An extreme event of our own: Were the floods of last September explained by more moisture in the air?

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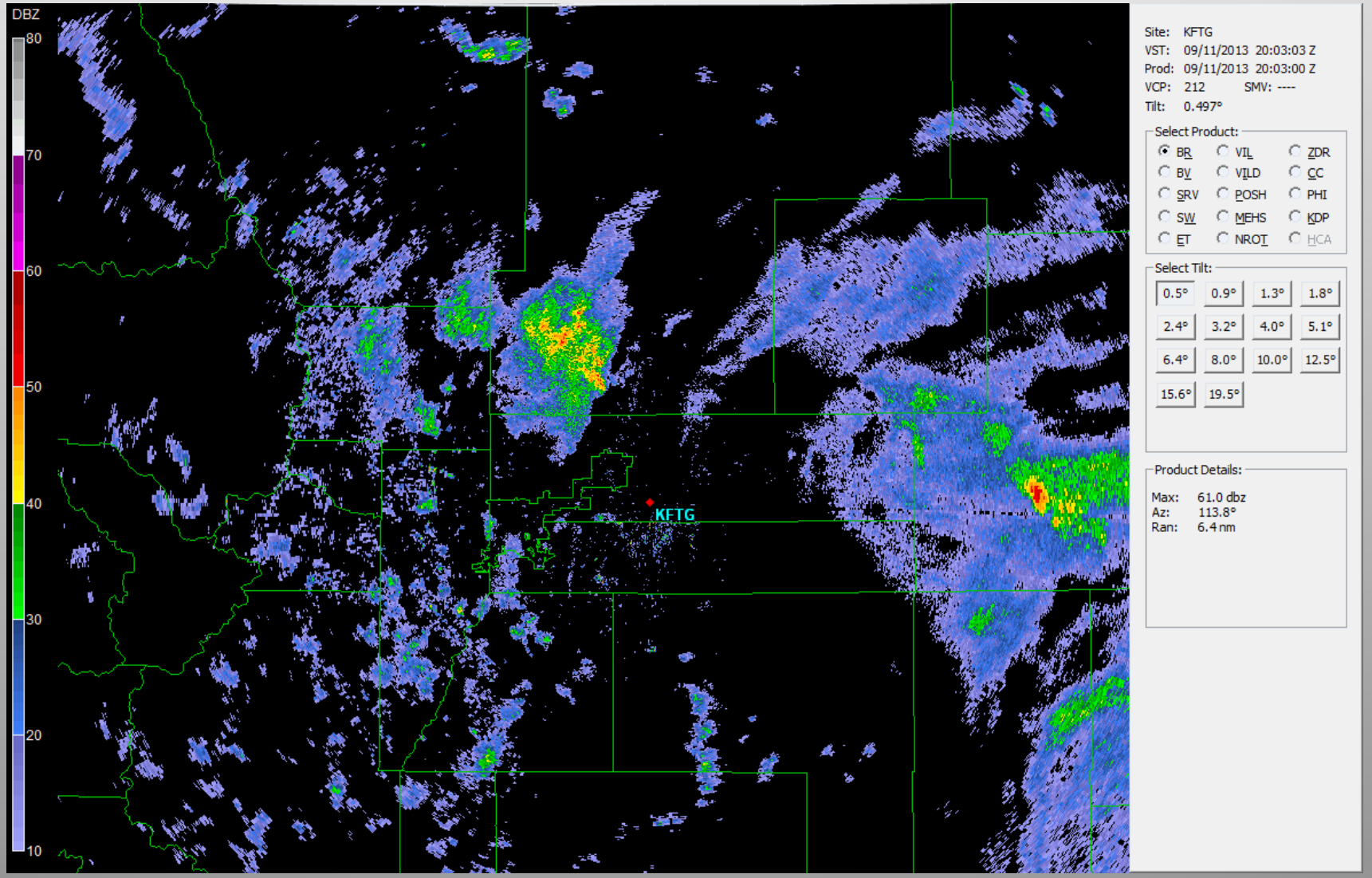
- ***Colorado disasters don't get bigger than this***
- ***Key ingredients***
- ***Focus on precipitable water in GEOS 5***
- ***We have only 'dipped our toes into the flood waters' – next***

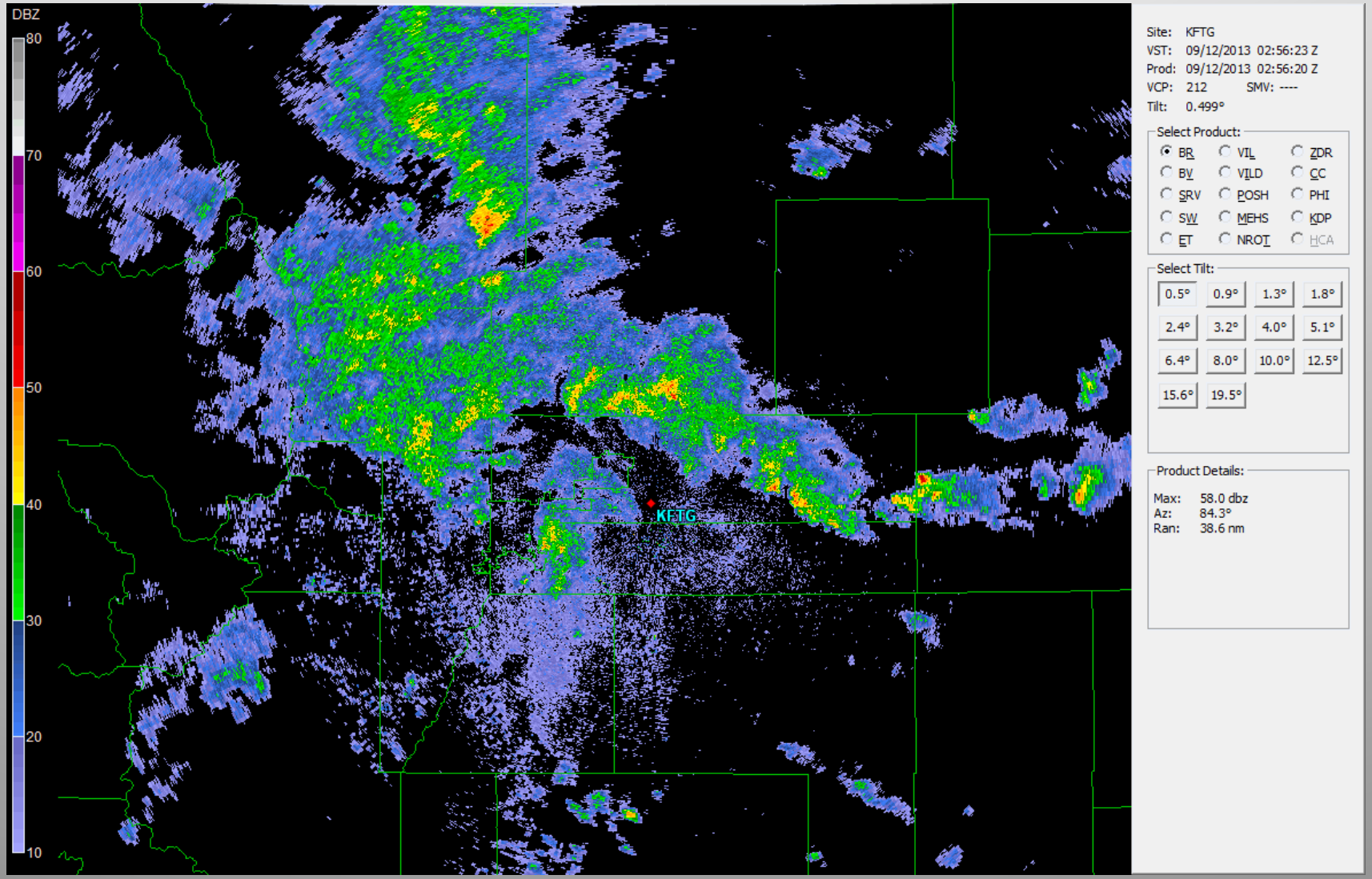
<NOAA-Atlas 14: Was it really a 1000-year event?>

<<Another analogue: September 1938>>

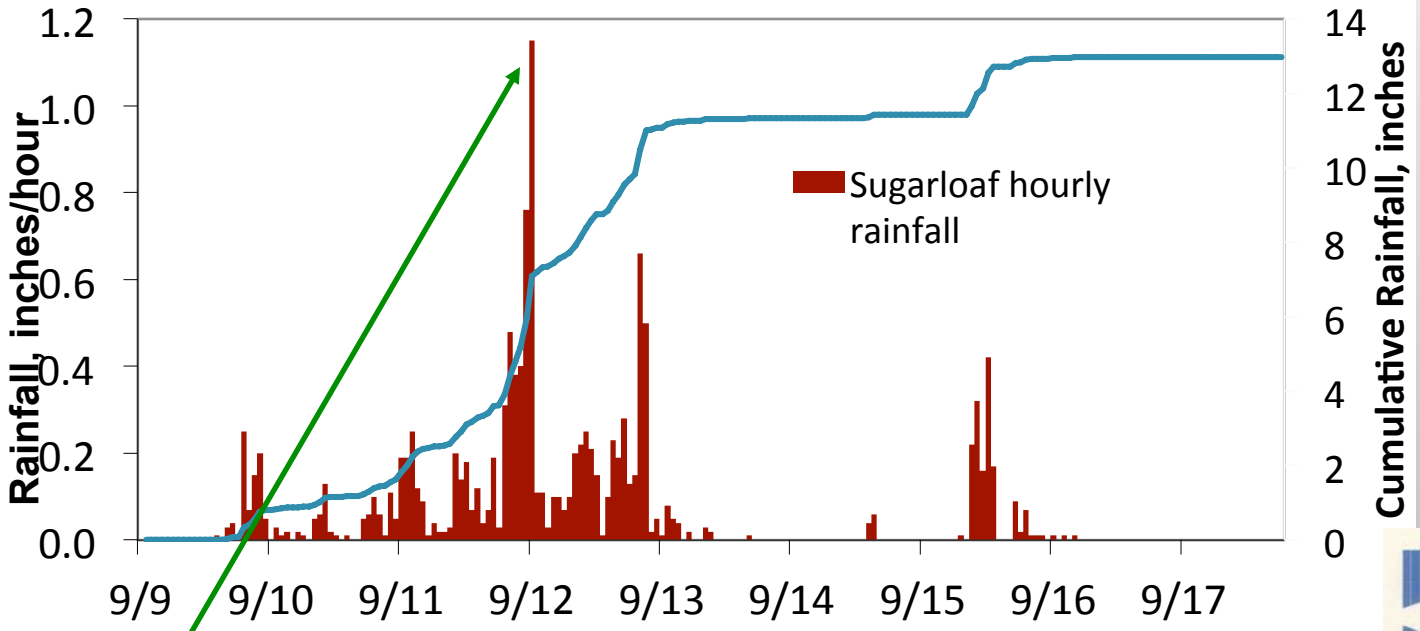
KFTG 9/11 20Z – 9/12 03Z



KFTG 9/12 03Z – 9/12 08Z

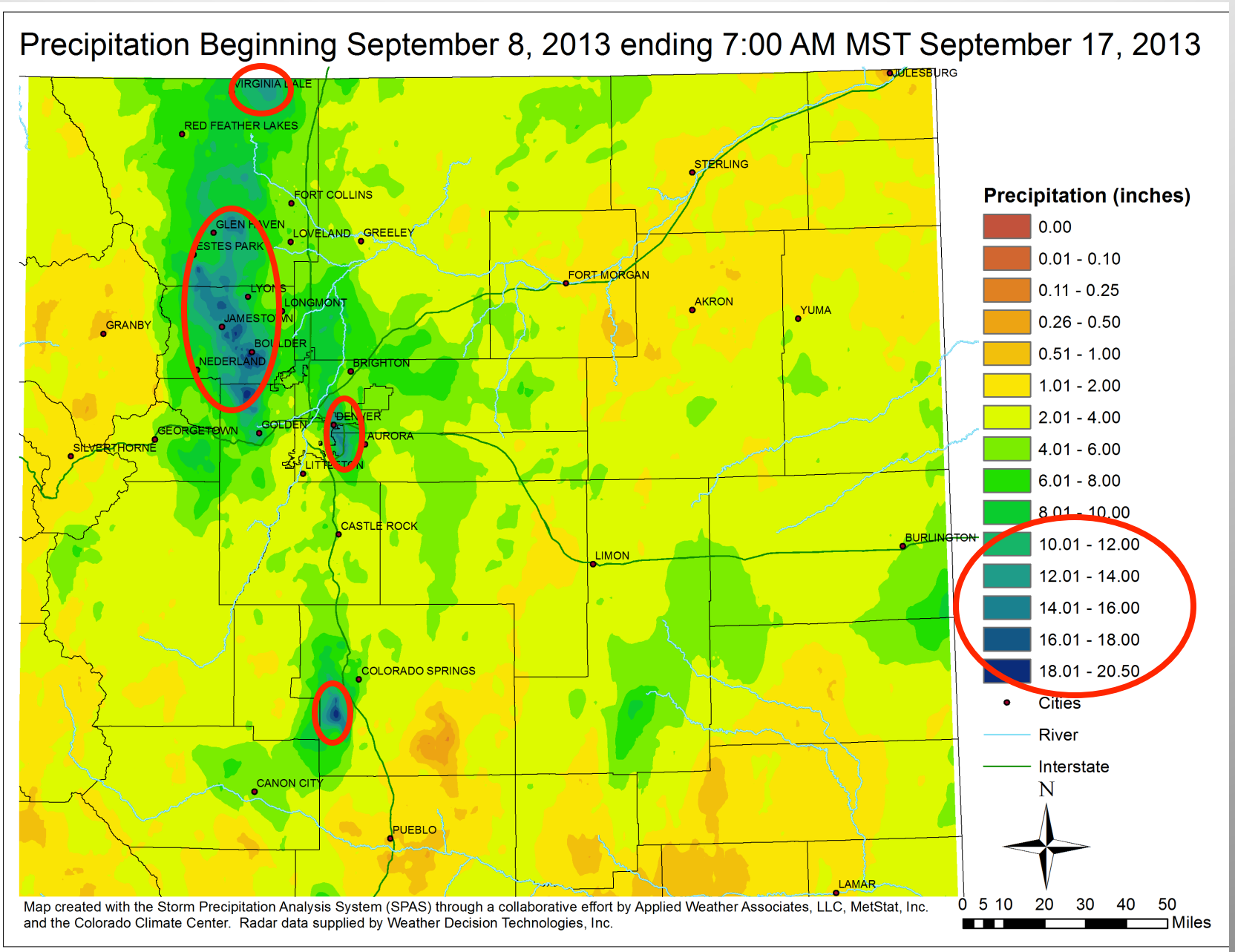


Hourly and cumulative precipitation, Sept 9-17, 2013
Sugarloaf RAWS station 6 mi (10km) west of Boulder



1"/h ~ 10yr event according NOAA Atlas 14, more like once in 2-5 year, based on my own measurements higher up since 1990

‘Final’ rainfall totals based on 2K+ observations



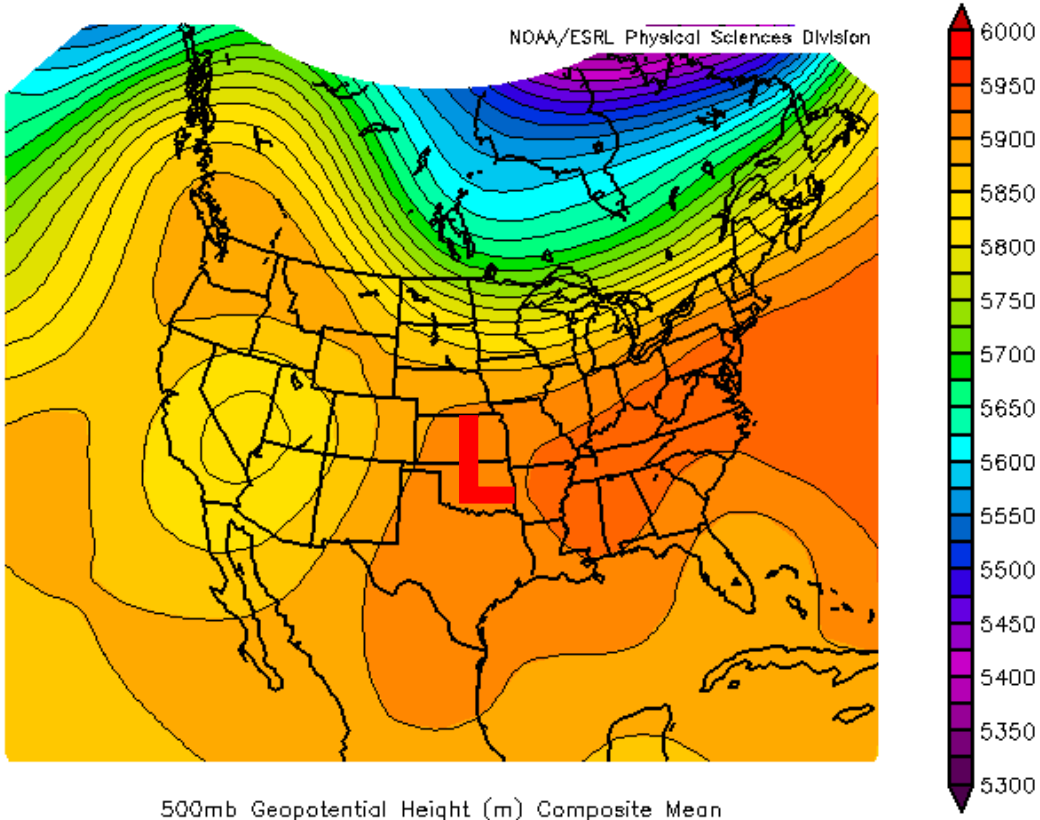
Impacts: Flooding and Debris Flows

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

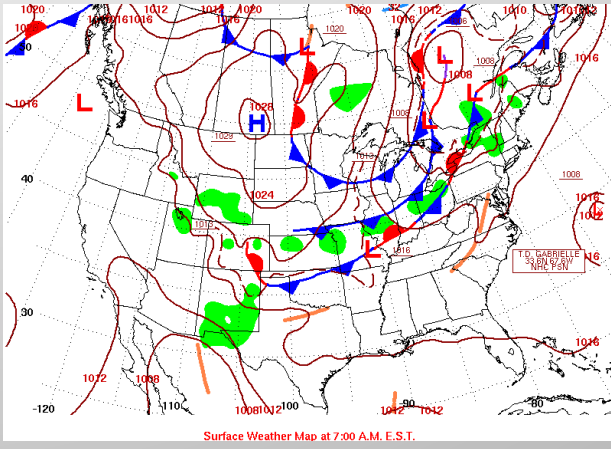
September 11-12th, 2013: Synoptic-scale features

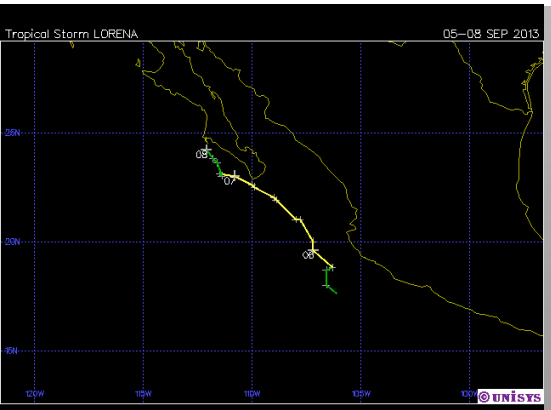
Blocking ridge to our north

Cutoff low to our southwest

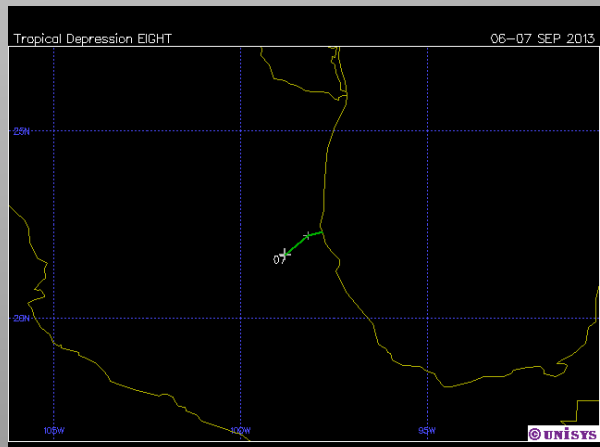


Stationary surface front just to our south

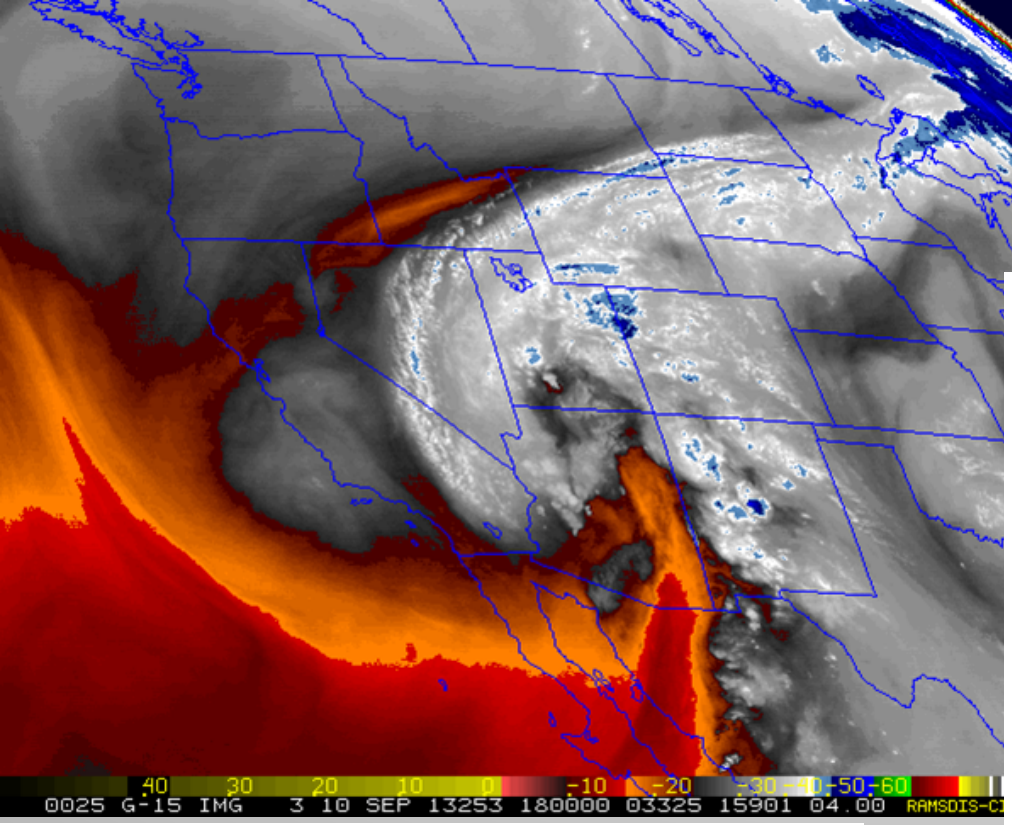


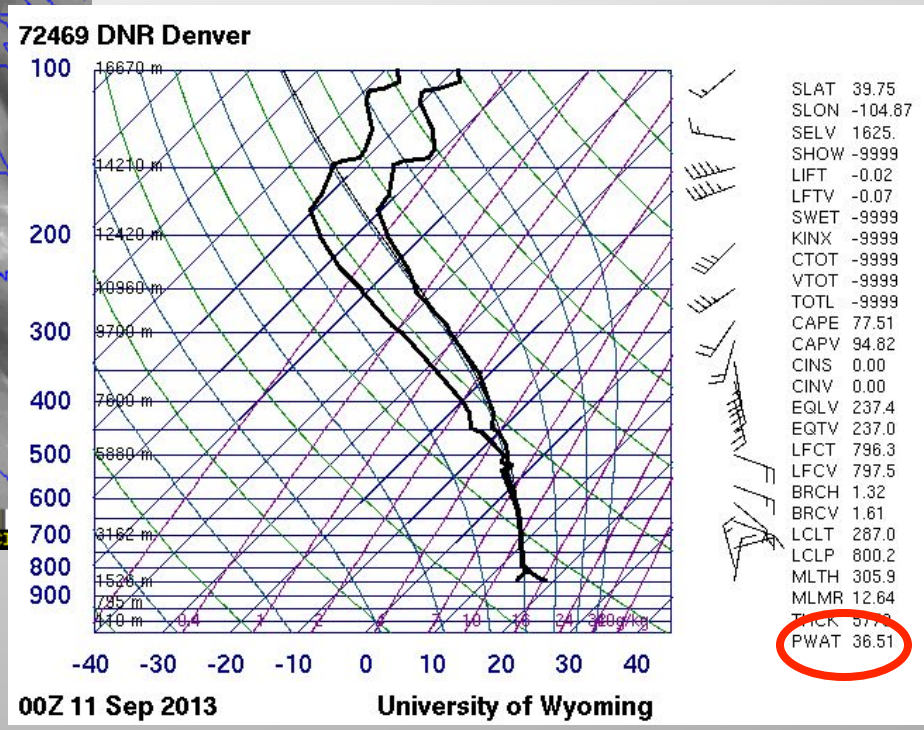


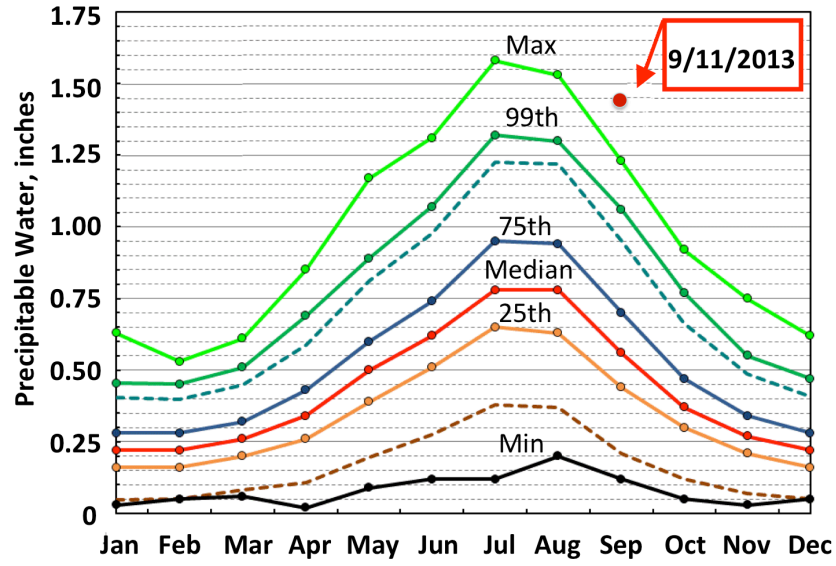
Nothing like landfalling tropical systems to 'prime the moisture pump'



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







The day it spilled…

Observed atmospheric precipitable water over Denver on September 11, 2013, compared to all observations from 1948-2012

Interpreting our September flood in the context of a warming globe

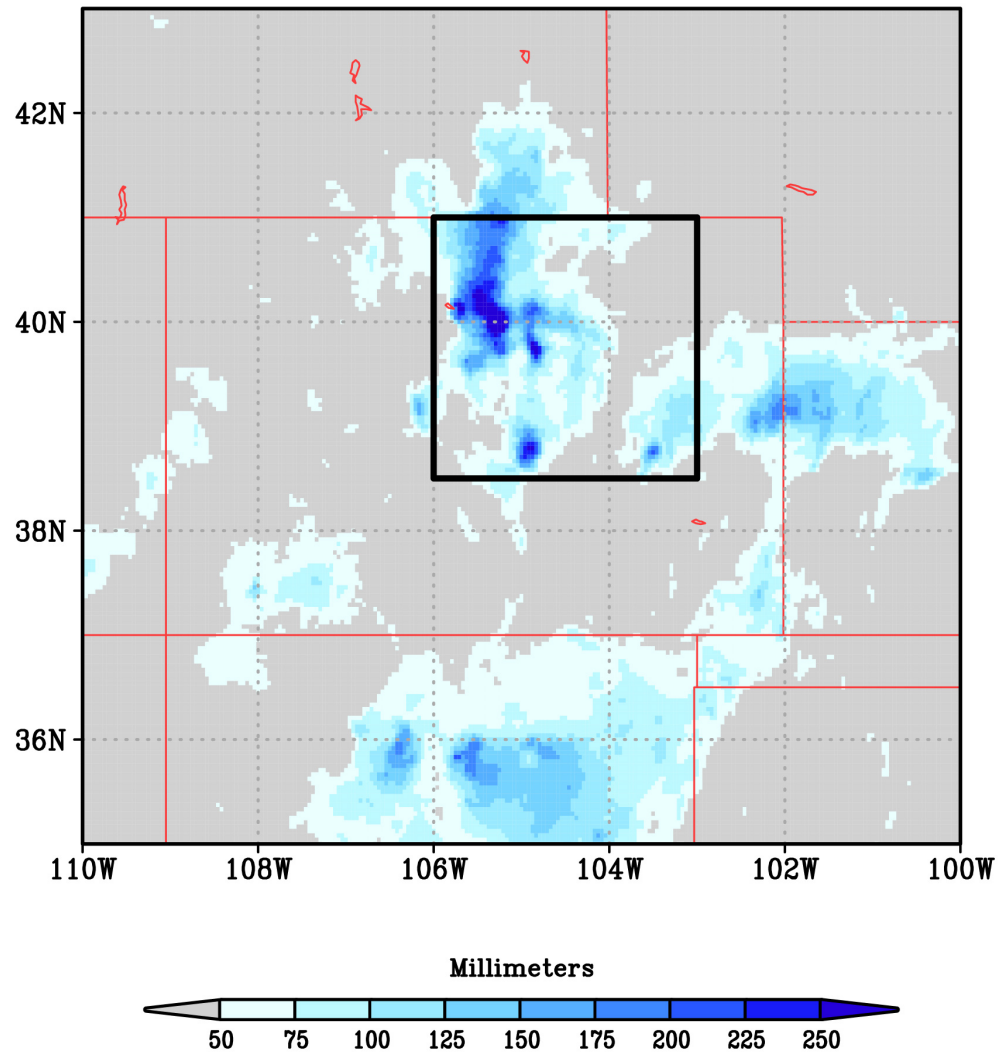
- ***What is the observed and modeled (GEOS 5) relationship between precipitable water (PPW) and precipitation over Northeast Colorado?***

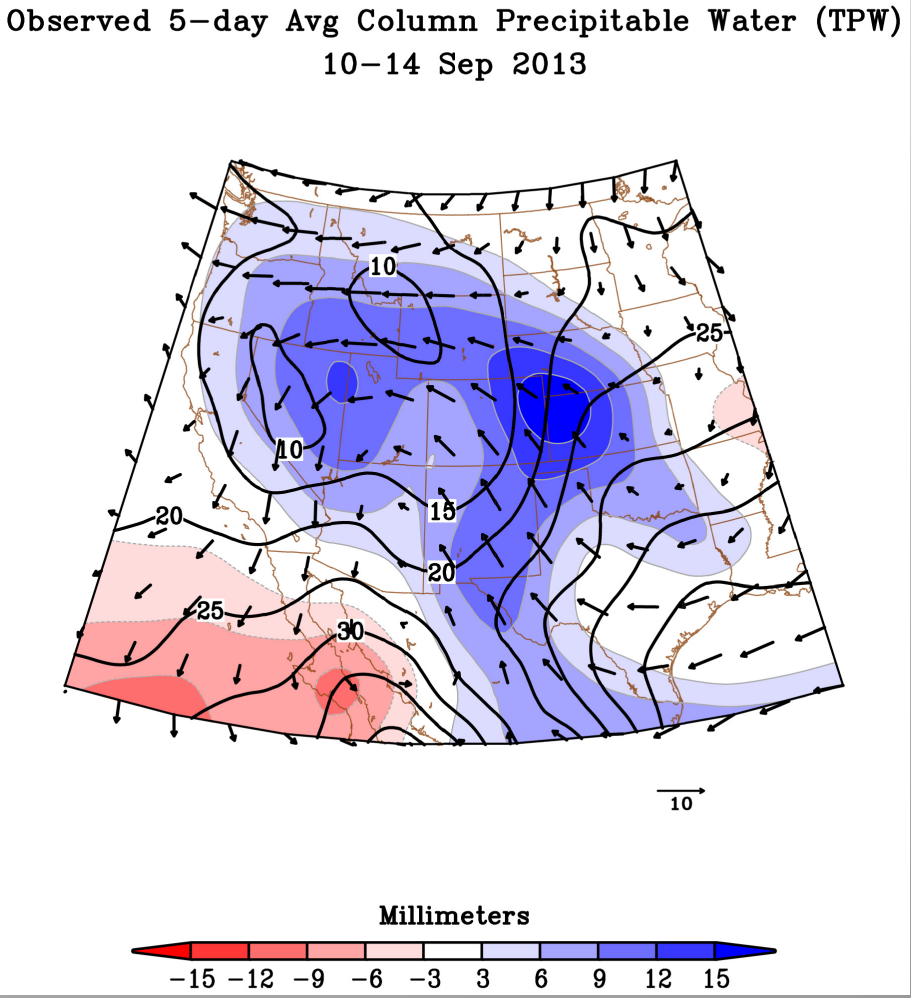
- ***Does the GEOS 5 model produce realistic precipitation pdf's for this region?***

- ***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 (1°x1° by Jon Eischeid)

Converting into 1°x1° universe (left), and a closer look at ppw (right)

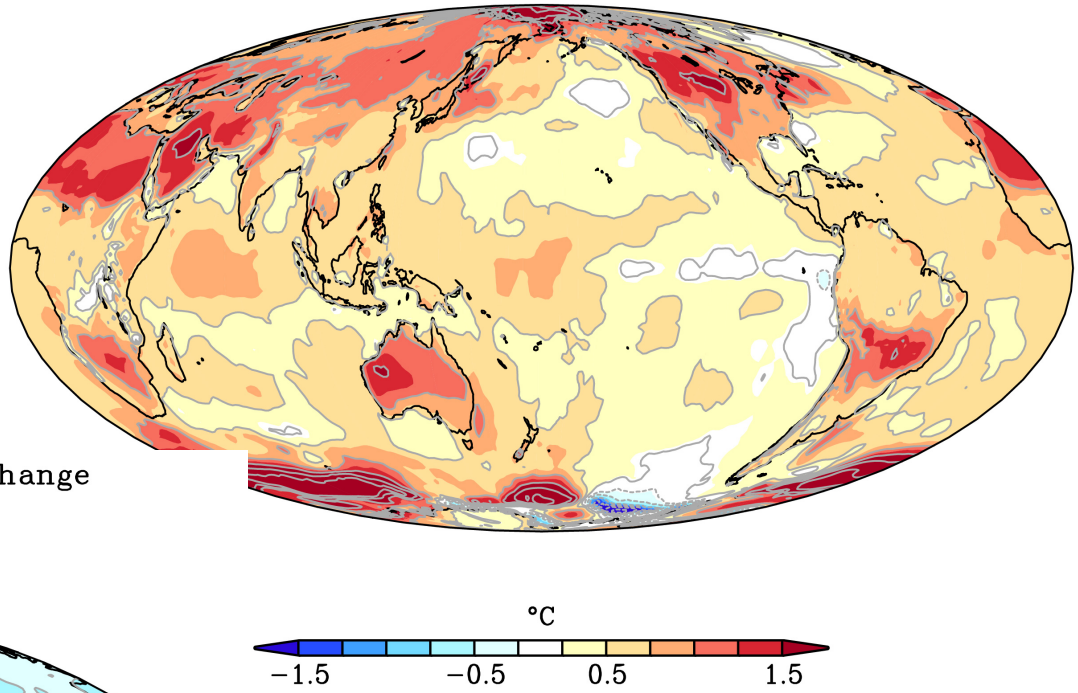




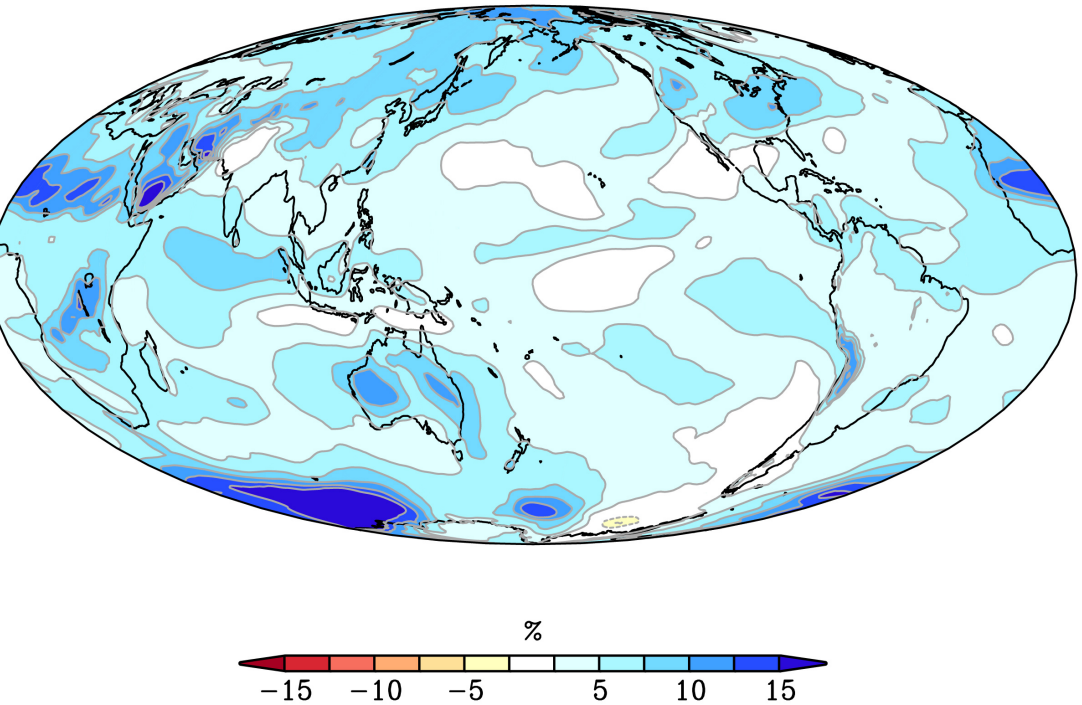
Hoerling et al. (BAMS, 2014)

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

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



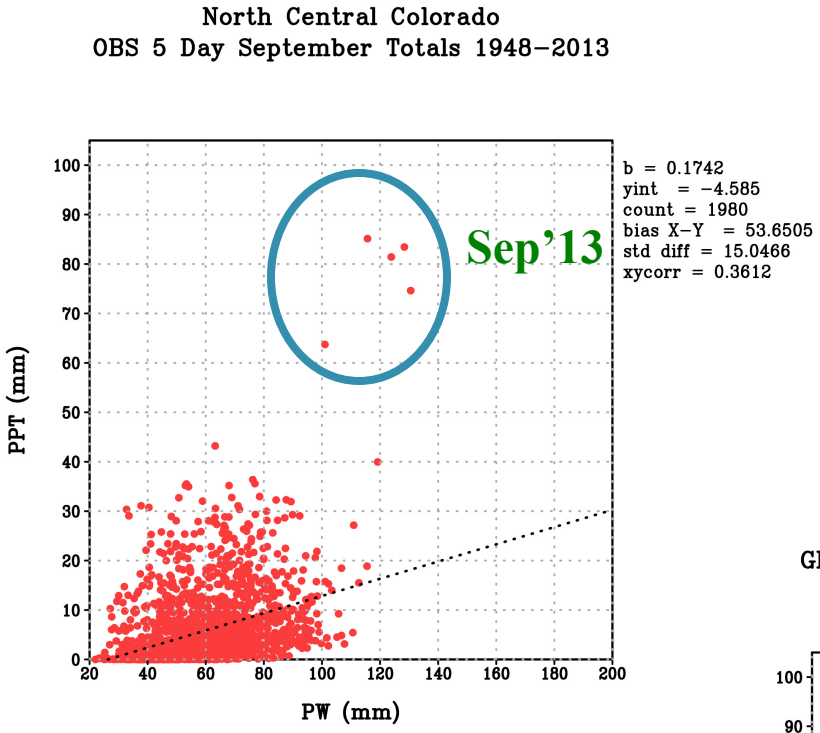
Simulated September Precipitable Water Change
(1984–2013) minus (1871–1900)



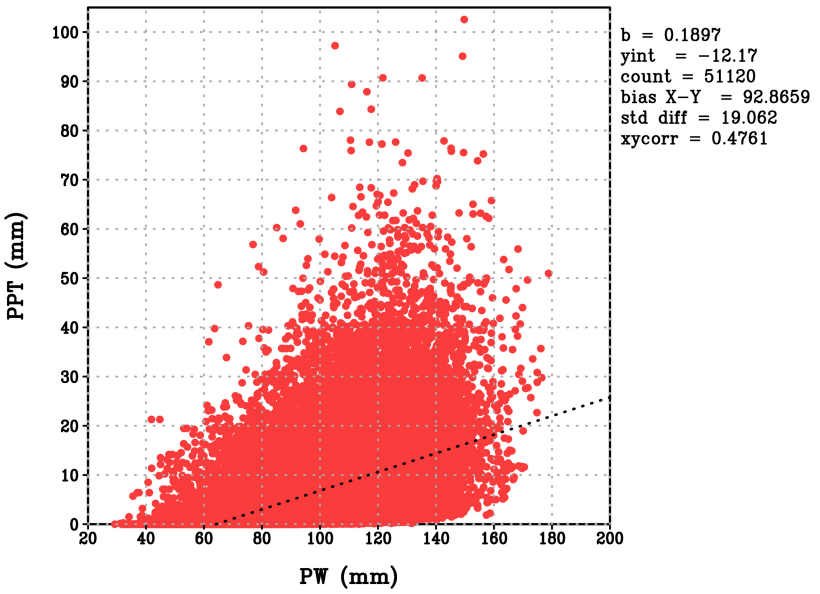
Global atmospheric water vapor has risen on the order 5% over the 20th century, and about 4% since 1970 (Trenberth et al. 2005). GEOS 5 shows an increase of 5.7% for the periods shown.

Hoerling et al. (BAMS, 2014)

Observed Relationship: 5-Day Pcpn vs PW

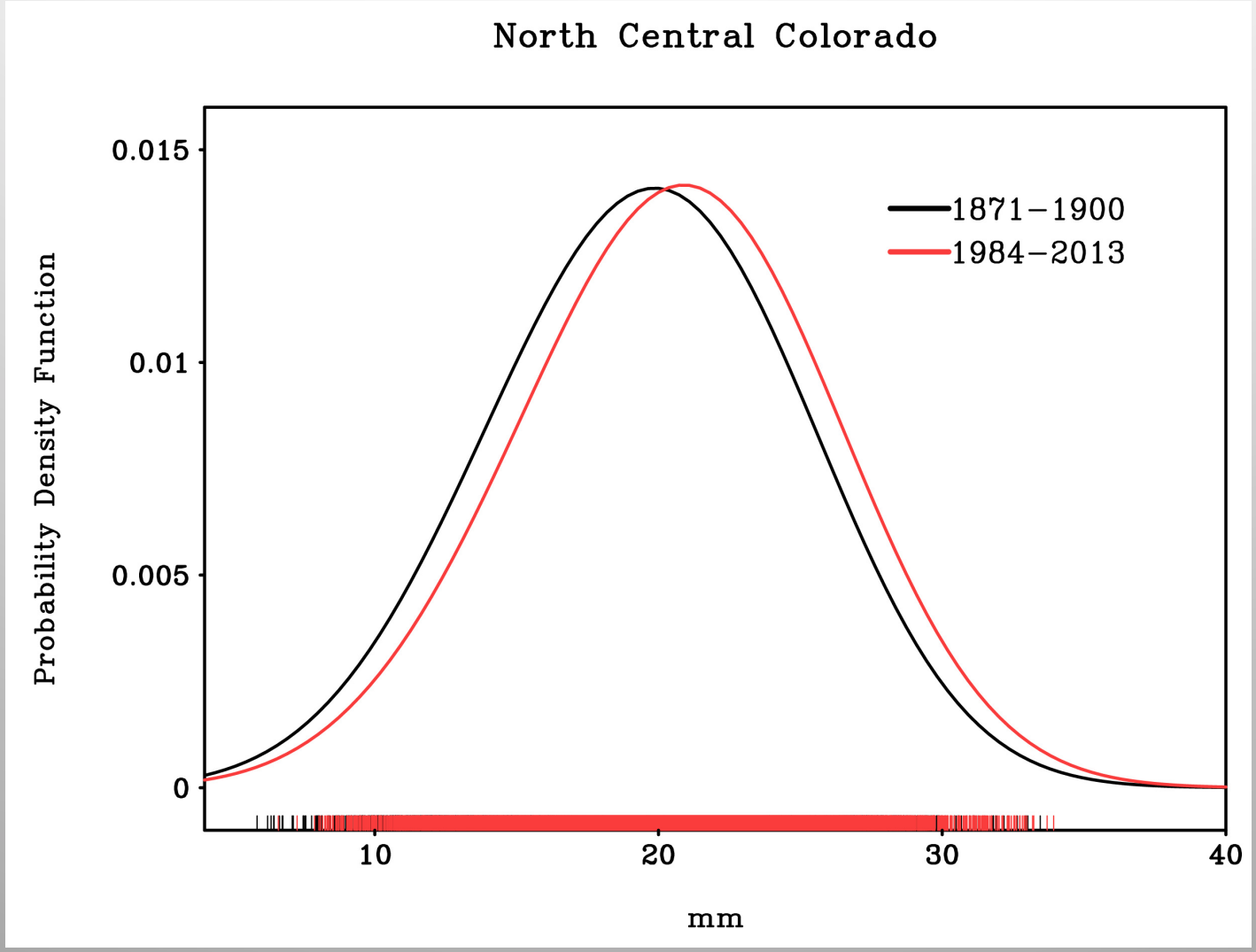


Modeled Relationship



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

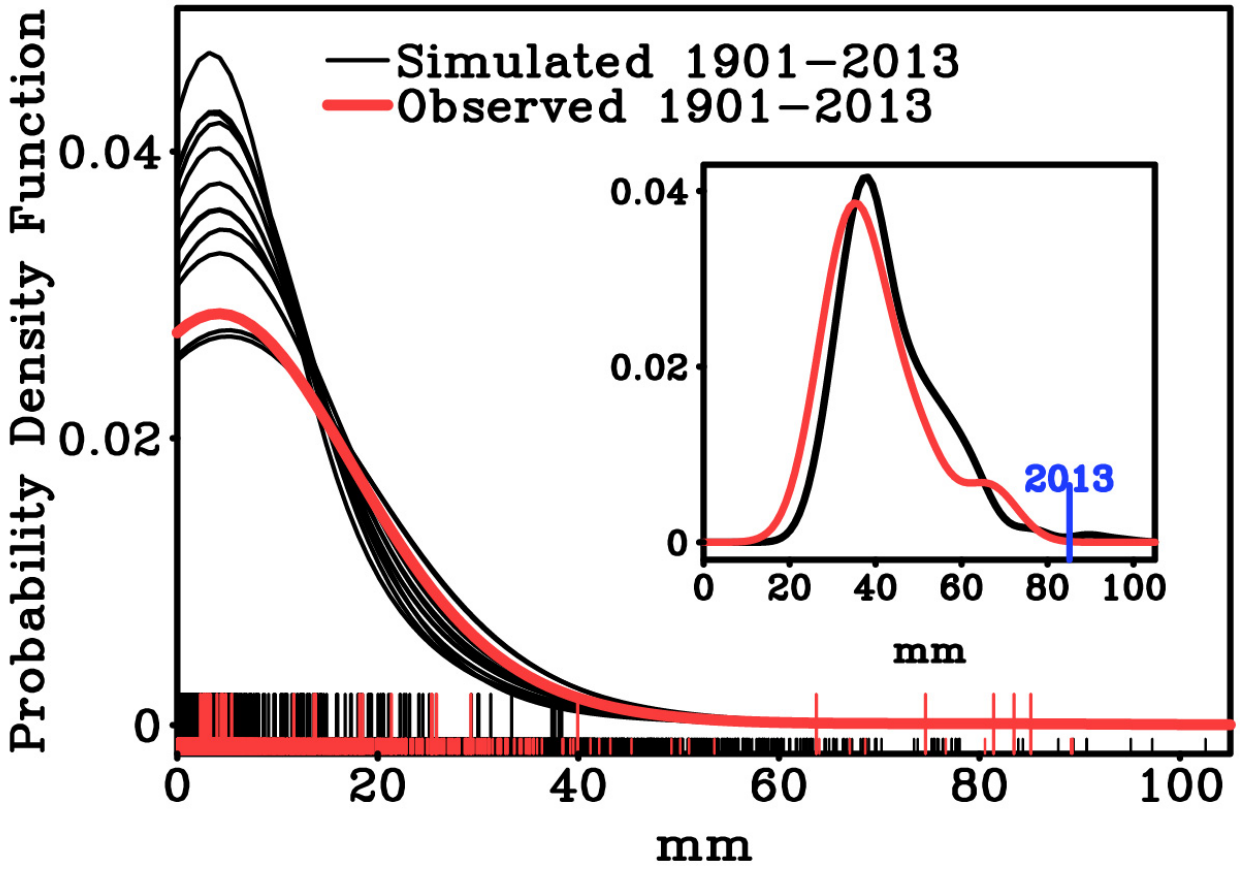
Relationship between precip and PPW is 'loose' (<25% variance)



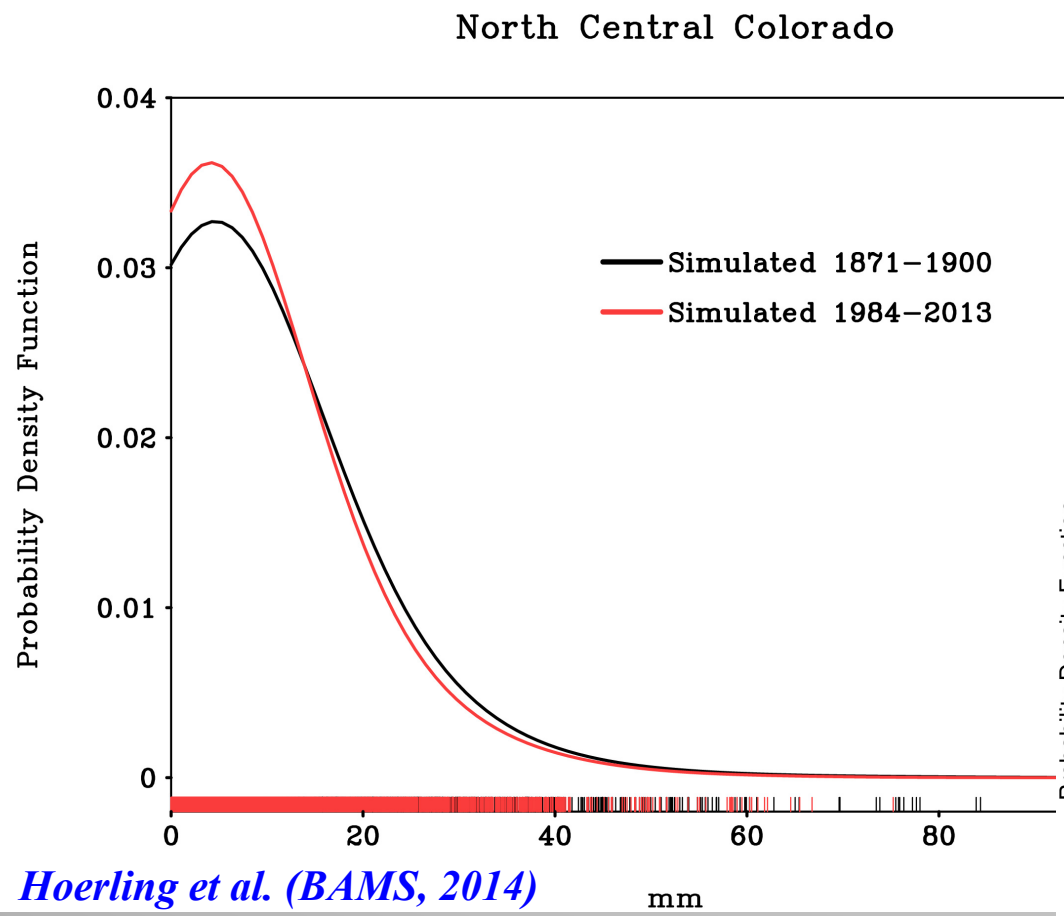
Climate model simulated frequency distributions of five-day September precipitable water (mm) over the study area for 1871–1900 (black curve) and the 1984–2013 (red curve) period utilizing twelve GEOS-5 model simulations (10800 values). Tick marks indicate individual samples.

Hoerling et al. (BAMS, 2014)

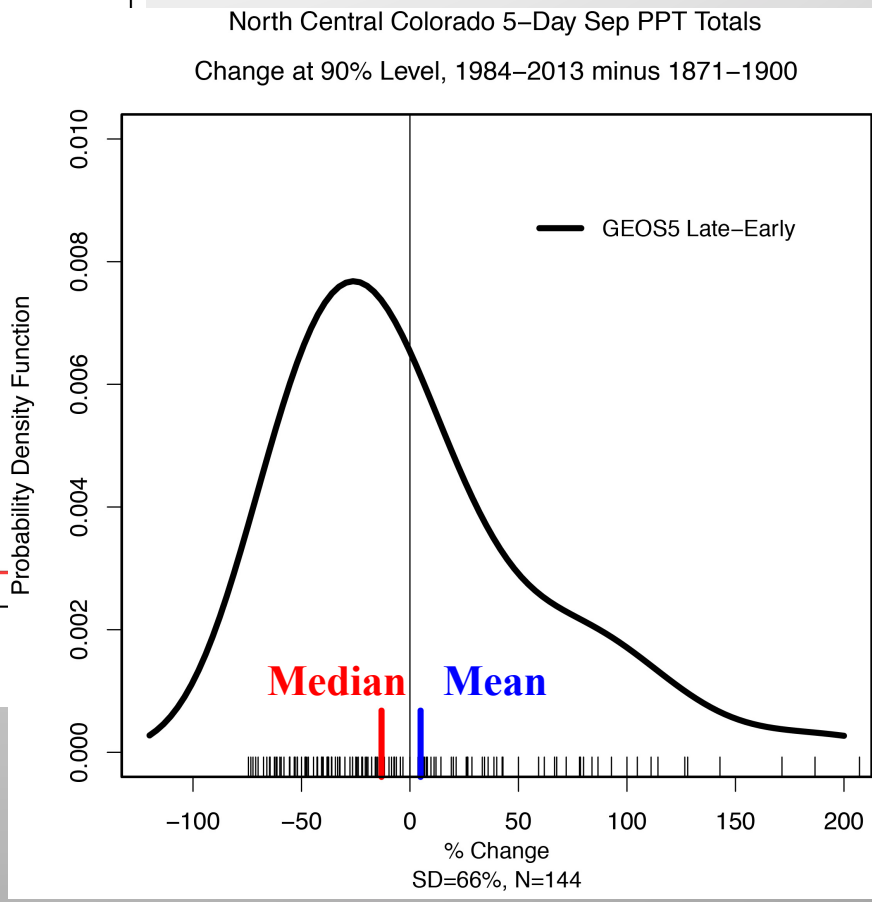
Hoerling et al. (BAMS, 2014)



Frequency distributions (PDFs) of five-day cumulative precipitation during September averaged over the study area for observation (red curve; 3390 values) and for individual ensemble members of climate model simulations (black curves; 3390 values per simulation, 51480 total) for the period 1901–2013. Individual 5-day running totals are shown with tick marks, and September 2013 values are indicated with taller tick marks. The PDFs are non-parametric curves utilizing kernel density estimation and a Gaussian smoother. Inset shows the frequency distribution of 100-year block maximum values of the wettest 5-day rainfall for all consecutive 5-day periods in September based on observations (red; 30 samples), and the ensemble of GEOS-5 simulations (black; 360 samples) for the 100-year period 1913–2012. Observed 5-day peak value in September 2013 shown by blue tick mark.

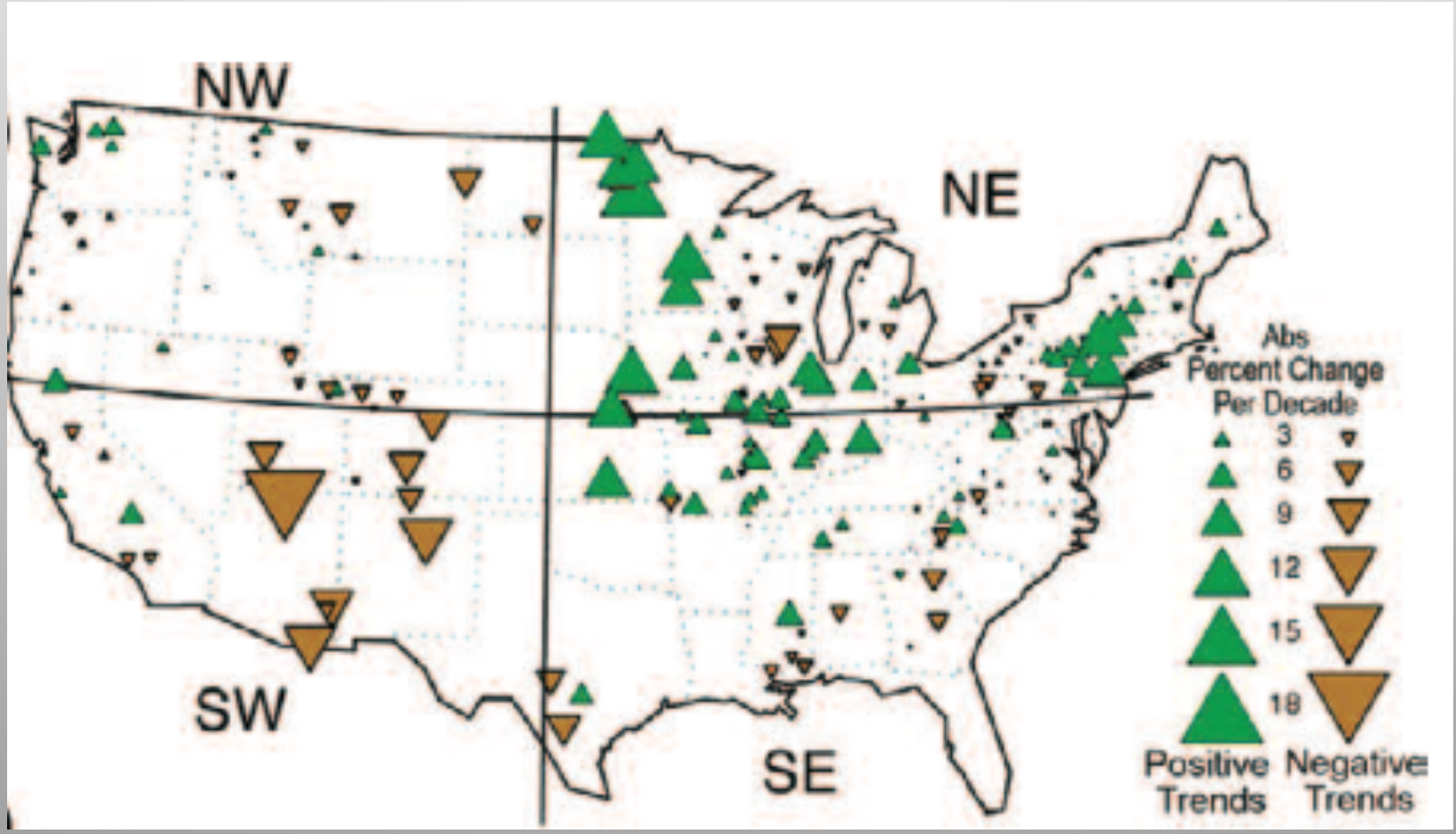


Hoerling et al. (BAMS, 2014)



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. *Change figure on the right compares all 12 ensemble members against each for the two 30yr periods.*

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



Summary

- **Record-breaking moisture (for September) was pushed against the Front Range one year ago, and remained in place for a long enough period to give Boulder the 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 reproduced 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 in particular?**
- **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?**

NOAA Atlas 14: http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume8.pdf

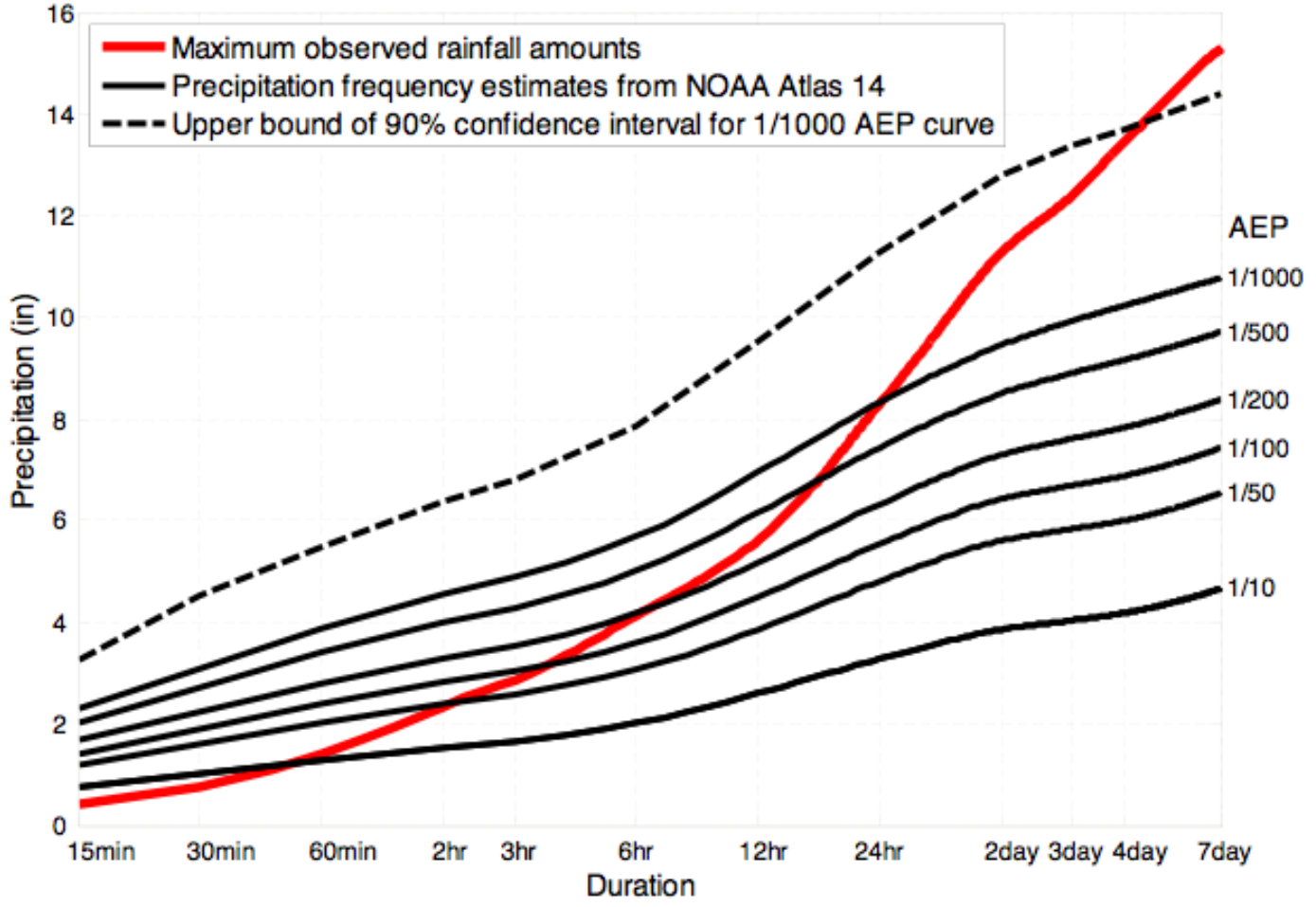


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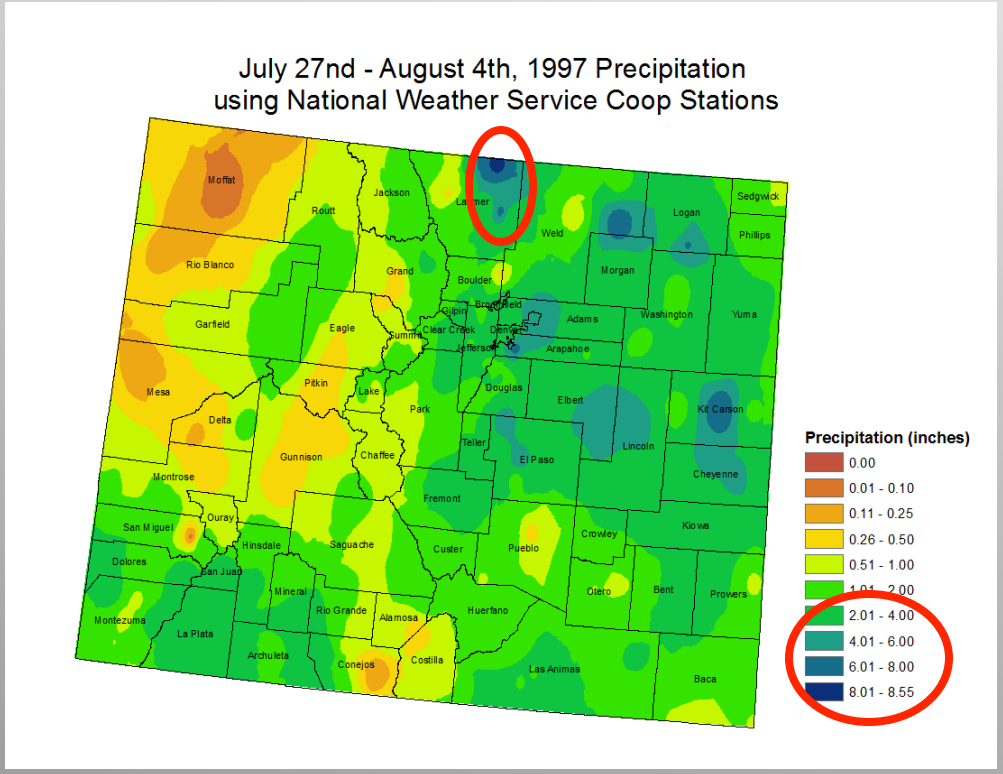
Figure 1. Maximum observed rainfall amounts in relationship to corresponding precipitation frequency estimates for the Justice Center gauge.

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



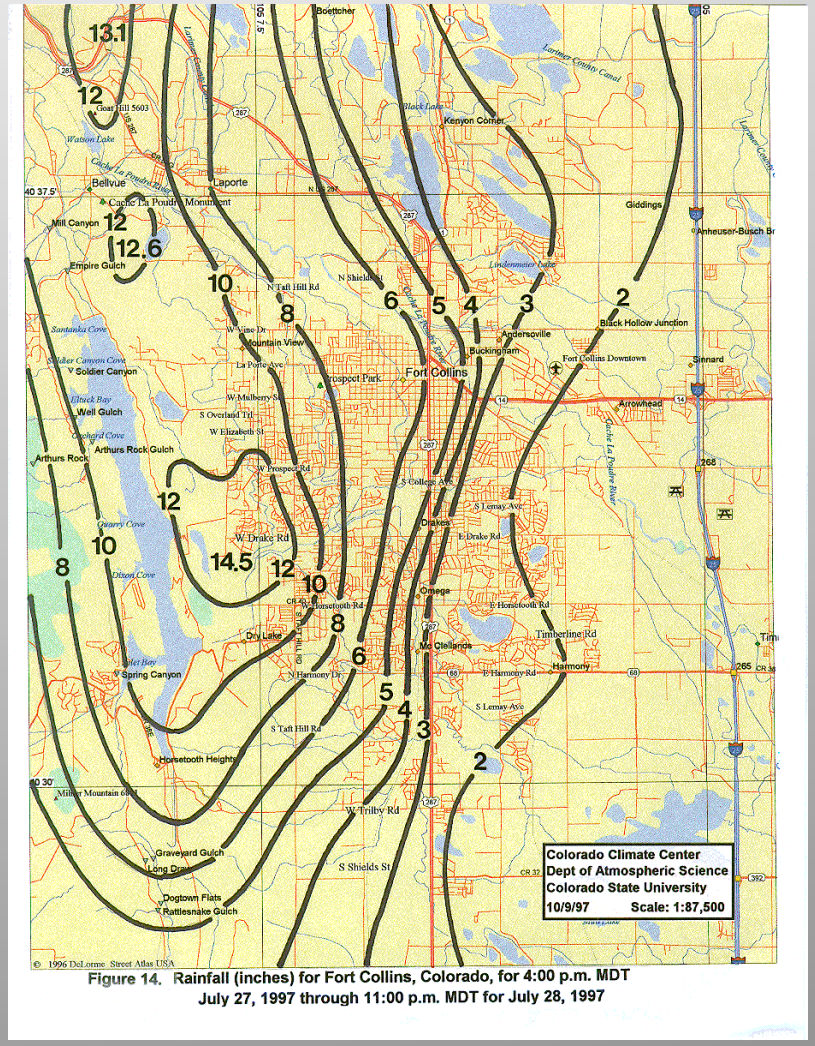


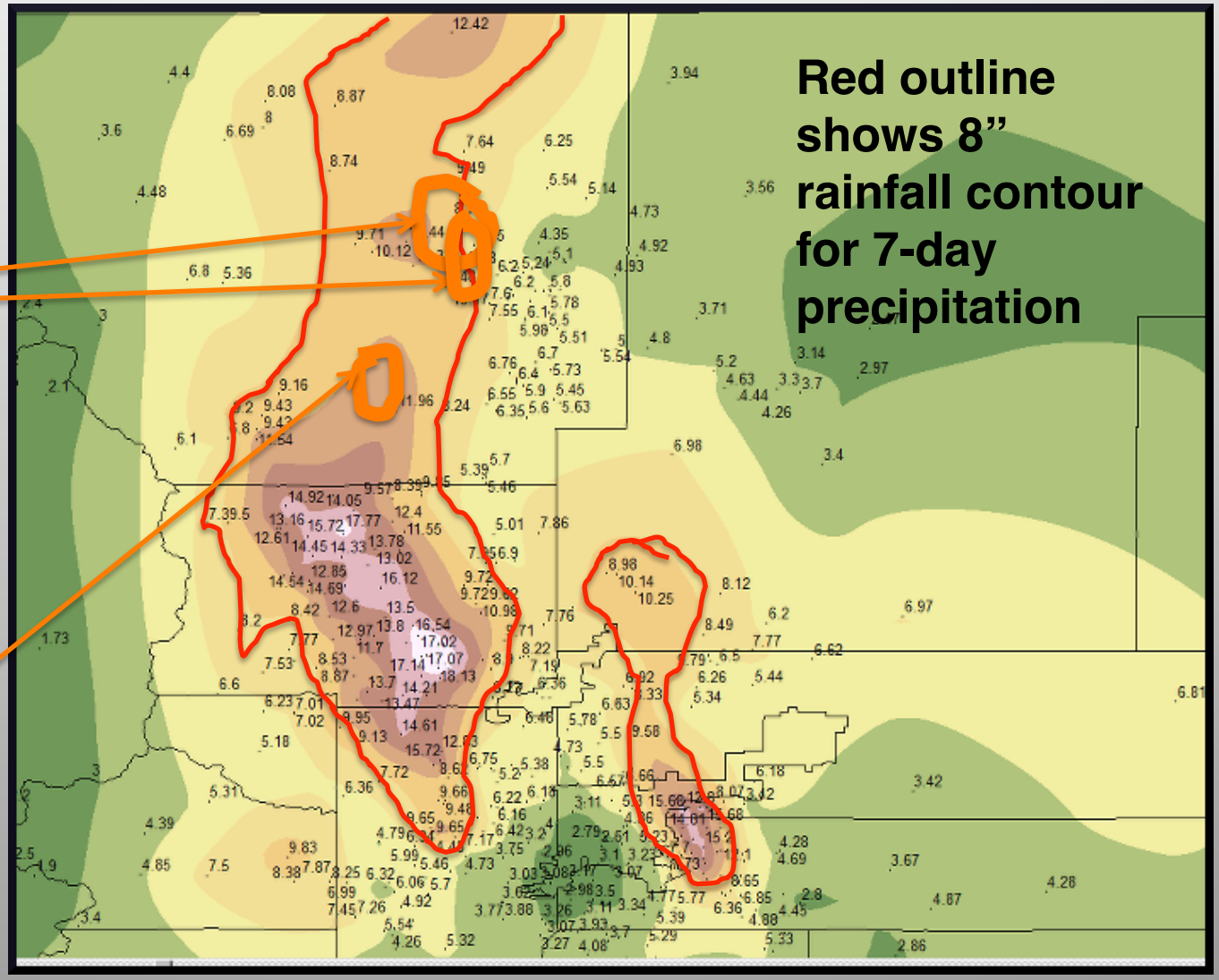
Figure 14. Rainfall (inches) for Fort Collins, Colorado, for 4:00 p.m. MDT July 27, 1997 through 11:00 p.m. MDT for July 28, 1997

Rainfall amounts: 9-16 September 2013

Estimate of 8” contour for 1997 Fort Collins flash flood, based on Doesken and McKee (1998)

Note: short-duration rainfall rates were higher in those events

Estimate of 8” contour for 1976 Big Thompson flash flood, based on Maddox et al. (1978)



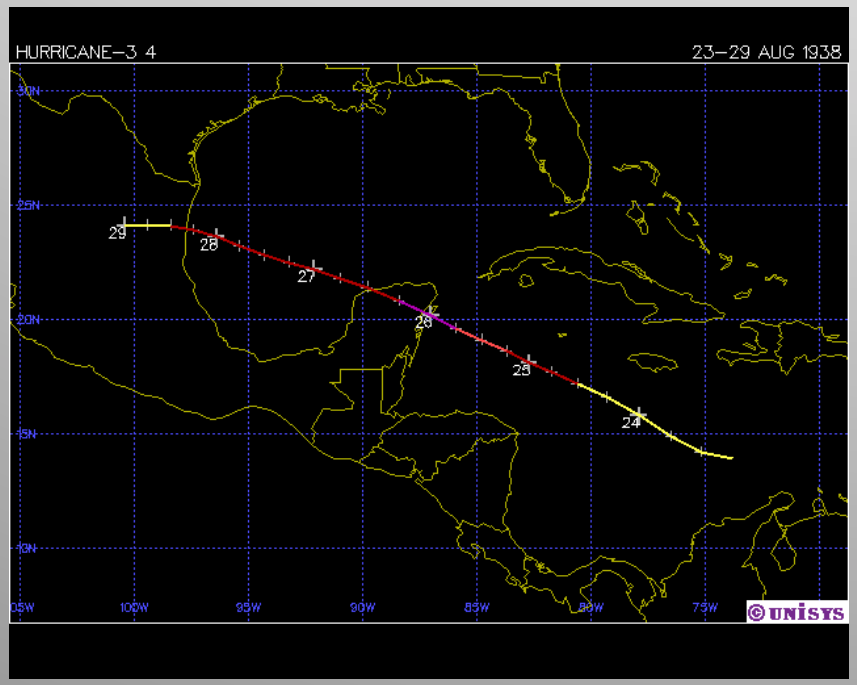
Before September 2013, we had at least five daily to weeklong events of 10”+ in the last five decades along the Colorado Front Range:

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!

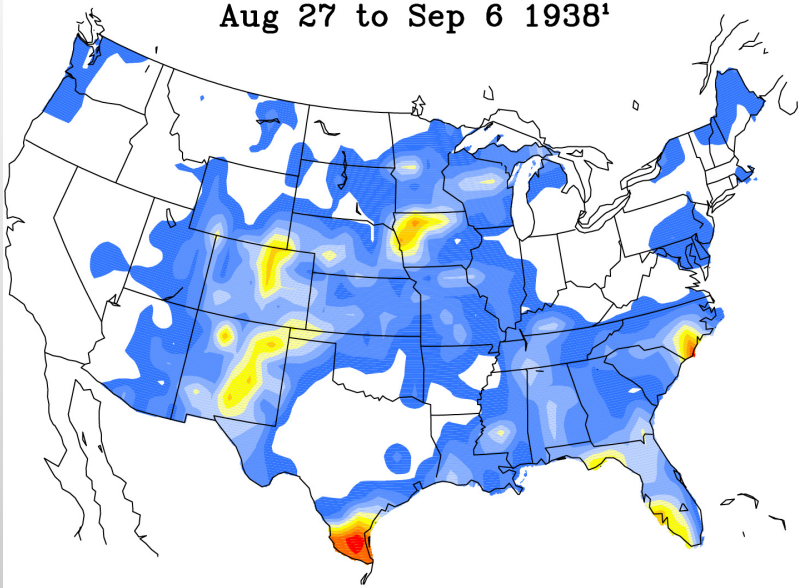
Perhaps we should expect to see these events more often than the term “1000-year event” would suggest…

Has something like this happened before?



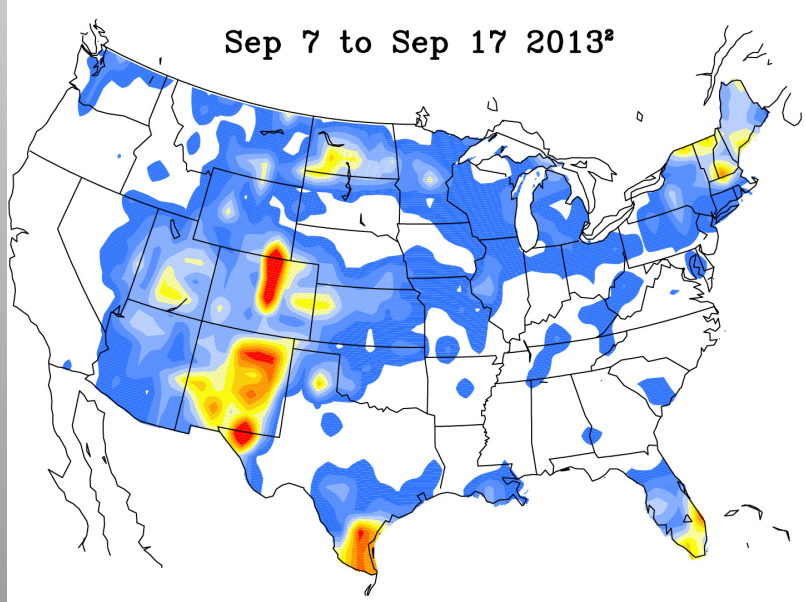
Ten Day Precipitation Totals

Aug 27 to Sep 6 1938[1]

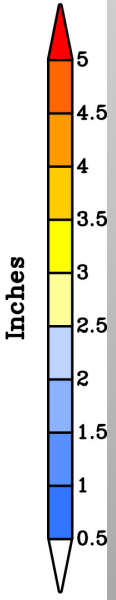


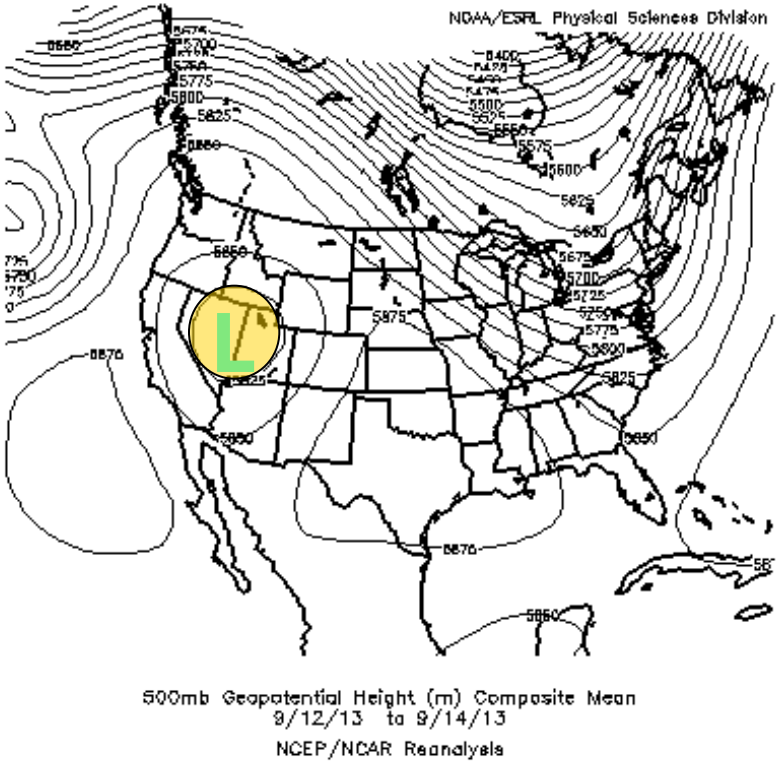
1 GDCN Station Data Analyzed at 1°x1°

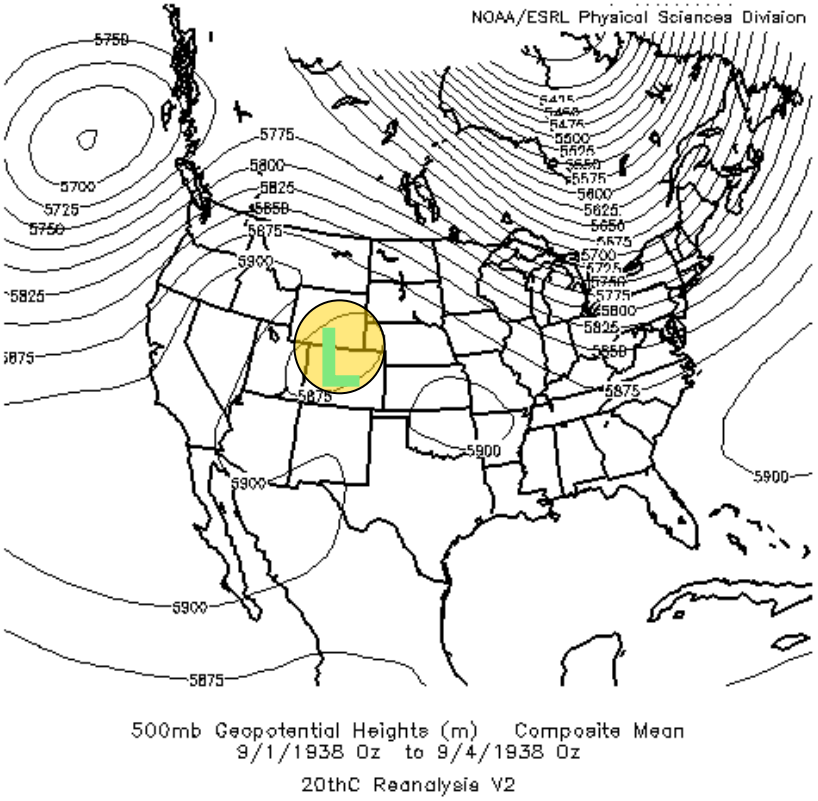
Sep 7 to Sep 17 2013[2]



2 CPC Real Time Data Analyzed at 1°x1°



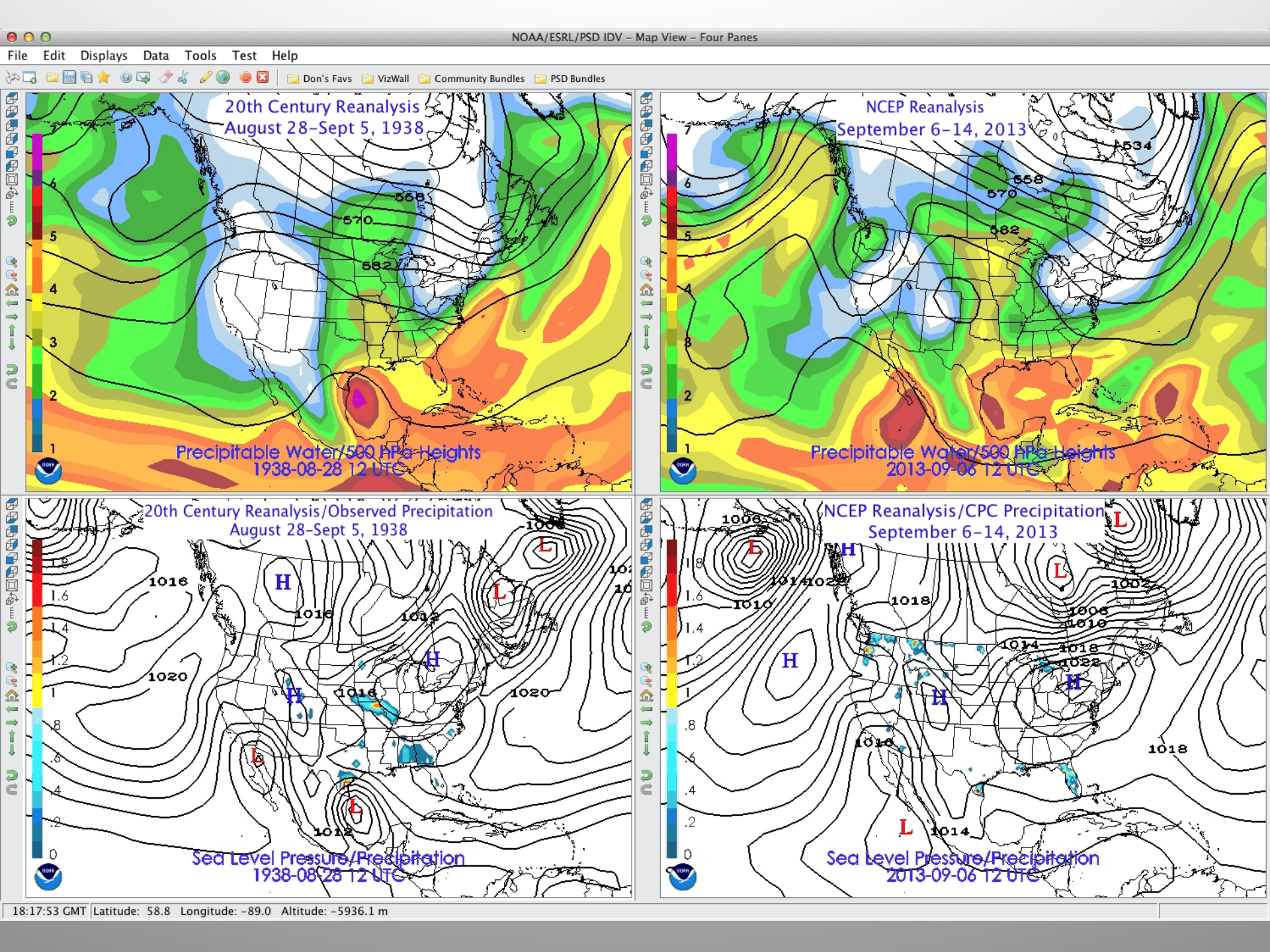




Sept. 12-14, 2013 **Sep. 1-4, 1938**

500 hPa Geopotential Height, averaged over ~3-day period of peak of rainfall in two Front Range heavy precip events

(Plots by Joe Barsugli; data: NCAR/NCEP and NOAA 20th C Reanalyses)


NOAA/ESRL/PSD IDV - Map View - Four Panes
File Edit Displays Data Tools Test Help
Don's Favs VizWall Community Bundles PSD Bundles
20th Century Reanalysis
August 28-Sept 5, 1938
Precipitable Water/500 hPa Heights
1938-08-28 12 UTC
NCEP Reanalysis
September 6-14, 2013
Precipitable Water/500 hPa Heights
2013-09-06 12 UTC
20th Century Reanalysis/Observed Precipitation
August 28-Sept 5, 1938
Sea Level Pressure/Precipitation
1938-08-28 12 UTC
NCEP Reanalysis/CPC Precipitation
September 6-14, 2013
Sea Level Pressure/Precipitation
2013-09-06 12 UTC
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