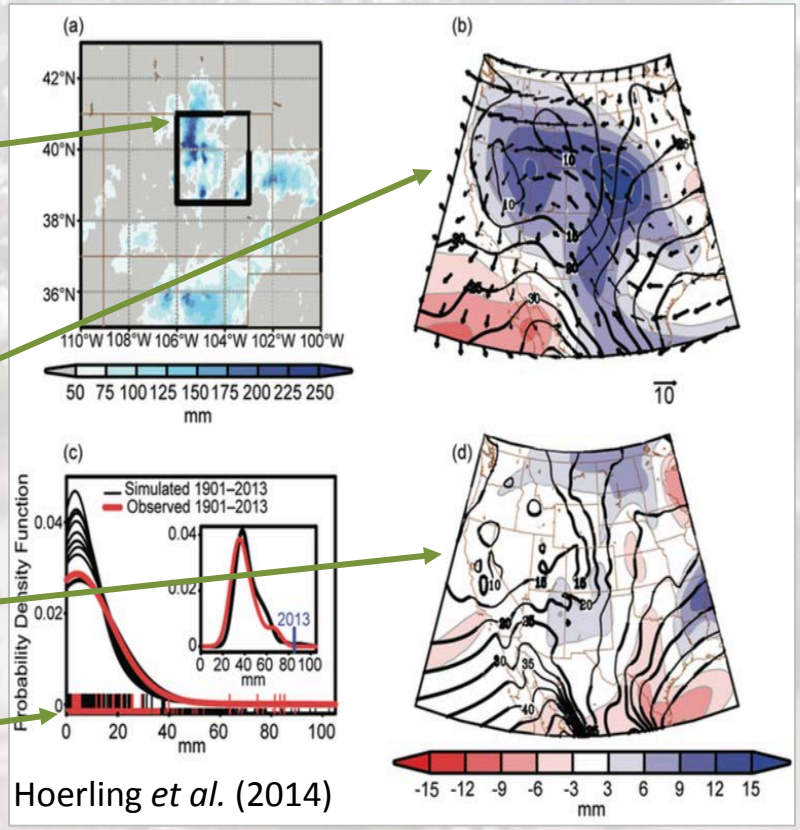
1) Used a larger CO domain than South Platte basin to avoid selection bias

-> Doing this doesn't much alter our Δ rain

2) Did not prescribe circulation in their 1° GEOS-5 atmospheric model (12-member ensembles), so observed precipitable water anomaly is not captured

3) Realistically simulate statistics of historical 5-day rainfall, but found a decrease in frequency of recent extremes compared to pre-industrial – despite an increase in precipitable water

-> Prescribing circulation at least gives us an observed-like pattern in Δ PW

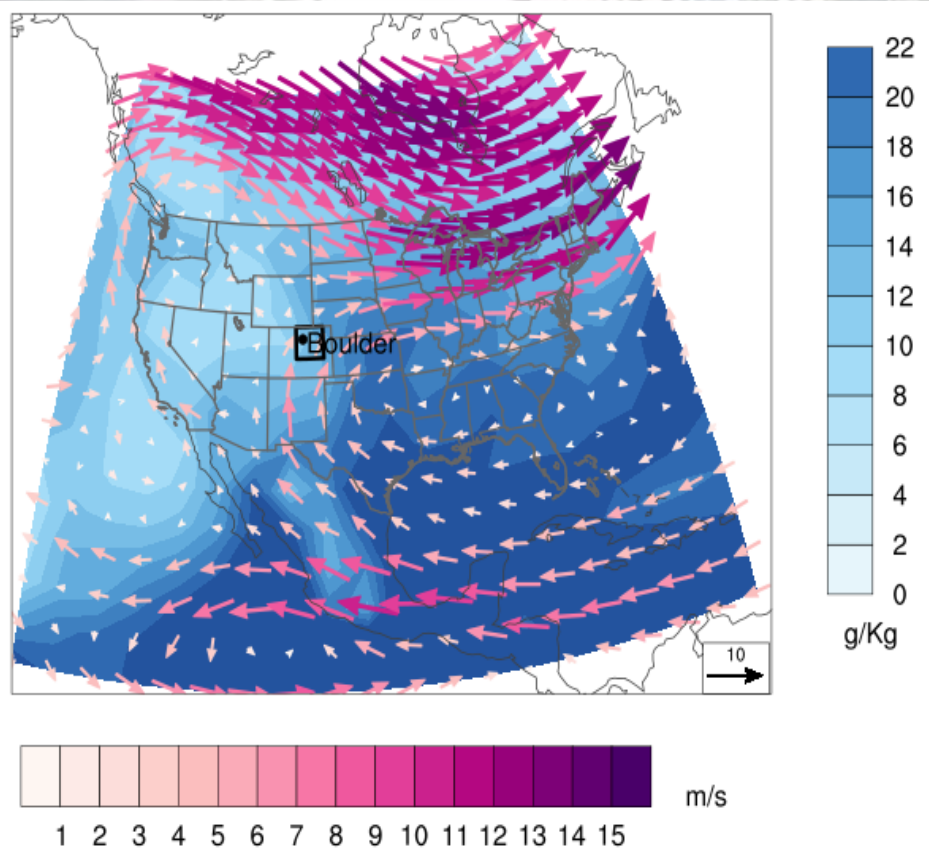


Hoerling *et al.* (2014)

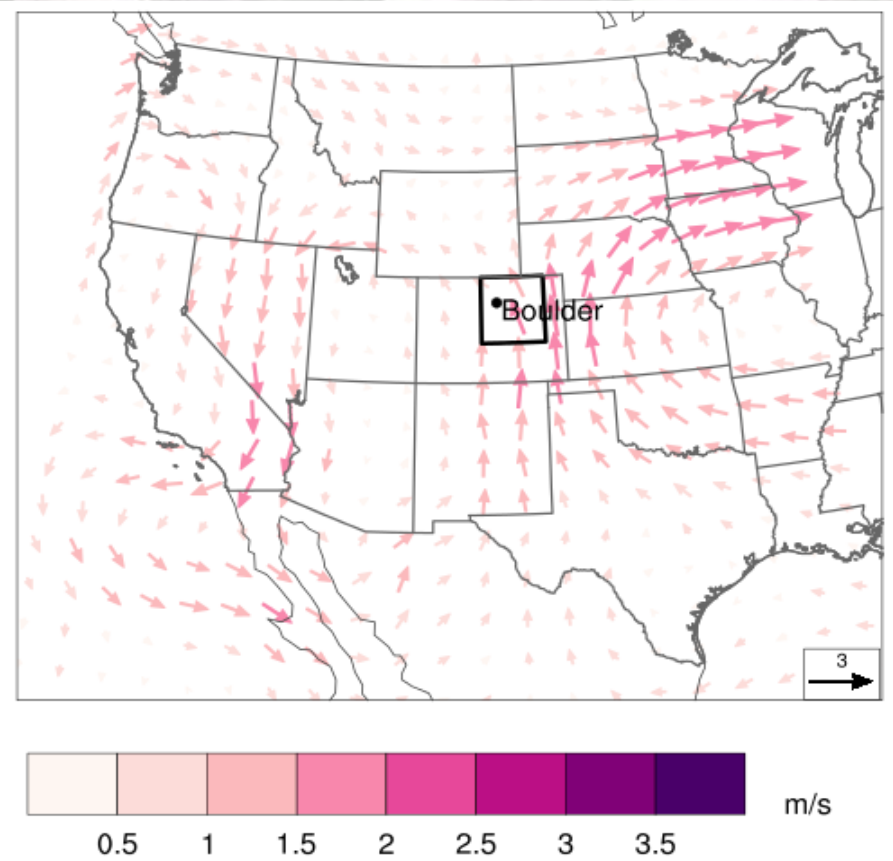
Colorado Sep 2013 floods: mechanisms?

- So does change in circulation account for the ~15% discrepancy between our Δ rain and Δ PW… what about super Clausius-Clapeyron?

u,v 500hPa (ms-1)



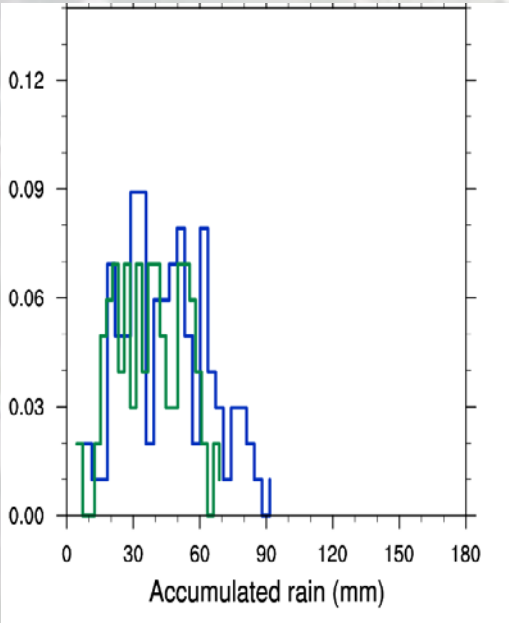
Δ u,v 500hPa (ms-1)



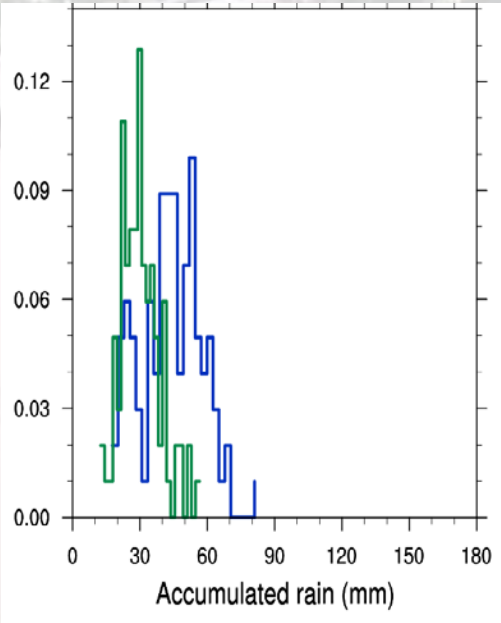
Colorado Sep 2013 floods: mechanisms?

- So does increase in circulation account for the ~15% discrepancy between our Δ rain and Δ PW…
- -> more convective precipitation and super C-C?

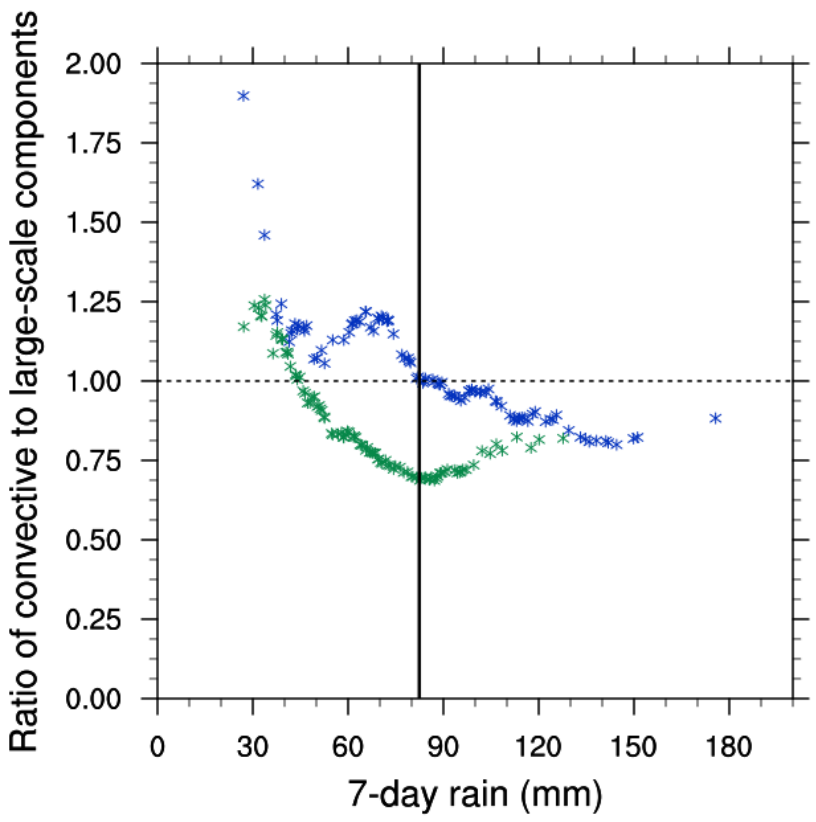
Large-scale



Convective



Convective vs Large-Scale scatter



Colorado Sep 2013 floods: summary

- Severe floods occurred in early September 2013 in Colorado, during prolonged heavy rains associated with a North American Monsoon-like weather system

- We simulate changes in Northeast Colorado 7-day rainfall totals between an anthropogenic and 'non-anthro' early September 2013 climate, based on prescribing and adjusting large-scale re-analysis (NCEP) coupled with a regional (WRF) model

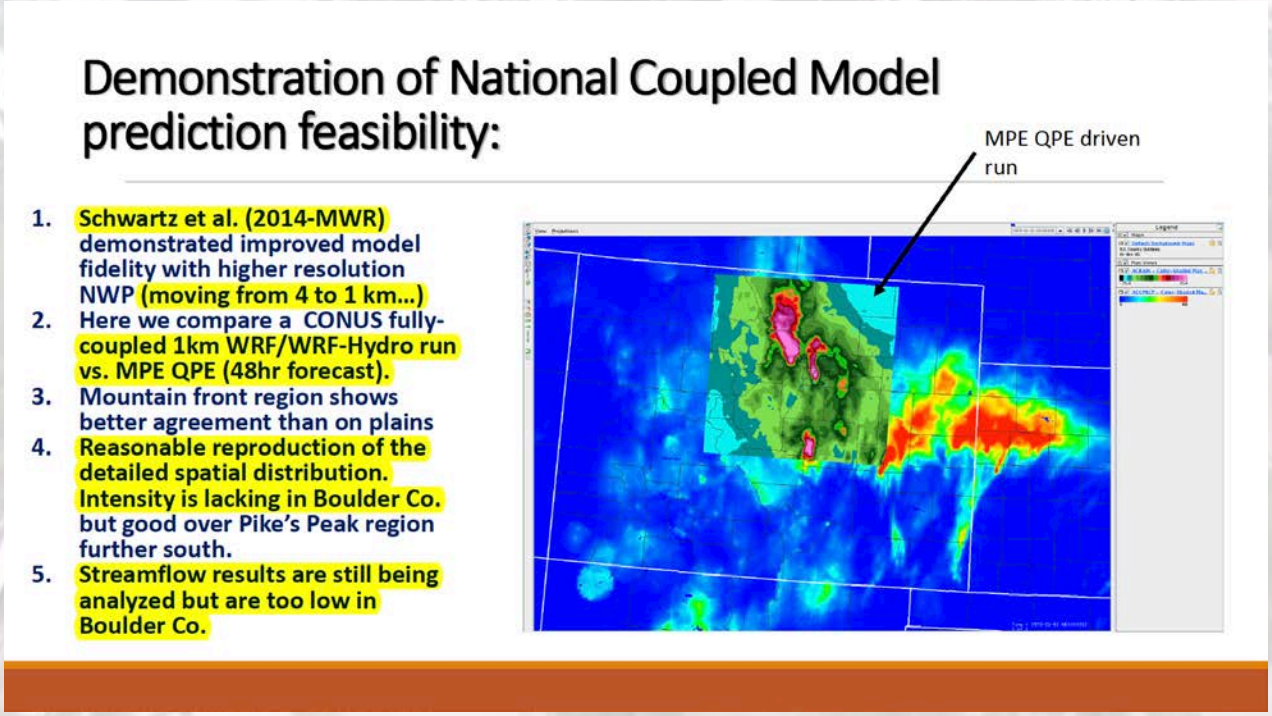
- We find a substantial increase in odds of heavy 7-day rainfall totals over Northeast Colorado – with a best guess doubling in odds, but this is sensitive to heavy rainfall threshold chose (though lower bound less so)

- Also, how do we interpret this 'conditional probability ratio'
  [CPR… *'Breathing new/even more life into event attribution…(!)'*]

- More robust is the substantial shift (~30%) in mean of rainfall distributions, that can be mechanistically explained as beyond a simple thermodynamic-induced increase, and involves increased convective precipitation.

Colorado Sep 2013 floods: next steps

- Feed WRF precipitation simulations into WRF-Hydro (1km > 100m) and repeat attribution exercise on South Platte river runoff



Slide courtesy of Dave Gochis, UCAR

- Will include sensitivity analysis to e.g. land-use, infiltration, baseflow

- What about using other hydrological models (e.g. VIC-2, CLM 4.5)?