

Northeast Colorado extreme 2013 rains interpreted in a climate change context

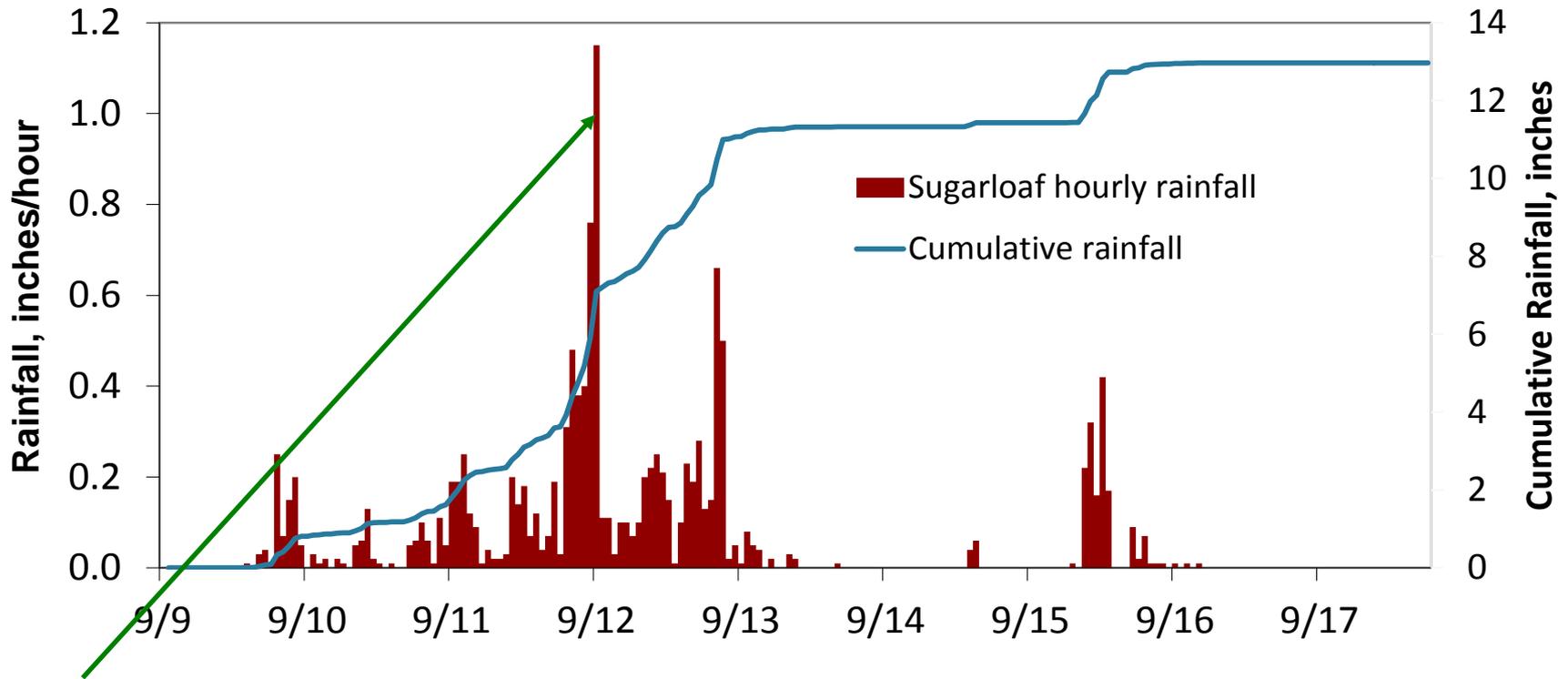
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- *Colorado disasters don't get any bigger than this*
- *Key ingredients*
- *Focus on precipitable water (PPW) in GEOS 5*
- *We have only 'dipped our toes into the flood waters' – next steps*

Hourly and cumulative precipitation, Sept 9-17, 2013

Sugarloaf RAWS station 6 mi (10km) west of Boulder

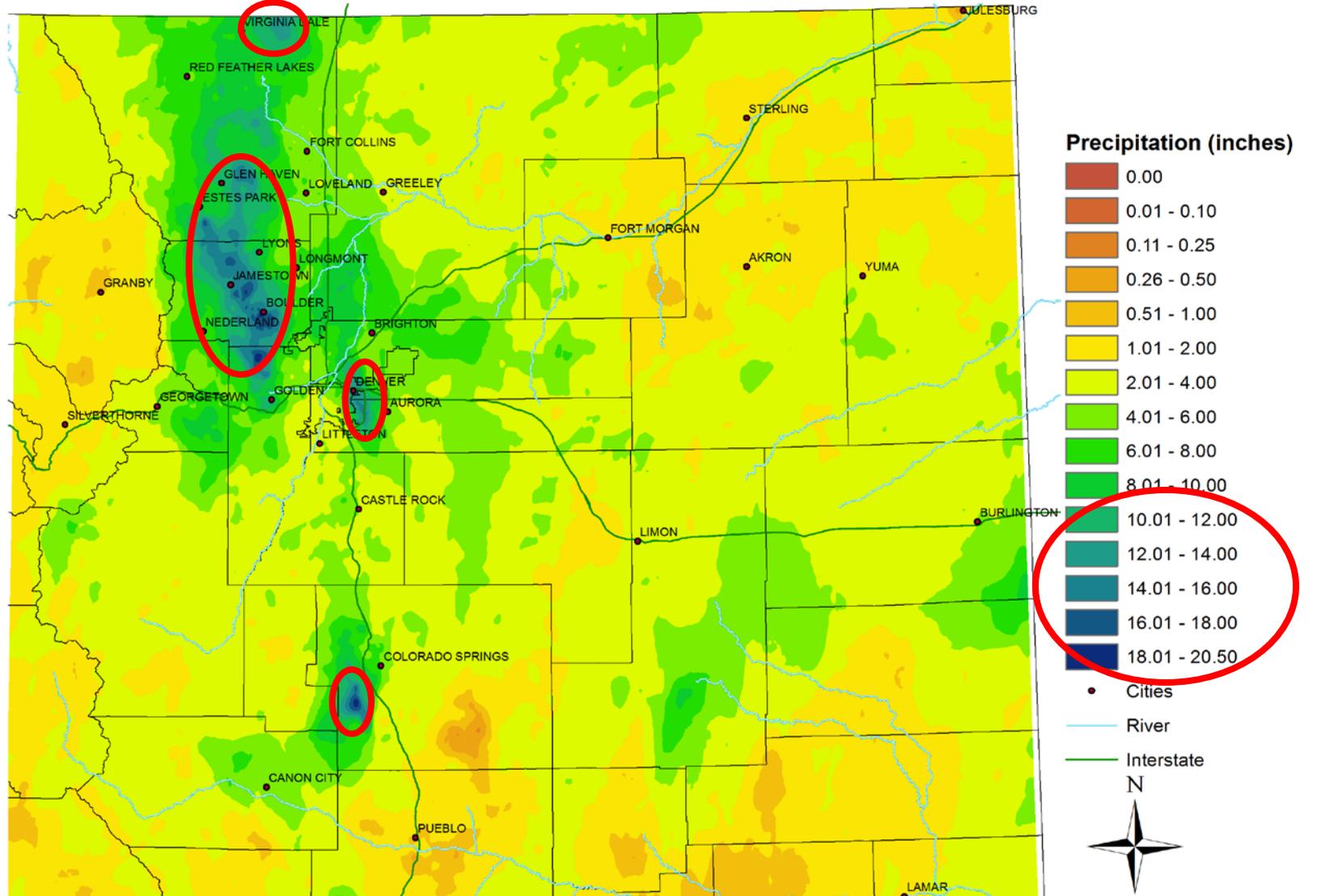


1"/h ~ 10yr event according to NOAA Atlas 14, in reality more like once every 2-5 years in last 25 years.

New all-time records were set in Boulder for 1-day (9.08") to 1-year totals (38.47"), while a new state record was set for 24h totals near Fort Carson: 12.46"

'Final' rainfall totals based on 2K+ observations

Precipitation Beginning September 8, 2013 ending 7:00 AM MST September 17, 2013



Map created with the Storm Precipitation Analysis System (SPAS) through a collaborative effort by Applied Weather Associates, LLC, MetStat, Inc. and the Colorado Climate Center. Radar data supplied by Weather Decision Technologies, Inc.

Impacts: Flooding and Debris Flows

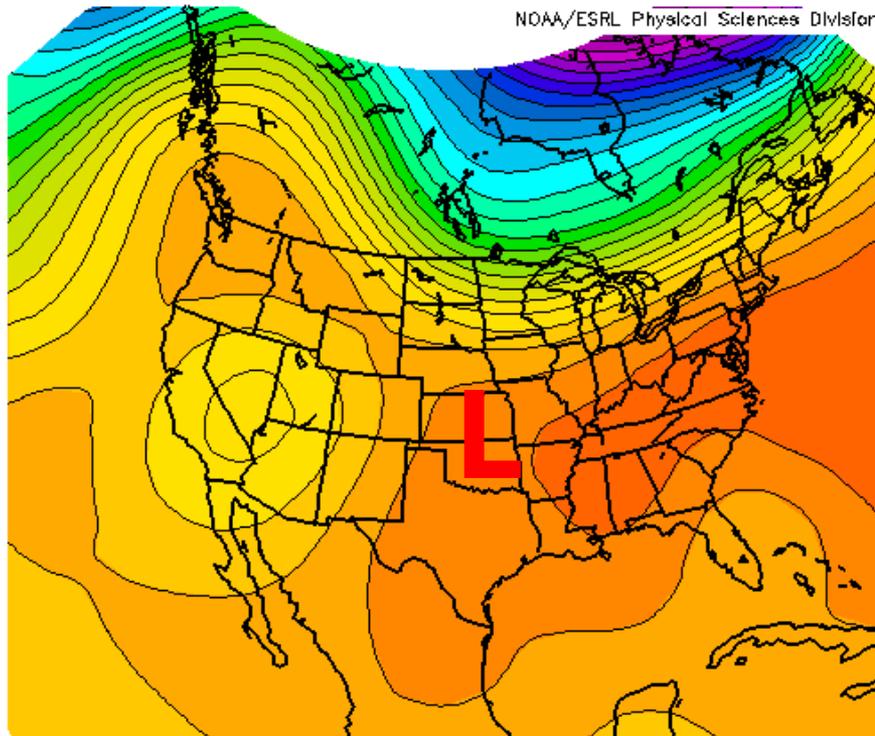


Tied with 1965 for costliest disaster in CO history (~\$3B&growing); “only” 10 deaths (reverse 911 calls);

1,300 debris flows = new record in CO



September 11-12th, 2013: Synoptic-scale features

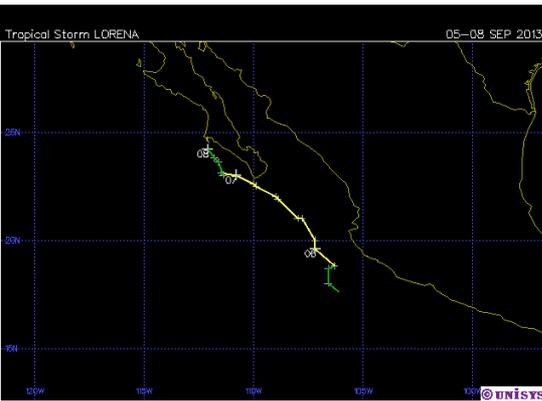
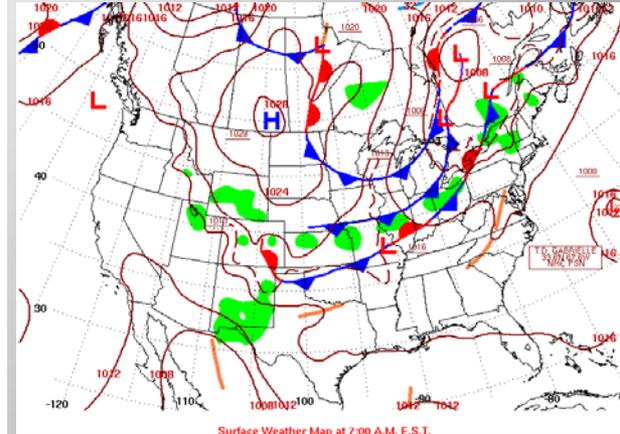


Blocking ridge to our north

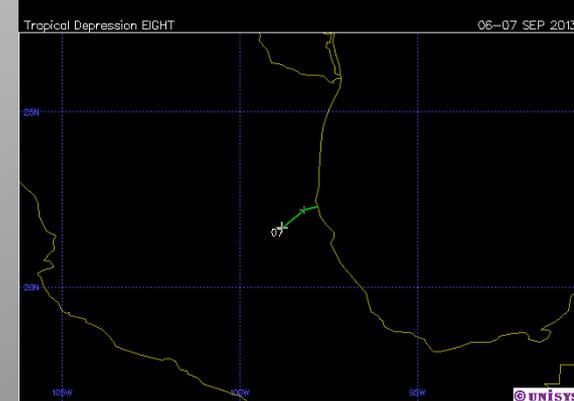
Cutoff low to our southwest

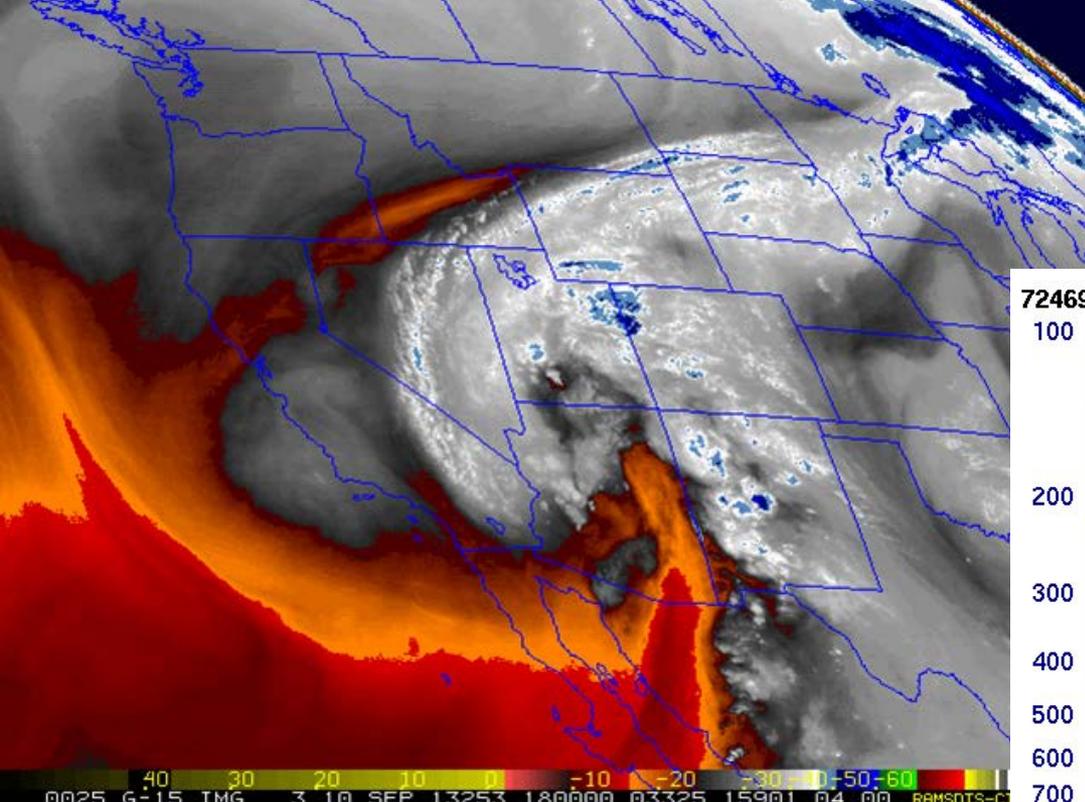
500mb Geopotential Height (m) Composite Mean
9/11/13
NCEP/NCAR Reanalysis

Stationary surface front 'hung up' just to our south



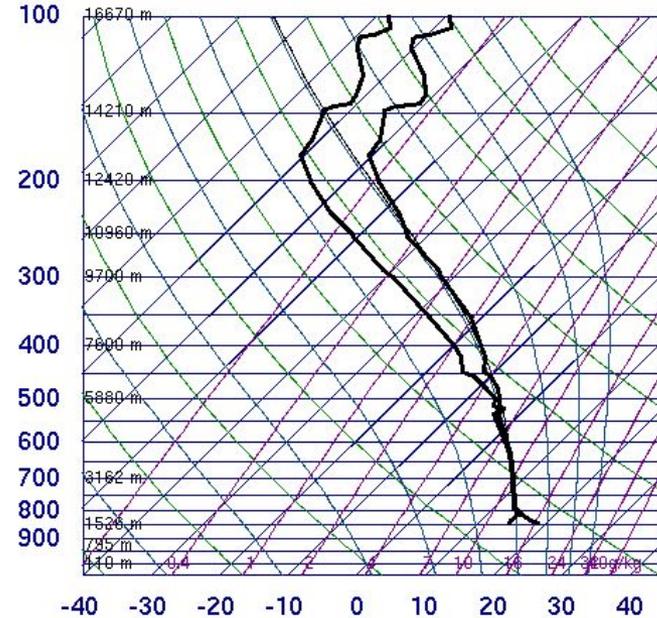
Nothing like landfalling tropical systems to 'prime the moisture pump'





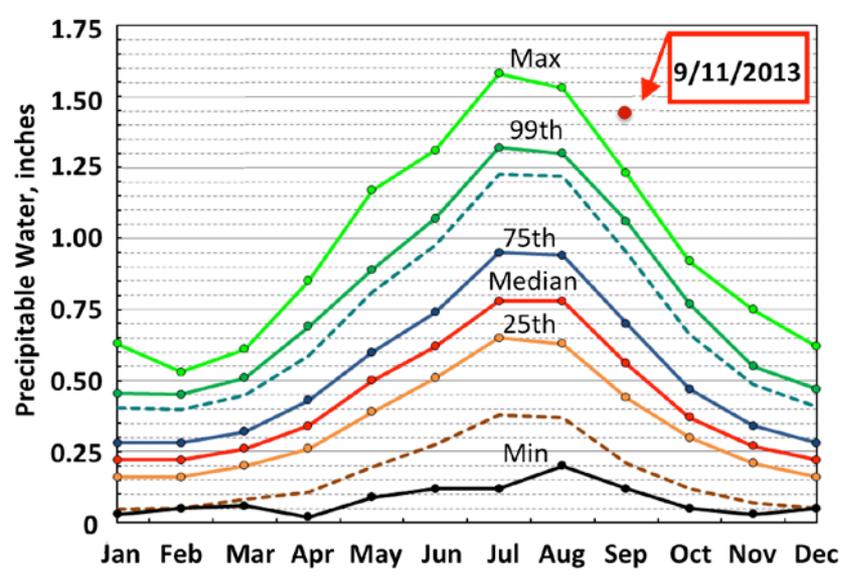
**As moist as it can get here,
one day before it 'spilled'**

72469 DNR Denver



SLAT	39.75
SLON	-104.87
SELV	1625.
SHOW	-9999
LIFT	-0.02
LFTV	-0.07
SWET	-9999
KINX	-9999
CTOT	-9999
VTOT	-9999
TOTL	-9999
CAPE	77.51
CAPV	94.82
CINS	0.00
CINV	0.00
EGLV	237.4
EGTV	237.0
LFCT	796.3
LFCV	797.5
BRCH	1.32
BRCV	1.61
LCLT	287.0
LCLP	800.2
MLTH	305.9
MLMR	12.64
WICK	57.5
PWAT	36.51

00Z 11 Sep 2013 University of Wyoming



The day it spilled...

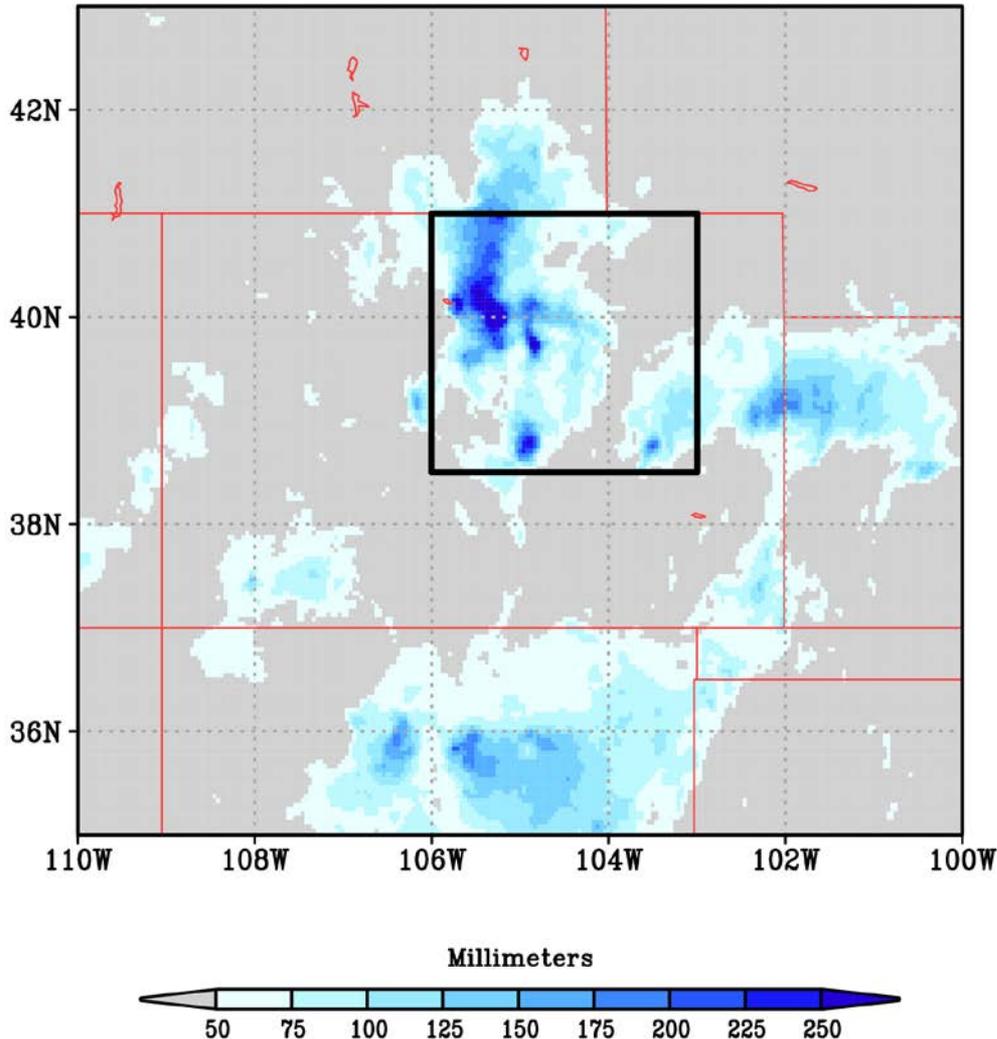
Observed atmospheric precipitable water over Denver on September 11, 2013, compared to all observations from 1948-2012: a new record for the month of September!

Interpreting our September flood in the context of a warming globe

- *What is the observed and modeled (GEOS 5) relationship between precipitable water (PPW) and precipitation over Northeast Colorado?*
- *Does the GEOS 5 model produce realistic precipitation pdf's for this region?*
- *How have the statistics of extreme values in 5-day precipitation changed since 1871 over Northeast Colorado during September, in relation to changes in PPW?*

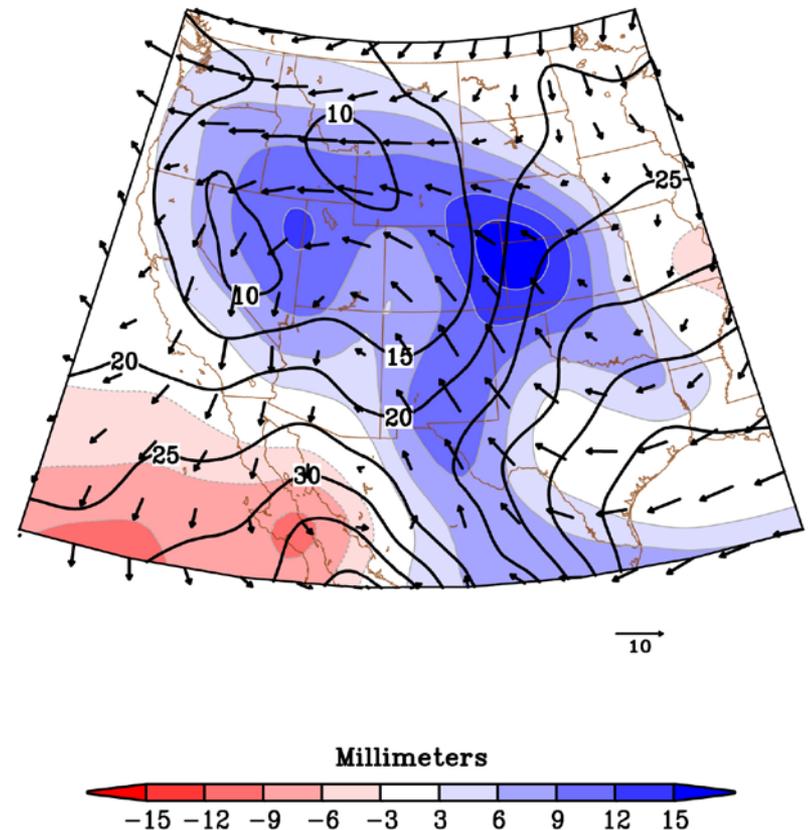
PRISM 5d precipitation

Observed 5-Day Total PPT 10-14 Sep 2013



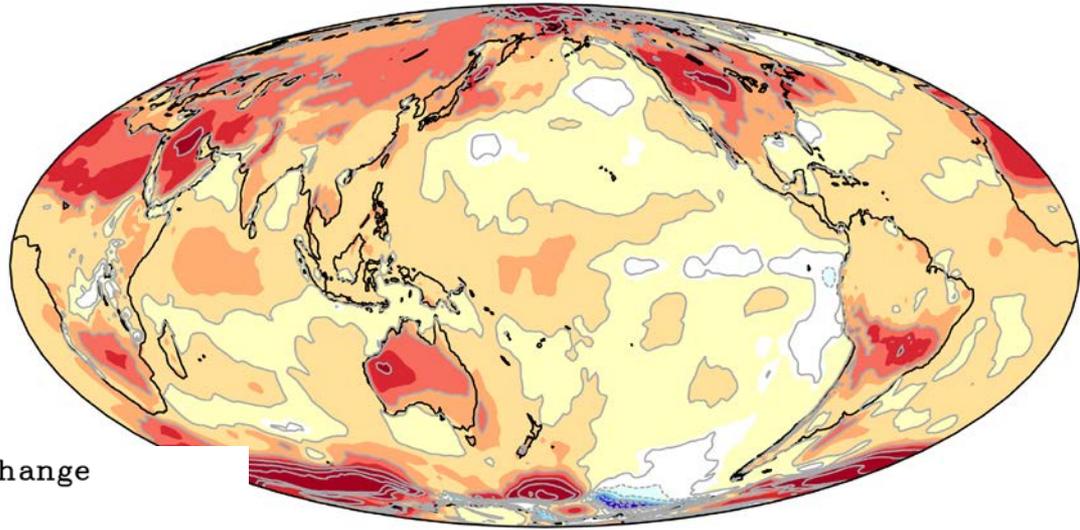
Converting into $\sim 1^\circ \times 1^\circ$ universe (left), and a look at PPW anomalies (right)

Observed 5-day Avg Column Precipitable Water (TPW)
10-14 Sep 2013

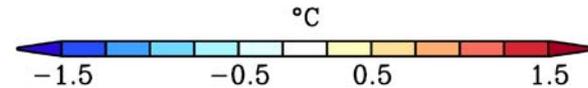
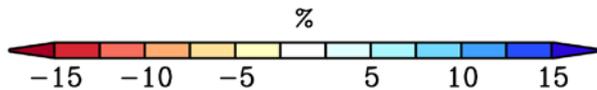
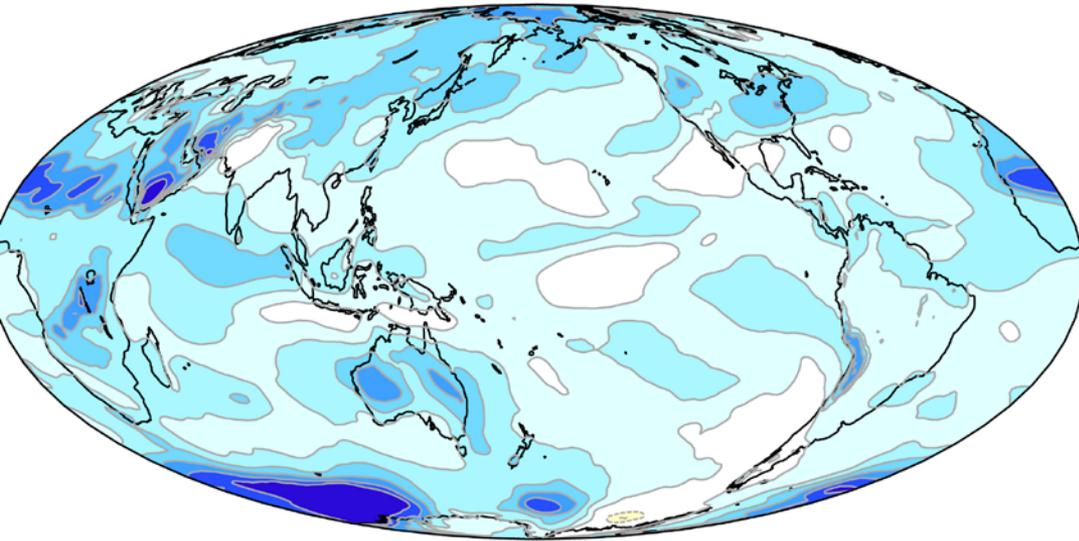


Hoerling et al. (BAMS, 2014)

Simulated September Temperature Change
(1984–2013) minus (1871–1900)



Simulated September Precipitable Water Change
(1984–2013) minus (1871–1900)



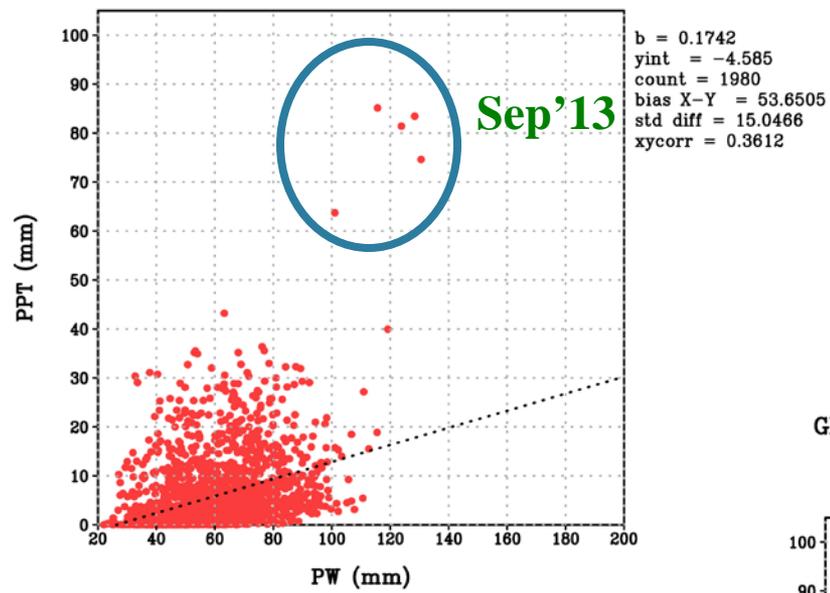
Global atmospheric water vapor has risen on the order 5% over the 20th century, and about 4% since 1970 (Trenberth et al. 2005). GEOS 5 shows an increase of 5.7% for the periods shown.

Hoerling et al. (BAMS, 2014)

Global temperatures have warmed roughly 0.9°C from 1880 to 2012 in GEOS 5, averaged over all land and ocean surfaces (matching IPCC 2013)

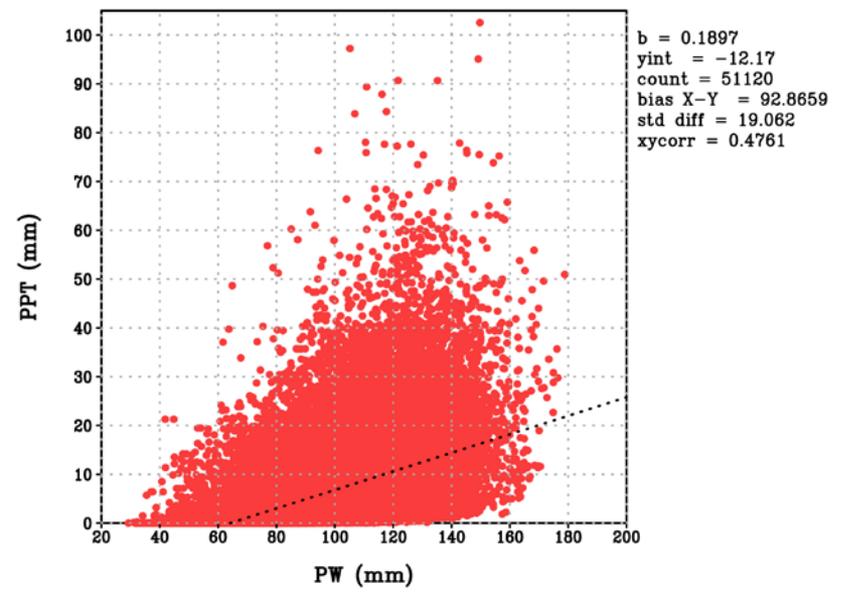
Observed Relationship: 5-Day Pcpn vs PPW

North Central Colorado
OBS 5 Day September Totals 1948-2013



Modeled Relationship

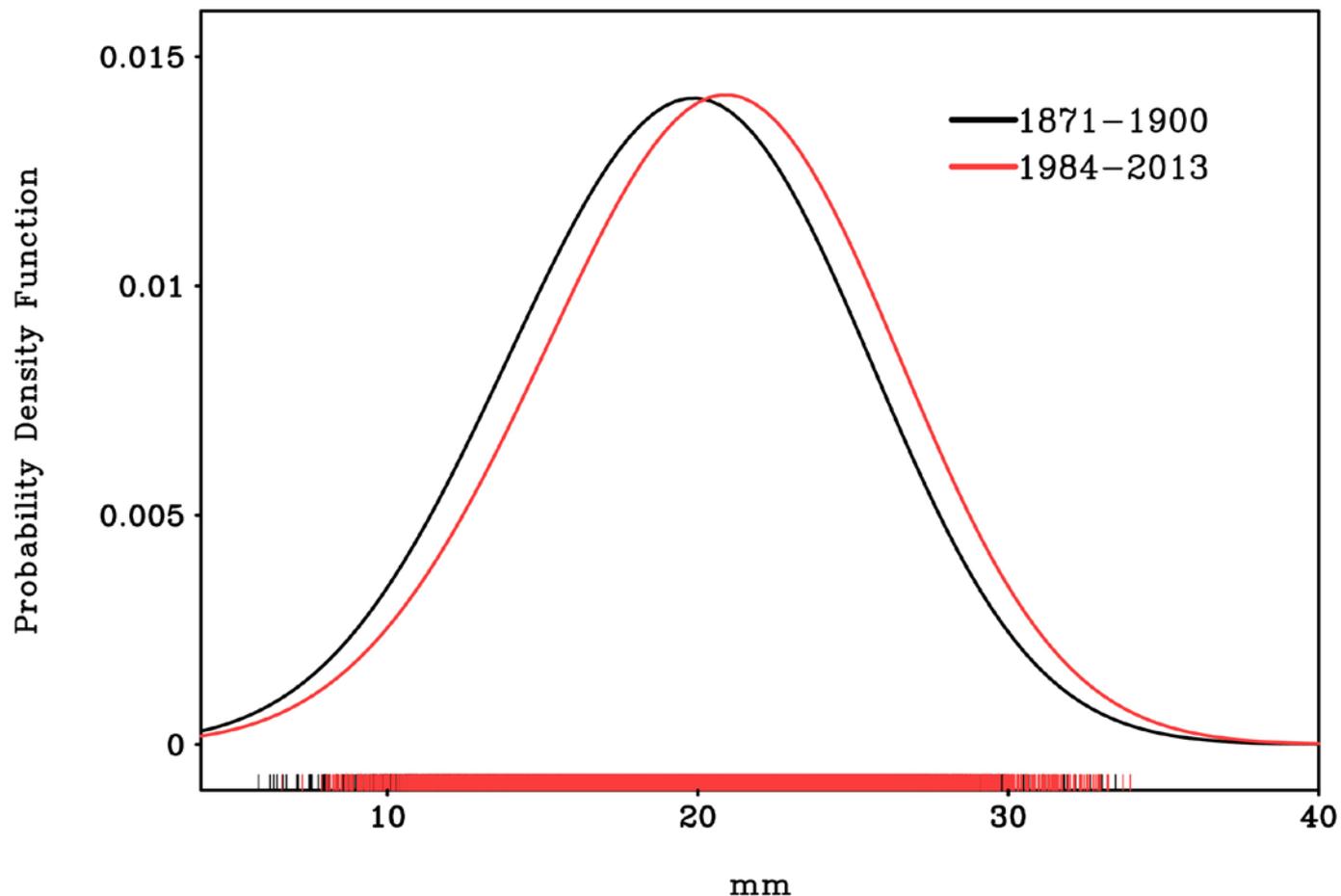
North Central Colorado
GEOS5 5 Day September Totals 1948-2013



GEOS-5 is too humid, but not bad for precipitation totals...

Relationship between precip and PPW is 'loose' in observations and model (<25% explained variance)

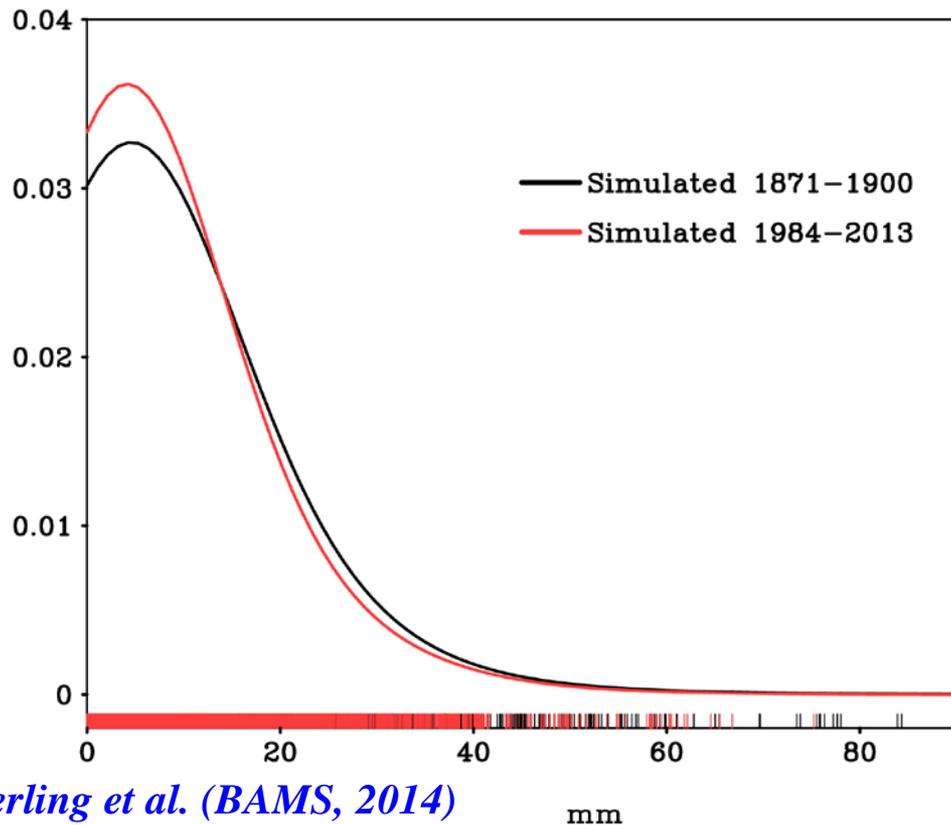
North Central Colorado



Climate model simulated frequency distributions of five-day September PPW (mm) over the study area for 1871–1900 (black curve) and the 1984–2013 (red curve) period utilizing twelve GEOS-5 model simulations (10800 values). Tick marks indicate individual samples.

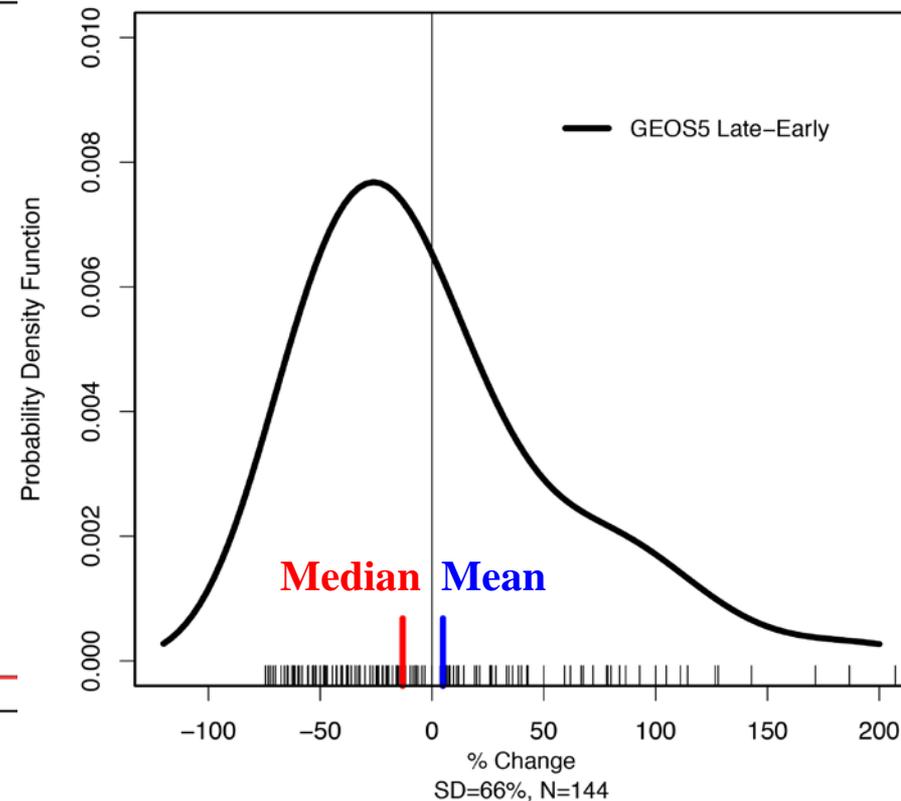
Hoerling et al. (BAMS, 2014)

North Central Colorado



Hoerling et al. (BAMS, 2014)

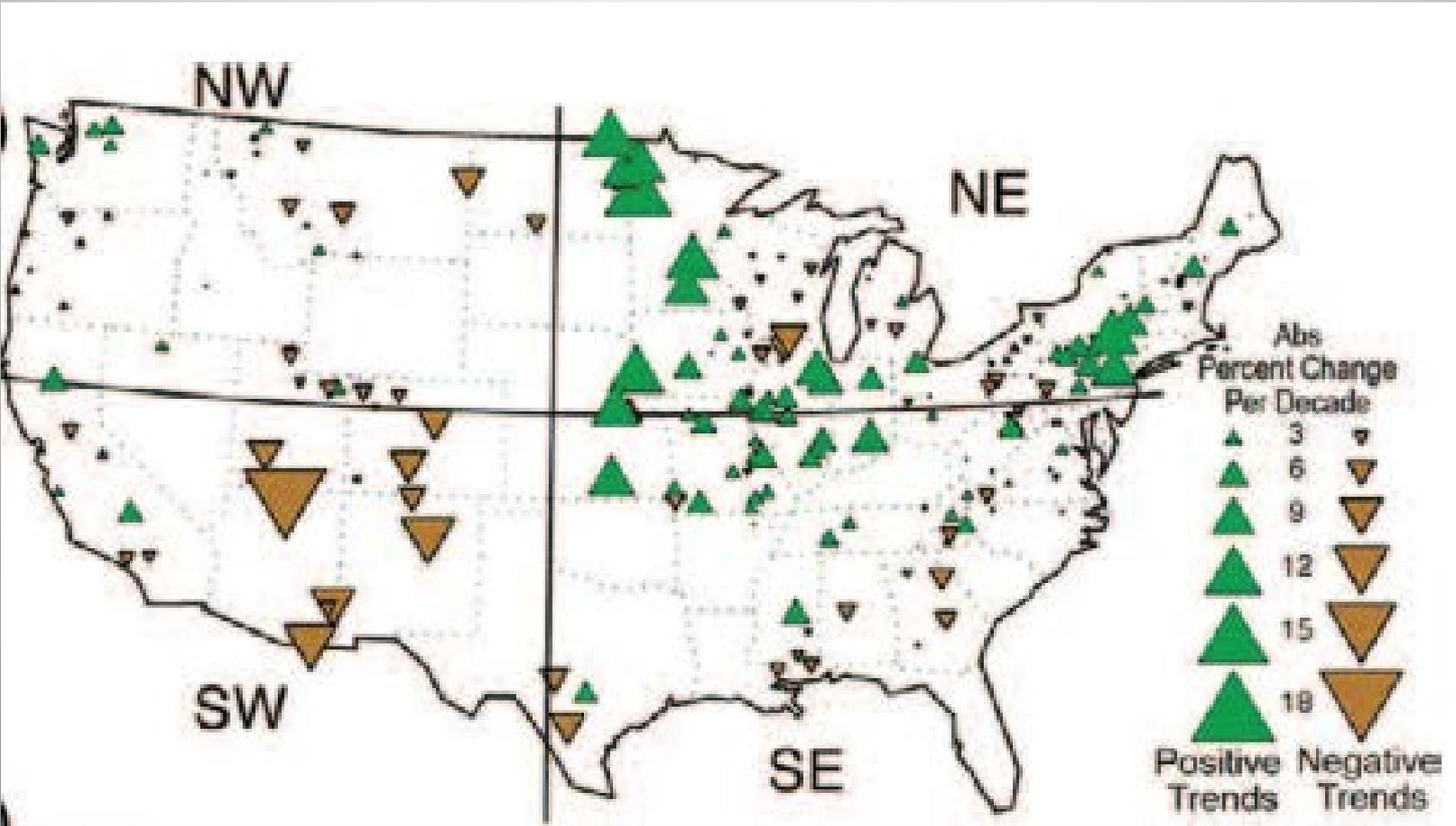
North Central Colorado 5–Day Sep PPT Totals Change at 90% Level, 1984–2013 minus 1871–1900



Left: Climate model simulated frequency distributions of five-day September precipitation totals (mm) over the study area for 1871–1900 (black curve) and the 1984–2013 (red curve) period utilizing twelve GEOS-5 model simulations (10800 values). Tick marks indicate individual samples.

Right: Change figure compares all 12 ensemble members against each for the two 30yr periods. Note that the median indicates a drop consistent with the published figure (left), while the mean outcome is actually an increase (skewed distribution).

Corroborating evidence from Peterson et al. (2013, BAMS): Annual flood frequency trends over last century: downward along the CO Front Range, consistent with lack of upward trend in extreme rainfall events (through 2012).



Summary

- **Record-breaking moisture (PPW for September) was pushed against the CO Front Range last year, and remained in place for a long enough period to give Boulder its biggest rainfall event on record from daily to annual time-scales.**
- **GEOS-5 was used to evaluate whether the regional footprint of climate change (PPW increase) can be invoked to explain this event (simple null-hypothesis). The model does a reasonable job in modeling the pdf of observed 5day precipitation in NE Colorado, but appears to have a wet bias for PPW.**
- **Since the late 19th century, modeled PPW has increased consistent with global changes, but modeled precipitation has not increased, *although the scatter is quite large around that result.***
- **High values of precipitable water are a necessary, but not sufficient condition for extreme rainfall events in NE Colorado, perhaps analogous to the role of SST in the generation of hurricanes. *Much more work is needed!***

Future research

- **Role of SST in this (*El Niño favors floods in CO, but not present in 2013*)**
- **Which parts of the large-scale synoptic features are reproduceable in coupled models in particular? Can similar storms be identified in such models and tracked over time? *Will they become more frequent/intense/longer-lasting in the future?***
- **How important are meso-scale features to understand Front Range flooding?**
- ***Is there a better way to define extreme rainfall events than NOAA Atlas 14? Can we make better estimates based on the much denser network of precipitation stations with shorter histories? Can we reconcile flooding records with precipitation records?***

The NOAA assessment is handicapped by the lack of reliable long-term station data

July 27nd - August 4th, 1997 Precipitation using National Weather Service Coop Stations

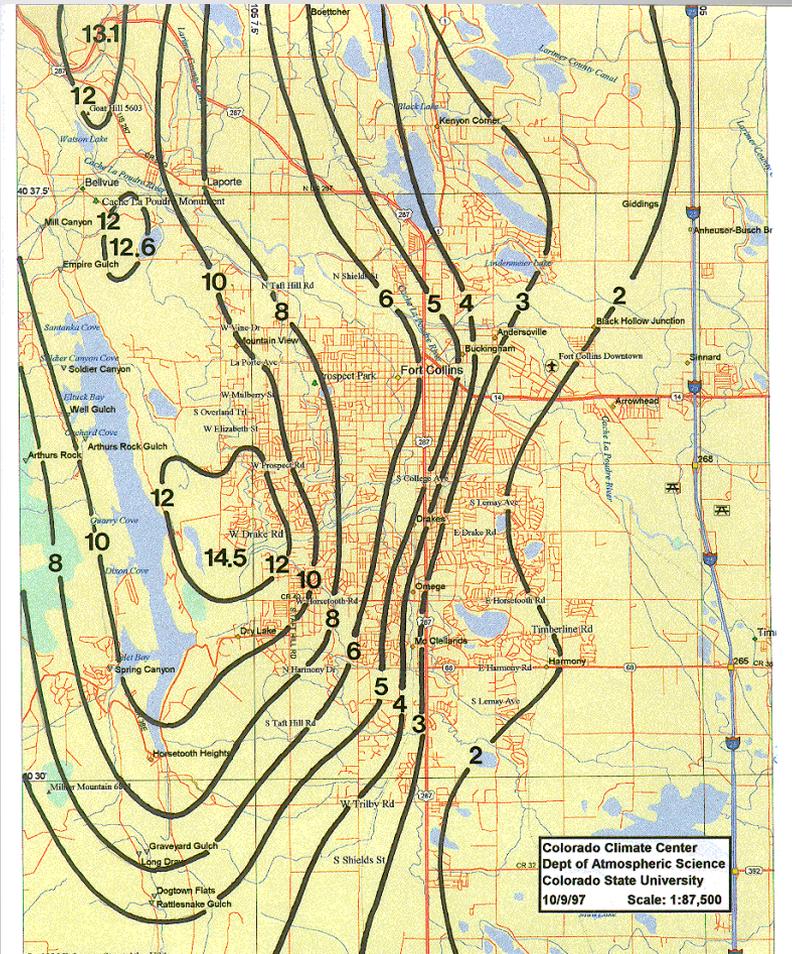
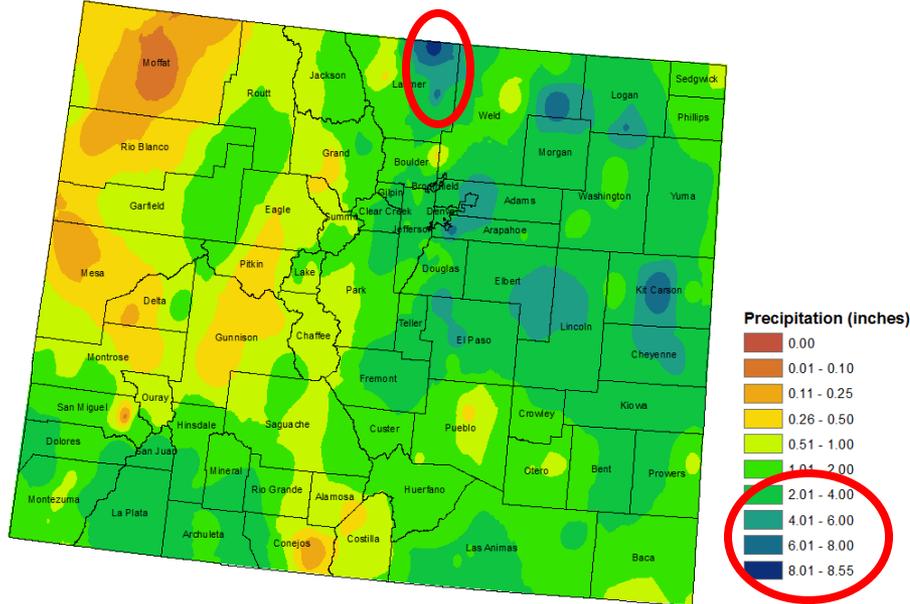


Figure 14. Rainfall (inches) for Fort Collins, Colorado, for 4:00 p.m. MDT July 27, 1997 through 11:00 p.m. MDT for July 28, 1997

Colorado Climate Center
Dept of Atmospheric Science
Colorado State University
10/9/97 Scale: 1:87,500

Before September 2013, we had at least five daily to weeklong events of 10"+ in the last five decades along the Colorado Front Range:

June 1965, May 1969, July 1976, July 1997, April-May 1999

Most of them were not captured by long-term climate stations, but they happened nevertheless!

Perhaps we should expect to see these events more often than the term "1000-year event" would suggest...